NEDC

Nutrient and Pest Management Considerations in Conservation Planning

Student Workbook

Modules 1–6

Self-Paced Study Guide

National Employee Development Center
Natural Resources Conservation Service
United States Department of Agriculture
June 2001

Acknowledgement

Special thanks are extended to the following specialists for their assistance in the designing and developing of this training program:

Design/Development Team

James C. Wood, Water Quality Specialist, NRCS, Boise, ID

Stefanie G. Aschmann, Ph.D., Agroecologist, NRCS Watershed Science Institute, University of Nebraska, USFS-East Campus, Lincoln, NE

Joseph K. Bagdon, Pest Management Specialist, National Water and Climate Center, NRCS, Amherst, MA

Sam H. Davis, Hydrologist, NRCS, Vicksburg, MS

Dave Drennan, Employee Development Specialist, National Employee Development Center, Fort Worth, TX

Bill Donham, Conservation Agronomist, NRCS, Stephenville, TX

Eric Hesketh, Soil Scientist/Pest Management Specialist, National Water and Climate Center, NRCS, Amherst, MA

Bill Kuenstler, Agronomist, National Cartography and Geospatial Center, NRCS, Fort Worth, TX

Jerry Lemunyon, Ph.D., Nutrient and Pest Management Specialist, NRCS, (located at GLTI), Temple, TX

Ken Pfeiffer, Pest Management Specialist, National Water and Climate Center, NRCS, Portland, OR

Brett L. Roberts, Water Quality Specialist, NRCS, Champaign, IL

Special thanks are extended to the following for their contributions to the development of the instructional materials:

Doug Beegle, Ph.D., Professor, Penn State University, University Park, PA

Edward J. Bechinski, Ph.D., Associate Professor and Extension IPM Coordinator, University of Idaho, Moscow, ID

Jeffrey Jenkins, Ph.D., Associate Professor, Oregon State University, Corvallis, OR

Robert Stevens, Ph.D., Professor, Washington State University, Prosser, WA

Table of Contents

Module 4, Part B—Water Management's Influence on Nutrient and Pest Management 33

Module 1—Introduction to Nutrient and Pest Management Components of a Conservation Plan

Overall Learning Objective

Describe your role in nutrient and pest management, and the policies, rules, and regulations that impact nutrient and pest management components of a Conservation Plan at the Resource Management System level.

Supporting Objectives

- Explain NRCS responsibilities in nutrient management.
- Explain NRCS responsibilities in pest management.
- List major policies and regulations that relate to nutrient management planning and explain their significance.
- List major policies and regulations that relate to pest management planning and explain their significance.
- Explain the importance of environmental risk analysis as it relates to nutrient management.
- Explain the importance of environmental risk analysis as it relates to pest management.

Introduction

Resource conservation, restoration, and sustained use are the primary goals of NRCS assistance. This is accomplished with conservation planning at the Resource Management System (RMS) level. Nutrient and pest management are critical components of an RMS. Inadequate nutrient and pest management can limit crop quantity and quality. Improper use of nutrients, pesticides and non-chemical pest control techniques, can negatively impact non-target plant and animal species.

Nutrients, pesticides and non-chemical pest control can have unintentional impacts both in the field where they are applied and in soil, water, and air whenever contaminants are transported from the field. Ground and surface water quality impairment due to non-point source nutrient and pesticide contamination is a major concern in many agricultural areas. Non-chemical pest management can also have potential environmental risks. For example, cultivation for weed control and burying or burning crop residue for disease and insect control can negatively impact soil, air and water resources. To adequately address these environmental risks, conservation planning must include nutrient and pest management components that minimize negative impacts to all identified resource concerns. For sensitive sites, conservation plans must also include appropriate mitigation strategies like filter strips, riparian forest buffers, and sediment control basins. Mitigation in this case is defined as: "Minimizing the potential for harmful impacts of nutrient and pest management activities on soil, water, air, plants, and animals through the application of conservation practices and/or management techniques."

Conservation planning involves more than just considering individual resources. It focuses on the natural systems and ecological processes that sustain the resources. The planner strives to balance natural resource issues with economic and social needs through the development of an RMS. This combination of conservation practices and resource management for the treatment of all identified resource concerns for soil, water, air, plants, and animals meets or exceeds the quality criteria in the Field Office Technical Guide (FOTG) for resource sustainability.

NRCS Mission in Nutrient and Pest Management

Nutrient and pest management components of a conservation plan are critical to resource conservation. Many nutrient and pest management principles are detailed and complex. Formal academic training is often required to master these principles. This training program cannot take the place of formal academic training, but it does provide conservation planners with a general background in nutrient and pest management. This background will help NRCS field staff to work more effectively with Cooperative Extension personnel, Certified Crop Advisors (CCAs), crop consultants, agrichemical dealers and others who make pest control and agrichemical recommendations, to cooperatively develop nutrient and pest management components of conservation plans.

Nutrient and pest management components of a conservation plan must provide the decision-maker with information that can help them to protect the resource base. On sensitive sites, conservation plans must often include mitigation strategies that reduce the off-site movement of nutrients and pesticides and related pollutants. Mitigation strategies can include nutrient, pest, crop, soil, and water management, as well as edge-of-field practices like conservation buffers. One of the primary responsibilities of a planner who develops the nutrient and pest management components of a conservation plan is to understand and quantify how mitigation strategies can minimize the potential for contamination, so that the overall plan can adequately protect and sustain the resource base.

NRCS has traditionally relied on Extension and crop consultants to provide nutrient and pest management recommendations to land users. This, however, does not adequately address our natural resource conservation mission. Policy revisions have helped to clarify that our primary role is to develop and provide nutrient and pest management related environmental risk information to all of our customers (landowners, landusers, Extension, crop consultants, agrichemical dealers and others who make nutrient and pest management recommendations and decisions). We will continue to use Extension nutrient and pest management recommendations based on efficacy, but we will add to these our recommendations for appropriate mitigation strategies that adequately protect the natural resource base. This new work will be difficult, complex, detailed, and dynamic. Nutrient and pest management planning are as important to our overall conservation mission as erosion control, so the effort is warranted.

To carry out this work, we need to set priorities. We do not have the staff to develop nutrient and pest management environmental risk information for every farm in the country. We need to identify priority areas that either have an existing natural resource impairment or an imminent risk of future impairment. This work will require strong partnerships with Extension, crop consultants and other nutrient and pest management advisors. The goal is to help farmers make future nutrient and pest management decisions based on environmental risk as well as efficacy and economics. Nutrient and pest management must also be fully integrated with other components of the conservation plan. Water management, crop residue management, conservation buffers, and soil erosion control practices all provide opportunities to mitigate the environmental risks associated with nutrient and pest management.

New NRCS nutrient and pest management policy provides guidance for 1) inventorying the resources involved, 2) assessing the impact of a nutrient or pest management strategy on these resources, and 3) planning conservation practices and management techniques that will mitigate unfavorable off-site impacts that the planned nutrient or pest management may have.

NRCS Nutrient Management

NRCS policy supports the development of site-specific nutrient management plans as a component of an overall conservation plan. The nutrient management component must include recommended rate, method, and timing of nutrient applications.

These recommendations can be developed by NRCS, Cooperative Extension personnel, Certified Crop Advisors (CCAs), crop consultants, agrichemical dealers, and others. Persons who review or approve nutrient management plans must be certified through a certification program acceptable to NRCS in the state involved. Leadership for site-specific nutrient management planning will vary by state or local area, but success will always depend on the cooperation of all parties involved.

NRCS Pest Management

NRCS roles in pest management are: evaluating environmental risks associated with probable pest management recommendations; developing appropriate mitigation alternatives to minimize environmental risks; assisting clients to adopt Integrated Pest Management (IPM) that helps protect natural resources; and assisting clients to develop and implement an acceptable pest management component of their overall conservation plan.

NRCS policy does not support NRCS originating site-specific pesticide recommendations. NRCS can supplement pest management recommendations from Cooperative Extension, Certified Crop Advisors (CCAs), crop consultants, agrichemical dealers and others, with site-specific environmental risk information and recommend mitigation strategies for sensitive sites. The primary goal of pest management in conservation planning, is to help decision-makers understand how pest management interrelates with climate, water management, crop management, and soil management, and how site-specific mitigation strategies can minimize risks to identified resources.

Student Activity 1

1. State the planner's responsibilities for nutrient management and indicate who can develop these nutrient management plans.

2. State the planner's responsibility for pest management and indicate who can develop pest management plans.

Nutrient and Pest Management Policy

References to and excerpts from USDA and NRCS policy and technical directives are presented to highlight some of the most important information that you will need to guide your nutrient and pest management conservation planning activities. Read each policy and directive in its entirety and note what each covers and where it is located for your future reference.

1) NRCS Nutrient Management Policy

Excerpts from Attachment 1: "190-GM, Part 402—Nutrient Management, May 1999."

402.01 Policy.

(a) The guidance and procedures contained in this section are applicable to all technical assistance that involves nutrient management and/or the utilization of organic by-products, including animal manure, where nutrients are applied to the land. All NRCS employees will follow these procedures when providing such technical assistance. Third party vendors and other non-NRCS employees will use these procedures when assisting with the implementation of Federal conservation programs for which NRCS has national technical responsibility and that include plans for nutrient management.

(b) Plans for nutrient management are developed in compliance with all applicable Federal, state, and/or local regulations. Federal, State, and/or local regulations take precedence over NRCS policy when more restrictive.

(c) NRCS at the State level will supplement this guidance to make it applicable to local conditions as appropriate.

402.03 Certification.

(a) All persons who review or approve plans for nutrient management will be certified through a certification program accepted by NRCS in the State involved.

(b) NRCS should identify all certification programs, available within the State, it judges to be acceptable methods for becoming certified.

(c) USDA recognized programs for certifying third party vendors are recommended for use in states that have or use no other recognized certification program.

402.04 Nutrient Management Plans.

(a) Plans for nutrient management may be stand-alone or be elements of a more comprehensive conservation plan. When plans for nutrient management are part of a more comprehensive conservation plan, the provisions for nutrient management are compatible with other provisions of the plan.

(b) Plans for nutrient management are developed in accordance with technical requirements of the NRCS Field Office Technical Guide (FOTG), policy requirements of the General Manual (GM), procedures contained in the National Planning Procedures Handbook (NPPH), and technical guidance contained in the National Agronomy Manual (NAM).

(c) Plans for nutrient management will include the following components, as applicable:

(1) Aerial site photographs or maps and a soil map.

(2) Current and/or planned plant production sequence or crop rotation.

(3) Soil test results and recommended nutrient application rates.

(4) Plant tissue test results, when used for nutrient management.

(5) A complete nutrient budget for nitrogen, phosphorus, and potassium for the plant production system.

(6) Realistic yield goals and a description of how they were determined.

(7) Quantification of all important nutrient sources (this could include but not be limited to commercial fertilizer, animal manure and other organic by-products, irrigation water, etc.).

(8) Planned rates, methods, and timing (month and year) of nutrient application.

(9) Location of designated sensitive areas or resources (if present on the conservation management unit).

(10) Guidance for implementation, operation, maintenance, and record keeping.

(d) When applicable, plans for nutrient management should include other practices or management activities as determined by specific regulation, program requirements, or producer goals.

(e) States are encouraged to adopt protocol for the format and appearance of nutrient management plans that are in accordance with the National Planning Procedures Handbook (NPPH) and other State developed guidance.

(f) If the Conservation Management Unit lies within a hydrologic unit area that has been identified or designated as having impaired water quality associated with nitrogen or phosphorus, plans for nutrient management include an assessment of the potential for nitrogen or phosphorus transport from the field. The Leaching Index (LI) and/or Phosphorus Index (PI), or other assessment tools accepted by NRCS, may be used to make these assessments.

(1) When such assessments are made, nutrient management plans will include:

(i) A record of the site rating for each field.

(ii) Information about conservation practices and management actions that can reduce the potential for phosphorus movement from the field.

(2) The results of such assessments and recommendations are discussed with the producer as a normal part of the planning process.

402.06 Nutrient Application Rates.

(a) Soil amendments are recommended, as needed, to adjust and maintain soil pH at the specific range of the crop for optimum availability and utilization of nutrients.

(b) Recommended nutrient application rates are based upon Land Grant University guidance or standard industry practice if recognized by the Land Grant University. Current soil test results, realistic yield goals, producer management capabilities, and other pertinent information are considered when determining recommended nutrient application rates.

(c) The planned and actual rates of nutrient application shall not normally exceed recommended rates when commercial fertilizer is the only source of nutrients being applied. When site specific conditions require that either planned or actual rates of application differ from or exceed recommended rates, the records for the plan shall document the reason.

(d) Producers shall be advised that the planned rates of nutrient application (nitrogen, phosphorus, and potassium) may exceed recommended rates when custom blended commercial fertilizers are not available, or when animal manures or other organic by-products are used as a nutrient source. When custom blended commercial fertilizers are not available, the planned rates of application shall match recommended rates as closely as possible. When animal manure or other organic by-products are applied, the following guidance shall be used for determining planned application rates:

(1) Nitrogen Application. Manure may be applied to legume crops at a rate equal to the estimated nitrogen removal in harvested plant biomass.

(2) Phosphorus application will be in accordance with one of the following options.

(i) Phosphorus Index (PI): When the PI is used, phosphorus may be applied at rates consistent with table 1.

(ii) Phosphorus Threshold: When soil specific Phosphorus Threshold (TH) values are available, phosphorus may be applied at rates consistent with table 2.

(iii) Soil Test Phosphorus: When soil test phosphorus levels are used, phosphorus may be applied at rates consistent with table 3 or figure 1.

Table 1 *

Phosphorus Index Rating	*Phosphorus Application*
Low Risk	Nitrogen Based
Medium Risk	Nitrogen Based
High Risk	Phosphorus Based (e.g. crop removal)
Very High Risk	Phosphorus Based (e.g. no application)

* See 402.06(d)(2)(v)

Table 2 *

Soil Phosphorus Threshold Level	*Phosphorus Application*
< 3/4 TH	Nitrogen Based
=> 3/4 TH, < 1 1/2 TH	Phosphorus Based (e.g. crop removal)
=> 1 1/2 TH, < 2 TH	Phosphorus Based (e.g. 1/2 crop removal)
=> 2 TH	Phosphorus Based (e.g. no application)

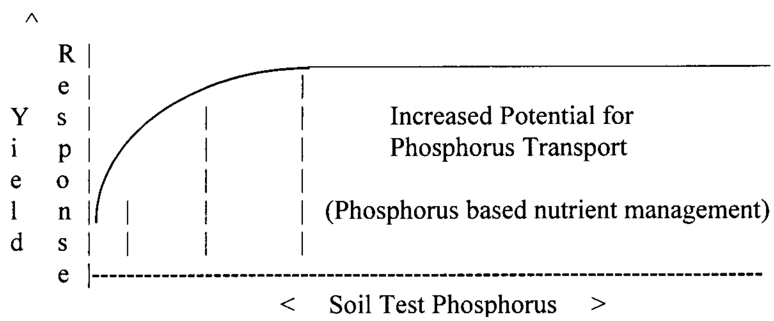
* See 402.06(d)(2)(v)

Table 3 *

Soil Test Phosphorus Level	*Phosphorus Application*
Low	Nitrogen Based
Medium	Nitrogen Based
High	Phosphorus Based (e.g. 1.5 times crop removal)
Very High	Phosphorus Based (e.g. crop removal)
Excessive	Phosphorus Based (e.g. no application)

* See 402.06(e)(2)(v)

Figure 1 **



(iv) State developed guidance for using tables 1, 2, and 3 and figure 1 will be used to establish criteria for a Resource Management System (RMS) level of nutrient management. State developed guidance will include input from the State Technical Committee and be coordinated across State lines to ensure compatibility and consistency with guidance developed in adjoining States.

(v) When using tables 1, 2, or 3, States determine acceptable phosphorus based application rates as a function of estimated phosphorus removal in harvested plant biomass. Rates of application should decrease as soil phosphorus levels or the risk of transport increase. Guidance may include recommendations for no application. The application rates shown in the tables are provided as guidance. Both the State Technical Committee and Land Grant University should be involved in developing these rates.

(vi) When using figure 1, States determine soil phosphorus levels at which nitrogen based manure application is acceptable and when phosphorus based manure application is recommended. Phosphorus based manure application rates shall be developed as a function of estimated phosphorus removal in harvested plant biomass. Phosphorus application rates should decrease as available soil phosphorus levels increase. Guidance may include a recommendation of no application. Both the State Technical Committee and Land Grant University should be involved in developing this guidance.

(vii) Accommodation may be made for a single application of phosphorus applied as manure at a rate equal to the recommended phosphorus application rate or estimated phosphorus removal in harvested plant biomass for the crop rotation or multiple years in the crop sequence. Multi-year phosphorus applications will not be at rates which exceed the annual nitrogen recommendation of the year of application or on sites considered vulnerable to off-site transport of phosphorus unless the appropriate conservation practices, best management practices, or management activities are used to reduce vulnerability.

(3) Potassium Application.

(i) Excess potassium will not be recommended in situations in which it causes unacceptable nutrient imbalances in crops or forages.

(ii) When forage quality and animal health are issues associated with excess potassium application, State standards will be used to set forage quality guidelines.

(e) Other plant nutrients should be applied as needed.

(f) Starter fertilizers containing nitrogen, phosphorus, and potassium may be recommended in accordance with Land Grant University guidance or industry practice if recognized by the Land Grant University within the State.

402.07 Special Considerations.

(a) Plans developed for nutrient management that include the use of manure or other organic by-products will:

(1) Identify the size of the land base needed to enable plan implementation based on phosphorus, even when initial implementation will be based on nitrogen, unless other provisions that do not involve land application are made for utilizing the manure.

(2) Document the soil phosphorus level at which plan implementation on a phosphorus standard would be desirable.

(3) Include a field-by-field assessment of the potential risk for phosphorus transport from the field. This assessment may be made using the Phosphorus Index (PI) or other assessment tool recognized and accepted by NRCS.

(i) When a phosphorus assessment is completed, the plans will describe:

A record of the ratings for each field.

Information about conservation practices and management activities that can reduce the potential for phosphorus transport from the field.

(ii) The results of a phosphorus assessment and recommendations will be discussed with the producer as a normal part of the planning process.

(4) Recognize that some manures contain heavy metals and should be accounted for in the plan for nutrient management.

Part 402.08 Record Keeping.

(a) It is the responsibility of producers, or the agents of producers, to maintain records that document the implementation of plans for nutrient management. Records include:

(1) Soil test results and recommended nutrient application rates.

(2) Quantities and sources of nutrients applied; and heavy metals if applicable.

(3) Dates (month and year) on which nutrients were applied.

(4) Methods by which nutrients were applied (e.g. broadcast, incorporated after broadcast, injected, or fertigation).

(5) Crops planted and dates of planting.

(6) Harvest dates and yields of crops.

(7) Where applicable, results of water quality tests (including irrigation water), plant tissue, or other organic by-products tests.

(8) The results of reviews including the identification of the person completing the review and any recommendations that resulted from the review.

(b) Records that document implementation of the plan should be retained for a period of 5 years; or for a period longer than 5 years if specified by other Federal or State agencies or local ordinances, or program or contract requirements.

(c) National Instruction No. 120-310, Amendment No. 4, dated June 17, 1998, provides guidance for responding to requests for access to these records.

2) Draft NRCS Pest Management Policy

Excerpts from Attachment 2: General Manual Title 190, Ecological Sciences Division, Part 404—Pest Management, Subpart B, March 2001 Draft.

404.10 Pest Management.

(a) Guidance and requirements in this Subpart are applicable to all NRCS technical assistance that involves pest management. All NRCS employees will follow these requirements when providing such technical assistance. Third Party Vendors and other non-NRCS employees will use these pest management requirements when assisting clients with conservation activities for which NRCS has technical responsibility.

(b) Pest management is an important component of the Resource Management System (RMS) planning process.

(c) NRCS roles in pest management are:

(1) Evaluating environmental risks associated with probable pest management recommendations;

(2) Developing appropriate mitigation alternatives to minimize environmental risks;

(3) Assisting clients to adopt IPM that helps protect natural resources; and

(4) Assisting clients to develop and implement an acceptable pest management component of their overall conservation plans.

(d) Mitigation techniques will be planned and implemented to reduce the environmental risks of pest management activities, in accordance with quality criteria in the local FOTG.

(e) NRCS, Third Party Vendors, and other non-NRCS employees will incorporate IPM that strives to balance economics, efficacy and environmental risk, where available, into planning alternatives. If commodity-specific IPM information is not available, NRCS, Third Party Vendors, and other non-NRCS employees will encourage the use of general IPM methods and principles, including pest prevention, avoidance, monitoring, and suppression strategies.

404.11 Certification.

(a) All persons (e.g., NRCS employees, Third Party Vendors, and other non-NRCS employees) who approve pest management components of NRCS conservation plans or revisions, must be certified through a certification program accepted by NRCS in the state involved. See Title 180, General Manual (Conservation Planning Policy) Part 409.11 Pest Management Certification Policy.

404.30 Pest Management Component of the Conservation Plan.

(a) The pest management component of the conservation plan is an integral part of the overall RMS plan for the CMU. Provisions of the pest management component shall recognize other requirements of the conservation plan and make it possible for clients to comply with both pest management provisions and all other provisions of the conservation plan.

(b) The pest management component of the conservation plan shall be developed in accordance with criteria in the Pest Management (595) conservation practice standard in the local FOTG. As a minimum, the following items shall be included in the pest management component of the conservation plan:

(1) Plan map and soil map of the managed site, if applicable (use RMS plan maps, if available);

(2) Location of sensitive resources and setbacks, if applicable (use RMS plan maps, if available);

(3) Environmental risk analysis, with approved tools and/or procedures, for probable pest management recommendations by crop, if applicable, and by pest;

(4) Interpretation of the environmental risk analysis and identification of appropriate mitigation techniques; and

(5) Operation and maintenance requirements.

(c) The pest management component of a conservation plan is to be developed to accommodate the client's management system including organic agriculture and sustainable agriculture.

(d) Clients, or their representatives, must document the implementation of their plans for pest management according to procedures outlined in the Pest Management (595) conservation practice standard in the local FOTG. Records will be reviewed by NRCS periodically to ensure that implementation is in accordance with the standard. Clients, or their representatives, should review and update their pest management plans periodically in order to incorporate new IPM technology, respond to cropping system and pest complex changes, and avoid the development of pest resistance.

(e) Certified planners must approve revisions to the pest management component of the conservation plan.

404.31 Pesticide Management Application.

(a) Risks to beneficial insects (e.g., honeybees, parasitic wasps, lady beetles, etc.) must be considered when developing the pest management component of the conservation plan.

(b) For animal agriculture (including aquaculture), risks to water quality, to animals being grown, and to consumers of those animals or animal products, must all be considered when developing the pest management component of the conservation plan.

(c) NRCS does not develop pesticide recommendations or change any label instructions or recommended pesticide application specifications.

(d) It is the clients' or their representatives' responsibility to ensure that all pesticides included in the pest management component of their conservation plans are currently registered for use at their location by the U.S. Environmental Protection Agency. The product label must contain specific instructions for the proposed use; or, the proposed use must be permitted by special local needs registration or emergency exemptions from registration.

(e) Clients are to be instructed to pay special attention to all environmental hazards and site-specific application criteria listed on the pesticide label and contained in Extension and crop consultant recommendations (e.g., ground water advisory statements, application setbacks, application rate limitations on highly erodible land, soil type exclusions, etc.).

404.35 Pest Management Environmental Risk Analysis.

(a) Environmental risks of pest management must be evaluated for all resource concerns identified in the conservation planning process, including the negative impacts of pesticides in ground and surface water on humans and non-target plants and animals. The pest management component of the conservation plan must be designed to minimize negative impacts of pest control on all identified resource concerns.

(b) Offsite effects of pest management must be evaluated with approved tools and/or procedures. WIN-PST and NAPRA are approved for evaluating offsite pesticide movement through runoff and leaching. WIN-PST is designed for general field office use and provides qualitative environmental risk analysis that is adequate for most situations. NAPRA is more sensitive to pesticide application

techniques than WIN-PST and provides quantitative results. NAPRA is designed to be used by state specialists to quantify mitigation benefits in high-risk areas that are identified with field office use of WIN-PST. State (or equivalent) specialists must interpret NAPRA results for field office use. Since WIN-PST is designed to err on the side of resource protection, NAPRA can also be used to refine high-risk WIN-PST results. States (or equivalent) utilizing pesticide environmental risk screening tools other than WIN-PST and NAPRA, need to coordinate their use with NWCC Pest Management Specialists and the National Pest Management Technology Specialist to ensure that the technology being applied is consistent with WIN-PST and NAPRA. The risk of environmental degradation by other pest management methods and management techniques (i.e., tillage, burning, biological predation, etc.) must also be assessed with appropriate analysis tools such as the Revised Universal Soil Loss Equation (RUSLE), the Wind Erosion Equation (WEQ), or the Soil Conditioning Index (SCI). If an appropriate analysis tool or procedure is not available for a proposed
pest management method, environmental risk analysis is left to the professional judgment of the planner. Analysis inputs and results must be documented in the conservation plan to justify the need for mitigation described in section 404.35(c) below.

(c) When pest management alternatives have significant potential to impact identified resources negatively; appropriate mitigation techniques must be planned and implemented to address identified risks to humans and non-target plants and animals. Mitigation techniques include conservation practices (e.g., Filter Strip, Conservation Crop Rotation, Irrigation Water Management, etc.) and management techniques (e.g., application method, application timing, product choice, etc.). For example, utilizing pesticides that have “Extra High,” “High,” or “Intermediate” WIN-PST soil/pesticide human risk ratings in the drainage area of a drinking water reservoir would require an appropriate set of mitigation techniques. State (or equivalent) standards will identify appropriate mitigation techniques for major pest management risks by loss pathway to each resource concern.

3) USDA Policy for Ground Water Quality

This policy includes the concept that all USDA programs shall be implemented in a manner that avoids harmful levels of contamination in ground water. This means that NRCS personnel in the field need to be aware of how ground water quality may be affected by the conservation practices and resource management systems they recommend. There is also a need to be aware of the potential health and environmental effects of any resulting ground water quality changes.

Excerpt from Attachment 3: Departmental Regulation 9500-8, November 9, 1987

(3) USDA General Policy for Ground Water Quality

With the need to continue the prudent and sustained use of the nation's renewable resources, it is the policy of USDA to help protect water users and natural environment from exposure to harmful substances in ground water, especially in rural areas, and to enhance ground water quality where appropriate.

4) NRCS Water Quality Policy

Water quality impairments from the agricultural use of nutrients and pesticides are the primary natural resource concern related to nutrient and pest management. NRCS water quality policy is contained in attachment 1. Please pay particular attention to the following excerpts from this policy:

Excerpt from Attachment 4: 460 GM Part 401.10, January 1997, Part 401—Water Quality Policy, Subpart A—Policy

401.0 Purpose.

This part establishes the Natural Resources Conservation Service's (NRCS) policy for integrating both surface water and ground water quality protection and improvement into NRCS programs and activities.

401.3 Responsibilities

(f) The state conservationist will:

(1) Assist local conservation districts, other Federal and State government agencies, and the private sector to identify and treat nonpoint source pollution problems;

(2) Ensure that actions, investments, and programs conform with water quality nonpoint source pollution programs adopted by State and local governments;

(3) Prepare Plans of Operation that incorporate both short- and long-term water quality objectives;

(4) Maintain NRCS's role as an interagency participant and advocate of the implementation of state water quality management plans;

(5) Incorporate best management practices (BMPs) as parts of resource management systems (RMSs), which are the most effective and practical means of preventing or reducing pollutants from nonpoint sources;

(6) Implement and assess the effectiveness of RMSs based upon site-specific conditions that reflect natural background and natural variability of nonpoint sources. Political, social, economic, and technical feasibility should be considered;

(7) Encourage landowners and land users to treat each acre within its capability and according to its needs for both surface and ground water quality protection and improvement;

(8) In cooperation with local conservation districts, develop conservation plans that use resource management systems to minimize pollution problems from animal wastes, nutrients, pesticides, salts, sediments, and related pollutants;

(9) Review as needed, directives, procedural manuals, and technical guides, to incorporate appropriate technical and administrative information on water quality;

(10) Develop an information program to create a better public understanding of water quality concerns and share information gained from water quality projects with conservation districts, State soil and water conservation agencies, and other interested agencies and organizations;

(11) Maintain adequately trained personnel in surface water and ground water quality concepts and management techniques;

(12) Analyze and evaluate the effects of NRCS-assisted water quality actions. The level and duration of monitoring and evaluation will be based on the scope of the program or activities; and

(13) Provide information as requested, on actions and activities to implement this policy.

Water Quality Policy Background

A Memorandum of Understanding (MOU) between the Cooperative Extension Service [now Cooperative State Research, Education and Extension Service (CSREES) and the Soil Conservation Service [now the Natural Resources Conservation Service (NRCS), dated June 3, 1988, filed in 460-GM Part 401—Water Quality Policy, establishes a framework to increase cooperation and coordination between the agencies for implementing USDA water quality policies and programs. The following excepts from this Water Quality MOU (attachment 5) are particularly important:

The Extension Service agrees to:

A. Provide leadership for the Cooperative Extension System in developing and delivering education programs that emphasize the adoption of management practices to protect or enhance water quality.

B. Integrate water quality concepts and management techniques into all programs to address nonpoint sources of pollution.

C. Provide assistance to NRCS in support of the development and use of site specific information to address water quality issues.

IV. The Soil Conservation Service agrees to:

A. Integrate water quality concepts and management techniques into all programs to address nonpoint sources of pollution.

B. Provide technical assistance to ES and the State CES in support of the development and use of educational materials.

C. Encourage the National Association of Conservation Districts and the local Conservation Districts to cooperate in addressing the water quality priorities of the USDA Conservation Program.

VI. The Extension Service and The Soil Conservation Service Mutually agree to: (A-C skipped)

D. Cooperate in encouraging each state CES and SCS organization to develop guidelines and appropriate pesticide and nutrient management components for use in landowners'/operators' conservation plan.

The June 3, 1988 MOU was based on a USDA document describing the roles of CSREES and NRCS, dated June 1998, and issued under the same cover letter as the MOU. The following excerpts from this document (included with the MOU in attachment 5) are particularly important:

I. Toxic Substances (A-C skipped)

D. Pesticides

(1) Role of the Soil Conservation Service

(a) Provide site specific resource data and planning assistance with regard to pesticide use and impacts of water quality to pesticide users and others making land use and management decisions.

(b) Assist landowners with the implementation of acceptable pesticide management practices.

II. Nutrients and Organics

A. Chemical Fertilizer Management

(1) Agricultural Use

(b) Role of the Soil Conservation Service

(i) Provide resource data and the interpretation of the data and planning assistance to landowners, land users, and others making land use and treatment decisions for the proper use of lime, chemical fertilizer, and animal waste practices for the safe and efficient utilization of nutrient materials.

(ii) Assist landowners with the implementation of site specific recommendations for the proper use of lime, chemical fertilizers, and animal wastes.

B. Organic Waste Management

(1) Agricultural Use

(b) Role of the Soil Conservation Service

(iii) Provide site specific resource data and planning assistance to landowners and land users and others making land use and management decisions with regard to proper handling and use of animal waste to minimize the potential for nutrient contamination of water resources.

(iv) Assist landowners with the design and implementation of site specific recommendations for animal waste management practices.

USDA Secretary's Memorandum No. 1929, dated December 12, 1977 (404.4), provides the United States Department of Agriculture (USDA) policy statement on management of pest problems. This Memorandum is still in force.

NRCS pest management guidance is derived from national initiatives such as the President's 1993 Integrated Pest Management (IPM) Initiative, Pesticide Environmental Stewardship Program (PESP) 1994, Safe Drinking Water Act (SDWA) of 1996 as amended, and Food Quality Protection Act (FQPA) of 1996. These initiatives and laws have committed all USDA agencies to reduce the use and the risks of pesticides and promote sustainable agriculture that reduces contamination of the nation's natural resources.

In meeting the requirements of the Food Quality Protection Act, NRCS is committed to an IPM program that promotes both economic and environmental benefits and encourages research and extension of information throughout the nation. Integrated Pest Management applies a broad interdisciplinary approach and uses scientific principles of plant protection to bring together a variety of management tactics into an overall systems strategy.

5) The National Planning Procedures Handbook (NPPH)

The National Planning Procedures Handbook provides guidance on Conservation Planning at the Resource Management System (RMS) level that includes nutrient and pest management components. An RMS is a combination of conservation practices and resource management for the treatment of all identified resource concerns for soil, water, air, plants, and animals, that meets or exceeds the quality criteria in the Field Office Technical Guide (FOTG) for resource sustainability. Planning at the RMS level includes meeting water quality criteria for excess nutrients and pesticides, which are potential water contaminants. Progressive planning at incrementally higher levels of treatment eventually results in an RMS that prevents degradation and permits sustained use. The NPPH is covered in more detail in Module 5.

6) Field Office Technical Guide (FOTG) Section IV

Section IV of the FOTG in each state contains NRCS Conservation Practice Standards developed for that state. These state standards are based on national standards in the NRCS National Handbook of Conservation Practices. National standards establish minimum requirements for State standards, which are specifically tailored to each State's local conditions. Conservation Practice Standards include the Name, Code and Unit of Measure for the practice. They also include a Definition of the practice, list the Purpose(s) of the practice, describe the Conditions Where the Practice Applies (as well as where the practice may not apply), identify the minimum quality Criteria for successfully achieving a single purpose or for multiple purposes, discuss special Considerations, which may be important to the successful operation of the practice after it has been applied, provide guidance for the development of Plans and Specifications used to install the practice, and provide instructions for developing the

Operation and Maintenance guidance that will be used after the practice has been installed. Some standards also include a list of References that may contain more in depth information about the practice. Two standards that directly apply to nutrient and pest management are the Nutrient Management standard (590) and the Pest Management standard (595). Details of these standards will be presented in later modules of this course.

The FOTG is covered in more detail in Module 5.

Student Activity 2

1. List an example of a policy or regulation that relates to nutrient management and explain its significance.

2. List an example of a policy or regulation that relates to pest management and explain its significance.

3. Explain the importance of environmental risk analysis as it relates to nutrient and pest management

Additional regulations, policies, programs and standards that affect nutrient management are:

- NRCS Animal Waste Management conservation practice standard for Waste Utilization (633)
- USDA Environmental Quality Incentives Program (EQIP) implementation
- EPA Coastal Zone Management Act (CZMA) regulations - mandated Nutrient Management Plans (NMPs) and/or Best Management Practices (BMPs)
- EPA Safe Drinking Water Act (SDWA) regulations
- Public water supplier rules and regulations
- Local board of health rules and regulations
- Watershed association rules and regulations

Additional regulations, policies and programs that affect pest management are:

- EPA Total Maximum Daily Load (TMDL) regulations
- EPA Food Quality Protection Act (FQPA) regulations
- EPA Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) regulations
- EPA Endangered Species Act (ESA) regulations
- EPA Worker Protection Standard (WPS) regulations
- EPA Safe Drinking Water Act (SDWA) regulations
- EPA Pesticide Management Plan (formally State Management Plan) regulations
- EPA Coastal Zone Management Act (CZMA) regulations

- USDA 1990 Farm Bill - Pesticide Record Keeping requirements
- USDA Environmental Quality Incentives Program (EQIP) implementation
- State Government specific rules and regulations
- Public water supplier rules and regulations
- Local board of health rules and regulations
- Watershed association rules and regulations

Summary

Conservation planning assistance should be targeted to agricultural areas that are potential contributors to non-point source water quality impairments. Water quality monitoring data can help identify existing problems and environmental risk screening tools can help identify the potential for future impairments. In high risk areas, conservation planning should include nutrient management or pest management, or both, as appropriate.

Nutrient and pest management should consider site features (soil properties, field slope, depth to ground water, proximity to surface water bodies, etc.) that can influence both offsite agrichemical movement and its potential to impact nontarget plants and animals. This risk evaluation can then be used in conjunction with water resource sensitivity information, including the need to meet water quality standards for drinking water, cold water fisheries, recreation, and agricultural water supplies. Viable nutrient and pest management alternatives can then be identified along with appropriate mitigation measures, to help protect the natural resource base. Air quality standards may also be important, especially in sensitive areas.

Current agrichemical recommendations are acceptable when they perform adequately from efficacy, economic, and environmental standpoints. When they are not environmentally acceptable, NRCS should work in partnership with Cooperative Extension (CE), Certified Crop Advisors (CCAs) and agrichemical dealers to identify economically viable alternatives and mitigation measures that will help protect and sustain the natural resource base.

NRCS policy supports the development of specific nutrient recommendations, but it does not support the development of pesticide recommendations. NRCS can, however, communicate Cooperative Extension's pesticide recommendations to our customers and supplement them with natural resource data and environmental risk information, and provide recommendations for appropriate mitigation strategies. The goal is to identify a suite of environmentally acceptable conservation management alternatives from which land users may choose.

Nutrient and pest management planning will require continuing education to maintain technical competency in these areas. State specialists will be particularly challenged to advance their education to keep pace with rapidly changing nutrient and pest management technology. Flexibility will be essential as nutrient and pest management policy is implemented at the state level. State specialists should provide field staff continuing education in agrichemical management on a regular basis.

Successful implementation of nutrient and pest management in conservation planning will require close partnerships with Cooperative Extension, Certified Crop Advisors, Independent Crop Consultants, agrichemical dealers, and farmers. We must all work together to address our natural resource conservation goals, as well as any regulatory responsibilities. Our information, training materials, planning tools and conservation plans must all be formatted for easy use by our customers and conservation partners. Whenever possible, we must strive to leverage our efforts by influencing other farm advisors to consider environmental risks in their recommendations and document the benefits of their efforts in the conservation planning process.

Activity Answers

Student Activity 1

1. State the planner's responsibilities in the area of nutrient management and indicate who can develop these nutrient management plans.

   To develop site-specific nutrient management plans that include recommended rate, method, and timing of nutrient applications. These plans can be developed by NRCS, Cooperative Extension personnel, Certified Crop Advisors (CCAs), crop consultants, agrichemical dealers, and others. Persons who review or approve nutrient management plans must be certified through a certification program acceptable to NRCS in the State involved.

2. State the conservation planner's responsibility in the area of pest management and indicate who can develop the pest management component of a conservation plan.

   To evaluate environmental risks associated with probable pest management recommendations, develop appropriate mitigation alternatives that meet quality criteria in the local FOTG, and help clients to adopt IPM that strives to balance economics, efficacy, and environmental risk. Anyone can develop the pest management component of a conservation plan, but only planners that are certified by NRCS in the state involved can approve plans.

Student Activity 2

1. List an example of a policy or regulation that relates to nutrient management and explain its significance.

   190-GM, Part 402—Nutrient Management, May 1999: requires new or revised nutrient management plans to be certified by a certification program acceptable to NRCS within the pertinent state. It also lists the minimal requirements of a nutrient management plan.

   National Agronomy Manual (NAM) 404.5 states that all NRCS planning activities must be in compliance with National Environmental Policy Act (NEPA).

   Departmental Regulation 9500-8, November 9, 1987 states that all USDA programs shall be implemented to avoid harmful levels of contamination in ground water. This means that NRCS personnel in the field need to be aware of how ground water quality may be affected by the conservation practices and resource management systems they recommend. There is also a need to be aware of the potential health and environmental effects of any resulting ground water quality changes.

2. List an example of a policy or regulation that relates to pest management and explain its significance.

   General Manual Title 190 Part 404.10—Pest Management (November 2000 Draft) states that NRCS roles in pest management are:

   1) Evaluating environmental risks associated with probable pest management recommendations;

   2) Developing appropriate mitigation alternatives to minimize environmental risks;

   3) Assisting clients to adopt IPM that helps protect natural resources; and

4) Assisting clients to develop and implement an acceptable pest management component of their overall conservation plan.

General Manual Title 190 Part 404.10—Pest Management (November 2000 Draft) states that:

NRCS, Third Party Vendors, and other non-NRCS employees will incorporate IPM that strives to balance economics, efficacy, and environmental risk, where available, into planning alternatives. If commodity-specific IPM information is not available, NRCS, Third Party Vendors, and other non-NRCS employees will encourage the use of general IPM methods and principles, including pest prevention, avoidance, monitoring, and suppression strategies."

3. Explain the importance of environmental risk analysis as it relates to nutrient and pest management.

Environmental risks of nutrient and pest management must be evaluated for all resource concerns identified in the conservation planning process. Offsite effects must be evaluated with approved tools and procedures. Analysis inputs and results must be documented in the conservation plan to justify the need for mitigation. When nutrient and pest management alternatives have significant potential to negatively impact identified resources, appropriate mitigation techniques must be planned and implemented.

Attachment 1
Part 402—Nutrient Management

CONTENTS

402.01 Policy.

(a) The guidance and procedures contained in this section are applicable to all technical assistance that involves nutrient management and/or the utilization of organic by-products, including animal manure, where nutrients are applied to the land. All NRCS employees will follow these procedures when providing such technical assistance. Third party vendors and other non-NRCS employees will use these procedures when assisting with the implementation of Federal conservation programs for which NRCS has national technical responsibility and that include plans for nutrient management.

(b) Plans for nutrient management are developed in compliance with all applicable Federal, state, and/or local regulations. Federal, State, and/or local regulations take precedence over NRCS policy when more restrictive.

(c) NRCS at the State level will supplement this guidance to make it applicable to local conditions as appropriate.

402.02 Definitions.

(a) The following definitions apply to terms used in this section.

(1) Conservation Management Unit (CMU): A field, group of fields, or other land units of the same land use and having similar treatment needs and planned management. A CMU is a grouping by the planner to simplify planning activities and facilitate development of conservation management systems. A CMU has definite boundaries, such as fence, drainage, vegetation, topography, or soil lines.

(2) Nutrient: Any of the elements considered essential for plant growth, particularly the primary nutrients; nitrogen, phosphorus, and potassium.

(3) Nutrient Management: Managing the amount, source, placement, form, and timing of the application of nutrients and soil amendments to ensure adequate soil fertility for plant production and to minimize the potential for environmental degradation, particularly water quality impairment.

(4) Nutrient Management Plan: A documented record of how nutrients will be used for plant production prepared for reference and use by the producer or landowner.

(5) Nutrient Management Specialist: A person who provides technical assistance for nutrient management and has the appropriate certification.

(6) Nutrient Source: Any material (i.e. commercial fertilizer, animal manure, sewage sludge, irrigation water, etc.) that supplies one or more of the elements essential for plant growth.

(7) Other Organic By-product: Any organic material other than animal manure, sewage sludge, or urea applied to the land (e.g. food processing waste).

(8) Resource Management System (RMS): A prescribed combination of conservation practices and management identified by land or water uses that, when implemented, prevents resource degradation and permits sustained use by meeting quality criteria established in the FOTG for the treatment of soil, water, air, plant, and animal resources.

(9) Third Party Vendor: An individual (excluding NRCS employees, extension specialists, and conservation district employees) who has been certified by an approved certification organization as being qualified to provide specified types of conservation assistance, and whose certifying organization participates in the USDA Approved Vendor Process outlined in Part 504, "Conservation Assistance from Third Party Vendors" of the NRCS Conservation Programs Manual. Third Party Vendor certification programs may include, but are not limited to:

(i) Certified Crop Advisor (CCA) Program of the American Society of Agronomy.

(ii) Land Grant University certification programs.

(iii) National Alliance of Independent Crop Consultants (NAICC).

402.03 Certification.

(a) All persons who review or approve plans for nutrient management will be certified through a certification program accepted by NRCS in the State involved.

(b) NRCS should identify all certification programs, available within the State, it judges to be acceptable methods for becoming certified.

(c) USDA recognized programs for certifying third party vendors are recommended for use in states that have or use no other recognized certification program.

402.04 Nutrient Management Plans.

(a) Plans for nutrient management may be stand alone or be elements of a more comprehensive conservation plan. When plans for nutrient management are part of a more comprehensive conservation plan, the provisions for nutrient management are compatible with other provisions of the plan.

(b) Plans for nutrient management are developed in accordance with technical requirements of the NRCS Field Office Technical Guide (FOTG), policy requirements of the General Manual (GM), procedures contained in the National Planning Procedures Handbook (NPPH), and technical guidance contained in the National Agronomy Manual (NAM).

(c) Plans for nutrient management will include the following components, as applicable:

(1) Aerial site photographs or maps and a soil map.

(2) Current and/or planned plant production sequence or crop rotation.

(3) Soil test results and recommended nutrient application rates.

(4) Plant tissue test results, when used for nutrient management.

(5) A complete nutrient budget for nitrogen, phosphorus, and potassium for the plant production system.

(6) Realistic yield goals and a description of how they were determined.

(7) Quantification of all important nutrient sources (this could include but not be limited to commercial fertilizer, animal manure and other organic by-products, irrigation water, etc.).

(8) Planned rates, methods, and timing (month & year) of nutrient application.

(9) Location of designated sensitive areas or resources (if present on the conservation management unit).

(10) Guidance for implementation, operation, maintenance, and record keeping.

(d) When applicable, plans for nutrient management should include other practices or management activities as determined by specific regulation, program requirements, or producer goals.

Part 402—Nutrient Management

402.04(e)

(e) States are encouraged to adopt protocol for the format and appearance of nutrient management plans that is in accordance with the National Planning Procedures Handbook (NPPH) and other State developed guidance.

(f) If the Conservation Management Unit lies within a hydrologic unit area that has been identified or designated as having impaired water quality associated with nitrogen or phosphorus, plans for nutrient management include an assessment of the potential for nitrogen or phosphorus transport from the field. The Leaching Index (LI) and/or Phosphorus Index (PI), or other assessment tools accepted by NRCS, may be used to make these assessments.

(1) When such assessments are made, nutrient management plans will include:

(i) A record of the site rating for each field.

(ii) Information about conservation practices and management actions that can reduce the potential for phosphorus movement from the field.

(2) The results of such assessments and recommendations are discussed with the producer as a normal part of the planning process.

(g) Review and Revision of Nutrient Management Plans.

(1) Plans for nutrient management should be reviewed periodically to determine if adjustments or modifications are needed. Annual reviews are highly recommended. The results of such reviews should be documented in the plan, as well as the identification of the person who made the review.

(i) States are encouraged to develop procedures for periodic reviews so that they may be completed by the producer or the representative of the producer.

(ii) When a review indicates that a revision of the plan is needed, the revised plan is approved by a certified nutrient management specialist.

(2) A thorough review of plans for nutrient management plans is done on a regular cycle not to exceed 5 years. This review should coincide with the soil test cycle.

402.05 Soil and Plant Tissue Testing.

(a) Current soil test information is used in the development of all plans for nutrient management. As a minimum, tests should include information for pH, phosphorus, and potassium. Tests for other elements may be required when needed to develop plans for nutrient management or to comply with State or local requirements.

(1) Current soil tests are those no older than 5 years, or

(2) Are less than 5 years old if required by the State.

(b) Soil Sampling.

(1) Soil samples are taken and handled in accordance with Land Grant University guidance or standard industry practice if accepted by the Land Grant University within the State.

(2) In situations where there are special production or environmental considerations, the use of other sampling techniques is encouraged. For example:

(i) Sub-soil sampling for residual nitrate in irrigated crop production systems.

(ii) Pre-sidedress Nitrogen Test (PSNT) and/or Pre-Plant Soil Nitrate test.

(iii) Sampling of the surface layer (0-2 inches) for elevated soil phosphorus or soil acidity when there is permanent vegetation, non-inversion tillage, or when animal manure or other organic by-products are broadcast or surface applied and not incorporated.

(c) Soil test analysis is performed by laboratories that are accepted in one or more of the following programs:

(1) State Certified Programs.

(2) The North American Proficiency Testing Program (Soil Science Society of America).

(3) Laboratories participating in other programs whose tests are accepted by the Land Grant University in the State in which the tests are used as the basis for nutrient application.

(d) The use of tissue analysis and other such tests should be recommended when needed to ensure acceptable nutrient management.

(e) The nutrient content of animal manure and other organic by-products is based on:

(1) Laboratory analysis of the material.

(2) Accepted book values recognized by NRCS in the absence of

laboratory analysis.

(3) Historic records for the operation if they exist and give an accurate estimate of the nutrient content of the manure.

402.06 Nutrient Application Rates.

(a) Soil amendments are recommended, as needed, to adjust and maintain soil pH at the specific range of the crop for optimum availability and utilization of nutrients.

(b) Recommended nutrient application rates are based upon Land Grant University guidance or standard industry practice if recognized by the Land Grant University. Current soil test results, realistic yield goals, producer management capabilities, and other pertinent information are considered when determining recommended nutrient application rates.

(c) The planned and actual rates of nutrient application shall not normally exceed recommended rates when commercial fertilizer is the only source of nutrients being applied. When site specific conditions require that either planned or actual rates of application differ from or exceed recommended rates, the records for the plan shall document the reason.

(d) Producers shall be advised that the planned rates of nutrient application (nitrogen, phosphorus, and potassium) may exceed recommended rates when custom blended commercial fertilizers are not available, or when animal manures or other organic by-products are used as a nutrient source. When custom blended commercial fertilizers are not available, the planned rates of application shall match recommended rates as closely as possible. When animal manure or other organic by-products are applied, the following guidance shall be used for determining planned application rates:

(1) Nitrogen Application. Manure may be applied to legume crops at a rate equal to the estimated nitrogen removal in harvested plant biomass.

(2) Phosphorus application will be in accordance with one of the following options.

(i) Phosphorus Index (PI): When the PI is used, phosphorus may be applied at rates consistent with table 1.

(ii) Phosphorus Threshold: When soil specific Phosphorus Threshold (TH) values are available, phosphorus may be applied at rates consistent with Table 2.

(iii) Soil Test Phosphorus: When soil test phosphorus levels are used, phosphorus may be applied at rates consistent with table 3 or figure 1.

Table 1 *

Phosphorus Index Rating	*Phosphorus Application*
Low Risk	Nitrogen Based
Medium Risk	Nitrogen Based
High Risk	Phosphorus Based (e.g. crop removal)
Very High Risk	Phosphorus Based (e.g. no application)

* See 402.06(d)(2)(v)

Table 2 *

Soil Phosphorus Threshold Level	*Phosphorus Application*
< 3/4 TH	Nitrogen Based
=> 3/4 TH, < 1 1/2 TH	Phosphorus Based (e.g. crop removal)
=> 1 1/2 TH, < 2 TH	Phosphorus Based (e.g. 1/2 crop removal)
=> 2 TH	Phosphorus Based (e.g. no application)

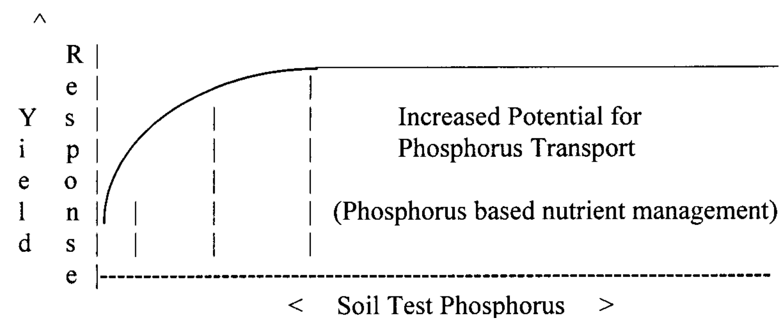
* See 402.06(d)(2)(v)

Table 3 *

Soil Test Phosphorus Level	*Phosphorus Application*
Low	Nitrogen Based
Medium	Nitrogen Based
High	Phosphorus Based (e.g. 1.5 times crop removal)
Very High	Phosphorus Based (e.g. crop removal)
Excessive	Phosphorus Based (e.g. no application)

* See 402.06(e)(2)(v)

Figure 1 **



(iv) State developed guidance for using tables 1, 2, and 3 and figure 1 will be used to establish criteria for a Resource Management System (RMS) level of nutrient management. State developed guidance will include input from the State Technical Committee and be coordinated across State lines to ensure compatibility and consistency with guidance developed in adjoining States.

(v) When using tables 1, 2, or 3, States determine acceptable phosphorus based application rates as a function of estimated phosphorus removal in harvested plant biomass. Rates of application should decrease as soil phosphorus levels or the risk of transport increase. Guidance may include recommendations for no application. The application rates shown in the tables are provided as guidance. Both the State Technical Committee and Land Grant University should be involved in developing these rates.

(vi) When using figure 1, States determine soil phosphorus levels at which nitrogen based manure application is acceptable and when phosphorus based manure application is recommended. Phosphorus based manure application rates shall be developed as a function of estimated phosphorus removal in harvested plant biomass. Phosphorus application rates should decrease as available soil phosphorus levels increase. Guidance may include a recommendation of no application. Both the State Technical Committee and Land Grant University should be involved in developing this guidance.

(vii) Accommodation may be made for a single application of phosphorus applied as manure at a rate equal to the recommended phosphorus application rate or estimated phosphorus removal in harvested plant biomass for the crop rotation or multiple years in the crop sequence. Multi-year phosphorus applications will not be at rates which exceed the annual nitrogen recommendation of the year of application or on sites considered vulnerable to off-site transport of phosphorus unless the appropriate conservation practices, best management practices, or management activities are used to reduce vulnerability.

(3) Potassium Application.

(i) Excess potassium will not be recommended in situations in which it causes unacceptable nutrient imbalances in crops or forages.

(ii) When forage quality and animal health are issues associated with excess potassium application, State standards will be used to set forage quality guidelines.

(e) Other plant nutrients should be applied as needed.

(f) Starter fertilizers containing nitrogen, phosphorus, and potassium may be recommended in accordance with Land Grant University guidance or industry practice if recognized by the Land Grant University within the State.

402.07 Special Considerations.

(a) Plans developed for nutrient management that include the use of manure or other organic by-products will:

(1) Identify the size of the land base needed to enable plan implementation based on phosphorus, even when initial implementation will be based on nitrogen, unless other provisions that do not involve land application are made for utilizing the manure.

(2) Document the soil phosphorus level at which plan implementation on a phosphorus standard would be desirable.

(3) Include a field-by-field assessment of the potential risk for phosphorus transport from the field. This assessment may be made using the Phosphorus Index (PI) or other assessment tool recognized and accepted by NRCS.

(i) When a phosphorus assessment is completed, the plans will describe:

A record of the ratings for each field.

Information about conservation practices and management activities that can reduce the potential for phosphorus transport from the field.

(ii) The results of a phosphorus assessment and recommendations will be discussed with the producer as a normal part of the planning process.

(4) Recognize that some manures contain heavy metals and should be accounted for in the plan for nutrient management.

(b) Progressive Planning.

(1) The National Planning Procedures Handbook, Part 600.1, provides guidance for progressive planning designed to assist producers who cannot initially plan for a Resource Management System (RMS).

(2) The progressive planning process may be used to help existing producers achieve an RMS level system when an RMS cannot be immediately implemented. Such plans shall include:

(i) A description of the RMS level system which the producer will be working to achieve.

(ii) Conservation practices, management activities, and milestones (installation schedules) that demonstrate movement toward an RMS.

(3) Annual review of nutrient management systems being implemented through the progressive planning process is highly encouraged to determine progress.

(c) When plans for nutrient management are developed and implemented in a way that results in expected increases in soil phosphorus levels, the plans will include:

(1) Discussion about the potential for phosphorus accumulation in the soil and how such accumulation increases the potential for transport, animal health, or crop production problems.

(2) Discussion of the potential for soil phosphorus draw-down from the production and harvesting of crops.

(d) In areas with specially protected water bodies, plans will be developed incorporating any special requirements that are applicable within these areas.

(e) Land application of sewage sludge

(1) When sewage sludge is applied to agricultural land, the accumulations of potential pollutants from such sources (including: Arsenic, Cadmium, Copper, Lead, Mercury, Selenium, and Zinc) in the soil is monitored in accordance with the U.S. Code Reference 40 CFR Parts 403 and 503, applicable State laws, and/or local ordinances. States may determine if such provisions should also be required for the land

required for the land application of animal manure and other organic by-products that contain any of these metals.

(2) Sewage sludge is analyzed prior to land application to determine its nutrient value, heavy metals, and salt content.

(3) Acceptable application rates of sewage sludge are determined using guidelines in this policy, and applicable Federal, State, or local regulations.

(f) Producers will be reminded that when producing "fresh, edible crops for the produce market, such as vegetables, root, or tuber crops" and using sewage sludge, animal manure, or other organic materials as a source of nutrients, applications should be in accordance with provisions of all applicable Federal, State, or local laws or policies.

402.08 Record Keeping.

(a) It is the responsibility of producers, or the agents of producers, to maintain records which document the implementation of plans for nutrient management. Records include:

(1) Soil test results and recommended nutrient application rates.

(2) Quantities and sources of nutrients applied; and heavy metals if applicable.

(3) Dates (month and year) on which nutrients were applied.

(4) Methods by which nutrients were applied (e.g. broadcast, incorporated after broadcast, injected, or fertigation).

(5) Crops planted and dates of planting.

(6) Harvest dates and yields of crops.

(7) Where applicable, results of water quality tests (including irrigation water), plant tissue, or other organic by-products tests.

(8) The results of reviews including the identification of the person completing the review and any recommendations that resulted from the review.

(b) Records which document implementation of the plan should be retained for a period of 5 years; or for a period longer than 5 years if specified by other Federal or State agencies or local ordinances, or program or contract requirements.

402.08(c)

(c) National Instruction No. 120-310, Amendment No. 4, dated June 17, 1998, provides guidance for responding to requests for access to these records.

(190-GM, Issue 9, April 1999)

402-12

Part 402—Nutrient Management

(190-GM, Issue 9, April 1999)

Attachment 2
Part 404—Pest Management

CONTENTS

(190-GM, Amend. 1, March 2001)

Subpart A—General

Part 404—Pest Management

SUBPART A—GENERAL

404.0 Purpose.

This directive sets forth Natural Resources Conservation Service (NRCS) policy and requirements for pest management. This pest management policy only applies to pests that are living organisms (e.g., weeds, insects, diseases, animals, etc.).

404.1 Background.

(a) A memorandum of understanding between the Cooperative State Research, Education and Extension Service (CSREES) (formerly the Cooperative Extension Service) and the NRCS (formerly the Soil Conservation Service), dated June 3, 1988, (i.e., Title 460 GM Part 401, Water Quality Policy) outlined various roles and responsibilities for CSREES and NRCS. (See section 404.20 of this Part for details.) Extension refers to the local component of CSREES.

(b) NRCS policy and responsibilities concerning soil, water, air, plants and animals are contained in Title 450, General Manual, Part 401, Subpart A. Pest management policy is contained in this Part and is applied through the Pest Management (595) conservation practice standard found in Section IV of the local Field Office Technical Guide (FOTG). General pest management guidance is found in the National Agronomy Manual, Section 503, Subpart C.

404.2 Authorities.

The following laws and initiatives require Department of Agriculture component agencies to reduce both the use and the risks of pesticides and to promote sustainable agriculture that reduces contamination of the Nation's natural resources:

(a) Executive Order 13112 of February 3, 1999, Invasive Species;

(b) Inter-Departmental Clean Water Action Plan, February 14, 1998, (i.e., signed by the Department of Agriculture and the U.S. Environmental Protection Agency);

(c) Safe Drinking Water Act of 1996, as amended;

(d) Food Quality Protection Act of 1996;

Part 404—Pest Management

404.2(e)

(e) U.S. Environmental Protection Agency's Pesticide Environmental Stewardship Program of 1994;

(f) Department of Agriculture's 1993 Integrated Pest Management (IPM) Initiative;

(g) Section 404.4 of the Secretary's Memorandum No. 1929, dated December 12, 1977, which provides the Department's policy statement on management of pest problems;

(h) Endangered Species Act of 1973, as amended;

(i) Clean Water Act of 1972, as amended; and

(j) National Environmental Policy Act of 1969, as amended.

404.3 Definitions.

(a) Avoidance — Avoiding pest populations (e.g., using pest resistant varieties, crop rotation, trap crops, etc.). Avoidance is the 'A' in the "PAMS" approach to IPM.

(b) Biological Pest Control — The process of conserving, augmenting or introducing beneficial living organisms to reduce a pest population or its impacts. It includes the use of insects, nematodes, mites, plant pathogens, plants, vertebrates, and other living organisms.

(c) Conservation Management Unit (CMU) — A field, group of fields, or other land units of the same land use and having similar treatment needs and planned management. A CMU is a grouping by the planner to simplify planning activities and facilitate development of a Resource Management System (RMS). A CMU has definite boundaries, such as: fence lines, drainage ways, or changes in vegetation.

(d) Chemical Pest Control — The use of pesticides, such as herbicides, insecticides or fungicides, to reduce a pest population or its impacts.

(e) Cultural Pest Control — The use of farming practices other than chemical and biological controls to reduce a pest population or its impacts. Cultural controls include techniques, such as: rotating crops, using pest-free seed and transplants, using pest resistant varieties, using good sanitation practices, burning, and all forms of mechanical pest control.

404-2

(190-GM, Amend. 1, March 2001)

(f) Environmental Risk — The potential to impact the ecosystem negatively.

(g) Genetically Modified Organism (GMO) — A living entity that has been modified or transformed with the application of recombinant DNA technology, commonly referred to as genetic engineering.

(h) Integrated Pest Management (IPM) — A sustainable approach to pest control that combines the use of Prevention, Avoidance, Monitoring, and Suppression strategies (PAMS), to maintain pest populations below economically damaging levels, to minimize pest resistance, and to minimize harmful effects of pest control on human health and environmental resources. IPM suppression systems include biological controls, cultural controls, and the judicious use of chemical controls.

(i) Invasive Species — Plants, animals, and microbes not native to a region which, when introduced either accidentally or intentionally, out-compete native species for available resources, reproduce prolifically, and dominate regions and ecosystems.

(j) Mechanical Pest Control — A component of cultural pest control that utilizes physical methods to reduce a pest population or its impacts. Mechanical controls include cultivation, hoeing, hand weeding, mowing, pruning, and vacuuming, etc.

(k) Mitigation — The process of minimizing the potential for harmful impacts of pest management activities on soil, water, air, plant, and animal resources through the application of conservation practices and/or management techniques.

(l) Monitoring — Identifying the extent of pest populations and/or the probability of future populations (e.g., pest scouting, soil testing, weather forecasting, etc.). Monitoring is the 'M' in the "PAMS" approach to IPM.

(m) National Agriculture Pesticide Risk Analysis (NAPRA) — A detailed pesticide environmental risk analysis tool, designed for use by NRCS specialists and their technology partners. NAPRA quantitatively evaluates the potential for pesticides to be transported by water and adversely affect non-target organisms, by modeling crop management techniques under specific weather and soil conditions. Results include the probabilities of pesticide leaching below the rootzone and runoff beyond the edge of the field to exceed toxicity thresholds for humans, fish, crustaceans, and algae. NAPRA can be used to refine Windows Pesticide Screening Tool (WIN-PST) results and quantify mitigation techniques needed to achieve RMS water quality criteria.

Part 404 - Pest Management

404.3(n)

(n) Pest — A weed, insect, disease, animal, and other organism (including invasive and non-invasive species) that directly or indirectly causes damage or annoyance by destroying food and fiber products, causing structural damage, or creating a poor environment for other organisms.

(o) Pest Management — Controlling organisms that cause damage or annoyance. NRCS defines pest management as utilizing environmentally sensitive prevention, avoidance, monitoring and suppression strategies to manage weeds, insects, diseases, animals and other organisms (e.g., including invasive and non-invasive species) that directly or indirectly cause damage or annoyance.

(p) Pest Management Component of a Conservation Plan — A portion of the conservation plan that is developed by implementing the Pest Management (595) conservation practice standard. The pest management component, at a minimum, contains the five elements identified in the plans and specifications section of the standard and in section 404.30(b) of this Part.

(q) Pest Management Environmental Risk Analysis — An evaluation of the potential for pest management (including the use of GMO's) to impact the ecosystem negatively.

(r) Pesticide — A substance or mixture of substances intended for preventing, destroying, repelling, or mitigating pests; or a substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant.

(s) Plant Regulator — Any substance or mixture of substances intended, through physiological action, for accelerating or retarding the rate of growth or rate of maturation, or for otherwise altering the behavior of plants or the produce thereof.

(t) Prevention — Preventing pest populations (e.g., using pest-free seeds and transplants, cleaning tillage and harvesting equipment between fields, and scheduling irrigation to avoid situations conducive to disease development, etc.). Prevention is the 'P' in the "PAMS" approach to IPM.

(u) Resource Assessment — Analyzing soil, water, air, plants and animals information, and human considerations to determine resource vulnerability, current conditions, and trends.

(v) Resource Management System (RMS) — A combination of conservation practices and resource management for the treatment of all identified resource concerns for soil, water, air, plants, and animals that meets or exceeds the quality criteria in the FOTG for resource sustainability.

(w) Resource Vulnerability — Degree of susceptibility to injury based on a combination of intrinsic site characteristics and extrinsic management factors. For example, groundwater resource vulnerability is determined by intrinsic site characteristics, such as: climate, soil properties, and depth to groundwater; and extrinsic management factors, such as: crop selection, pesticide application, and water management.

(x) Suppression — Suppressing a pest population or its impacts using cultural, biological, or chemical pest controls. Suppression is the 'S' in the "PAMS" approach to IPM.

(y) Windows Pesticide Screening Tool (WIN-PST) — A basic pesticide environmental risk screening tool, designed for use by NRCS field office staff, crop consultants, certified crop advisors, and other partners. WIN-PST qualitatively evaluates the potential for pesticides to be transported by water from the area of application and adversely affect non-target organisms. WIN-PST considers the influence of climate, irrigation, residue management, and pesticide application method and rate class on the potential for pesticide leaching below the rootzone and runoff beyond the edge of the field. It also incorporates long-term pesticide toxicity to humans and aquatic life in its overall risk ratings of "Extra High," "High," "Intermediate," "Low," or "Very Low." WIN-PST provides environmental risk information that a planner can use to formulate appropriate mitigation techniques that meet RMS water quality criteria.

(z) Third Party Vendor — An individual in either the public or private sector who has been certified by an approved, independent certification organization or natural resource conservation agent as being qualified to provide certain types of conservation assistance and who participates in the Department of Agriculture-Approved Vendor Process, outlined in the NRCS Conservation Programs Manual, Part 504, Conservation Assistance from Third Party Vendors.

Subpart B—Policy

Part 404—Pest Management

SUBPART B—POLICY

404.10(e)

404.10 Pest Management.

(a) Guidance and requirements in this Subpart are applicable to all NRCS technical assistance that involves pest management. All NRCS employees will follow these requirements when providing such technical assistance. Third Party Vendors and other non-NRCS employees will use these pest management requirements when assisting clients with conservation activities for which NRCS has technical responsibility.

(b) Pest management is an important component of the Resource Management System (RMS) planning process.

(c) NRCS roles in pest management are:

(1) Evaluating environmental risks associated with probable pest management recommendations;

(2) Developing appropriate mitigation alternatives to minimize environmental risks;

(3) Assisting clients to adopt IPM that helps protect natural resources; and

(4) Assisting clients to develop and implement an acceptable pest management component of their overall conservation plans.

(d) Mitigation techniques will be planned and implemented to reduce the environmental risks of pest management activities, in accordance with quality criteria in the local FOTG.

(e) NRCS, Third Party Vendors, and other non-NRCS employees will incorporate IPM that strives to balance economics, efficacy and environmental risk, where available, into planning alternatives. If commodity-specific IPM information is not available, NRCS, Third Party Vendors, and other non-NRCS employees will encourage the use of general IPM methods and principles, including pest prevention, avoidance, monitoring, and suppression strategies.

404-7

(190-GM, Amend. 1, March 2001)

(f) NRCS pest management activities must be in compliance with the National Environmental Policy Act of 1969, as amended.

(g) The pest management component of a conservation plan is to be developed in compliance with all applicable Federal, Tribal, State, and/or local regulations. Federal, Tribal, State and/or local regulations take precedence over NRCS policy when they are more restrictive.

(h) NRCS State Conservationists/Directors of the Pacific Basin and Caribbean Areas will supplement this guidance, as necessary, to make it applicable to local conditions and provide a review copy to their Regional Conservationists.

404-11 Certification.

(a) All persons (e.g., NRCS employees, Third Party Vendors, and other non-NRCS employees) who approve pest management components of NRCS conservation plans or revisions, must be certified through a certification program accepted by NRCS in the state involved. *See* Title 180, General Manual (Conservation Planning Policy) Part 409.11 Pest Management Certification Policy.

Subpart C—Responsibilities

Part 404—Pest Management

SUBPART C—RESPONSIBILITIES

404.20 Department of Agriculture.

(a) Responsibilities, as described in a June 3, 1988, memorandum of understanding between CSREES and NRCS (i.e., Title 460 GM Part 401, Water Quality Policy), include:

(1) CSREES agrees to provide assistance to NRCS in support of the development and use of site-specific information and to address water quality issues;

(2) CSREES and NRCS agree to cooperate in encouraging each State's (or equivalent) Extension and NRCS organizational unit to develop guidelines and appropriate pesticide and nutrient management components for use in landowners'/operators' conservation plans; and

(3) NRCS agrees to (as outlined in a Department of Agriculture companion document to the June 3, 1988 memorandum of understanding between CSREES and NRCS):

(i) ". . . provide site-specific resource data and planning assistance with regard to pesticide use and impacts of water quality to pesticide users and others making land use and management decisions;" and

(ii) ". . . assist landowners with the implementation of acceptable pesticide management practices."

(b) Additionally, to meet the requirements of the Food Quality Protection Act of 1996, NRCS is committed to promoting IPM that provides both economic and environmental benefits.

404.21 NRCS National Headquarters Office.

(a) The Deputy Chief for Science and Technology, under the direction of the Chief, is responsible for providing national leadership for policy and procedures for NRCS pest management and identification of pest management research and technology development needs.

(b) The Director of the Ecological Sciences Division is responsible for developing, implementing, and evaluating NRCS pest management policy and procedures.

(c) The Pest Management Technology Specialist of the Ecological Sciences Division provides national leadership for pest management policy and training.

(d) The Director of the Conservation Engineering Division, through the National Water and Climate Center (NWCC), is responsible for pest management environmental risk analysis technology.

(e) The Director of the NWCC, within the Conservation Engineering Division, is responsible for establishing and maintaining data and information technology to support NRCS pest management environmental risk evaluation activities.

(f) Pest Management Specialists of the NWCC provide national leadership for pest management environmental risk technology. They have development, maintenance and training responsibilities for data sets and tools that support pest management environmental risk evaluation activities. This technical support includes WIN-PST and NAPRA technologies.

(g) The Director of the Soil Survey Division is responsible for maintaining the soil database to support interpretations for pesticide leaching, solution runoff, and adsorbed runoff loss potentials.

(h) The Director of the Conservation Operations Division is responsible for insuring that all NRCS programs, which include pest management, fully utilize the pest management science and technology set forth in this policy.

404.22 NRCS Regional Offices.

(a) Regional Conservationists (RC's) will ensure that State Conservationists/Directors of the Pacific Basin and Caribbean Areas coordinate pest management activities with adjoining states and regions (e.g., across Major Land Resource Area boundaries).

(b) Regional Technology Specialists will assist RC's in addressing pest management concerns.

Subpart C—Responsibilities

404.23(f)

404.23 NRCS State Offices (or equivalent).

State Conservationists/Directors of the Pacific Basin and Caribbean Areas are responsible for:

(a) Targeting pest management technical assistance to specific resource concerns and locations within their respective States/Areas (e.g., watersheds with pesticide-impaired sources of drinking water, pesticide Total Maximum Daily Load requirements, or highly vulnerable areas that may contribute to future pest management related contamination);

(b) Supplementing pest management guidance and requirements, as necessary, making it applicable to local conditions and providing a review copy to respective Regional Conservationists;

(c) Ensuring that appropriate training is provided to all NRCS personnel who provide pest management guidance to the public and establishing a process to provide continuing education to maintain employee competency and certification;

(d) Making certain that all NRCS personnel who provide pest management guidance to the public:

(1) Meet applicable requirements for their positions;

(2) Complete NRCS-endorsed pest management courses; and

(3) Pass State/Area or other local testing requirements.

(e) Developing an appropriate Pest Management (595) conservation practice standard for each local FOTG and ensuring that each conservation plan has a pest management component, if needed;

(f) Working in consultation with respective State Technical Committees to address pest management issues of Farm Bill programs and to approve pest management certification program(s) within the state; and

(g) Utilizing the best technology available to evaluate pest management environmental risks. (WIN-PST and NAPRA should be used to evaluate pesticide environmental risks. Use of other pesticide risk analysis tools that are considered better technology must be reviewed by NWCC Pest Management Specialists and the National Pest Management Specialist of the Ecological Sciences Division, to ensure consistency with WIN-PST and NAPRA.)

404.24 NRCS Field Service Centers (or equivalent).

(a) NRCS field service center technical leaders (e.g., District Conservationists and Team Leaders) are responsible for providing local leadership in implementing pest management policy and procedures.

(b) NRCS field service center (or equivalent) employees are responsible for:

(1) Implementing pest management policy provisions and using the Pest Management (595) conservation practice standard appropriately; and

(2) Identifying pest management needs and informing State Conservationists/ Directors of the Pacific Basin and Caribbean Areas, or designee(s), of these needs, as appropriate. (Examples include identifying environmental risk analysis tools, mitigation techniques, commodity-specific IPM information, and training, needed to incorporate pest management into conservation planning.)

Subpart D—Pest Management and Technical Assistance

Part 404—Pest Management

SUBPART D—PEST MANAGEMENT AND TECHNICAL ASSISTANCE

404.30 Pest Management Component of the Conservation Plan.

(a) The pest management component of the conservation plan is an integral part of the overall RMS plan for the CMU. Provisions of the pest management component will recognize other requirements of the conservation plan and make it possible for clients to comply with both pest management provisions and all other provisions of the conservation plan.

(b) The pest management component of the conservation plan is to be developed in accordance with criteria in the Pest Management (595) conservation practice standard in the local FOTG. As a minimum, the following items are to be included in the pest management component of the conservation plan:

(1) Plan map and soil map of the managed site, if applicable (use RMS plan maps, if available);

(2) Location of sensitive resources and setbacks, if applicable (use RMS plan maps, if available);

(3) Environmental risk analysis, with approved tools and/or procedures, for probable pest management recommendations by crop, if applicable, and by pest;

(4) Interpretation of the environmental risk analysis and identification of appropriate mitigation techniques; and

(5) Operation and maintenance requirements.

(c) The pest management component of a conservation plan is to be developed to accommodate the client's management system including organic agriculture and sustainable agriculture.

(d) Clients, or their representatives, must document the implementation of their plans for pest management according to procedures outlined in the Pest Management (595) conservation practice standard in the local FOTG. Records will be reviewed by NRCS periodically to ensure that implementation is in accordance with the standard. Clients, or their representatives, should review and update their pest management plans periodically in order to incorporate new IPM technology, respond to cropping system and pest complex changes, and avoid the development of pest resistance.

(e) Certified planners must approve revisions to the pest management component of the conservation plan.

404.31 Pesticide Management Application.

(a) Risks to beneficial insects (e.g., honeybees, parasitic wasps, lady beetles, etc.) must be considered when developing the pest management component of the conservation plan.

(b) For animal agriculture (including aquaculture), risks to water quality, to animals being grown, and to consumers of those animals or animal products, must all be considered when developing the pest management component of the conservation plan.

(c) NRCS does not develop pesticide recommendations or change any label instructions or recommended pesticide application specifications.

(d) It is the clients' or their representatives' responsibility to ensure that all pesticides included in the pest management component of their conservation plans are currently registered for use at their location by the U.S. Environmental Protection Agency. The product label must contain specific instructions for the proposed use; or, the proposed use must be permitted by special local needs registration or emergency exemptions from registration.

(e) Clients are to be instructed to pay special attention to all environmental hazards and site-specific application criteria listed on the pesticide label and contained in Extension and crop consultant recommendations (e.g., ground water advisory statements, application setbacks, application rate limitations on highly erodible land, soil type exclusions, etc.).

(f) Restricted-use pesticide application records, in accordance with the Department of Agriculture, Agricultural Marketing Service's Pesticide Record Keeping Program, must be maintained for at least two years. State-specific pesticide record keeping requirements may be more restrictive.

Subpart D—Pest Management and Technical Assistance

404.34

(g) NRCS employees must adhere to all Worker Protection Standard safety measures associated with pest management during the development of the conservation plan and throughout its implementation.

(h) Federal and State (or equivalent) level restrictions on the use of certain pesticides in designated areas (e.g., public wellhead protection areas, adjacent to sensitive crop areas, adjacent to endangered species habitat, etc.) must be followed.

(i) On NRCS-operated properties, such as plant material centers, personnel who apply or supervise the application of approved pesticides must follow all label instructions and be trained and certified according to State regulations.

(j) NRCS will cooperate with Federal and State (and equivalent) conservation agencies and the private sector to identify research needs for pest management and mitigation techniques that reduce environmental risks.

404.32 Social and Economic Considerations.

The pest management component of the conservation plan must be designed and implemented at an appropriate level of complexity to address social and economic constraints, resource limitations, management capabilities, pest management philosophies and other social and cultural issues. Social considerations include public health and safety and other societal goals, as well as social, family and religious values, ethnicity, risk tolerance or aversion, land tenure, and time availability. Economic considerations include: size of farm, type of farming system (e.g., high versus low technology, high versus low intensity cropping systems, etc.), available capital, and land tenure.

404.33 Environmental Justice.

The pest management component of a conservation plan will not create undue hardship on socially disadvantaged or other economically limited communities or individuals.

404.34 Cultural Resources.

NRCS General Manual, Title 420, Part 401, Cultural Resources Policy, lists the Pest Management (595) conservation practice under "Conservation Practices Not Considered as Undertakings" and states that "Such practices do not require cultural resources considerations."

404-15

(190-GM, Amend. 1, March 20001)

Part 404—Pest Management

404.35

404.35 Pest Management Environmental Risk Analysis.

(a) Environmental risks of pest management must be evaluated for all resource concerns identified in the conservation planning process, including the negative impacts of pesticides in ground and surface water on humans and non-target plants and animals. The pest management component of the conservation plan must be designed to minimize negative impacts of pest control on all identified resource concerns.

(b) Offsite effects of pest management must be evaluated with appropriate tools and/or procedures. WIN-PST and NAPRA are nationally supported for evaluating offsite pesticide movement through runoff and leaching. WIN-PST is designed for general field office use and provides qualitative environmental risk analysis that is adequate for most situations. NAPRA is more sensitive to pesticide application techniques than WIN-PST and provides quantitative results. NAPRA is designed to be used by state specialists to quantify mitigation benefits in high-risk areas that are identified with field office use of WIN-PST. State (or equivalent) specialists must interpret NAPRA results for field office use. Since WIN-PST is designed to err on the side of resource protection, NAPRA can also be used to refine high-risk WIN-PST results. States (or equivalent) utilizing pesticide environmental risk screening tools other than WIN-PST and NAPRA, need to coordinate their use with NWCC Pest Management Specialists and the National Pest Management Technology Specialist to ensure that the technology being applied is consistent with WIN-PST and NAPRA. The risk of environmental degradation by other pest management methods and management techniques (i.e., tillage, burning, biological predation, etc.) must also be assessed with appropriate analysis tools such as the Revised Universal Soil Loss Equation (RUSLE), the Wind Erosion Equation (WEQ), or the Soil Conditioning Index (SCI). If an appropriate analysis tool or procedure is not available for a proposed pest management method, environmental risk analysis is left to the professional judgment of the planner. Analysis inputs and results must be documented in the conservation plan to justify the need for mitigation described in section 404.35(c) below.

(c) When pest management alternatives have significant potential to impact identified resources negatively; appropriate mitigation techniques must be planned and implemented to address identified risks to humans and non-target plants and animals. Mitigation techniques include conservation practices (e.g., Filter Strip, Conservation Crop Rotation, Irrigation Water Management, etc.) and management techniques (e.g., application method, application timing, product choice, etc.). For example, utilizing pesticides that have "Extra High," "High," or "Intermediate" WIN-PST soil/pesticide human risk ratings in the drainage area of a drinking water reservoir would require an appropriate set of mitigation techniques. State (or equivalent) standards will identify appropriate mitigation techniques for major pest management risks by loss pathway to each resource concern.

Module 2—Pesticides and Nutrients in the Environment

Overall Learning Objective

Upon completion of this module, participants will be able to define environmental risk, list environmental concerns associated with pesticides and nutrients, and describe the processes that affect the fate of nutrients and pesticides in the environment.

Introduction

This module provides the participant with an understanding of the environmental concerns associated with the use of nutrients and pesticides, and the processes that affect the fate of nutrients and pesticides in the environment.

Environmental risk can be defined as the probability of undesirable or adverse impact of a substance on a sensitive population or resource due to the presence of the substance in concentrations great enough to cause the adverse impact. Note the key components to be aware of as nutrients and pesticides in the environment are discussed: the *presence* of the substance; the *concentrations* present; and the *sensitivity* or susceptibility of the resource or species at risk.

Environmental risk is important to resource planning and management because everything that takes place on the landscape in any given watershed or hydrologic unit has the potential to create an environmental risk. By linking the consequences of various land management actions to resulting environmental risk, appropriate conservation practices can be put in place across the landscape to minimize or eliminate adverse resource impacts.

Resource planners should strive to help their clients better understand the nature of the environmental risk, how the actions or the circumstances related to the client's operation may be contributing to an adverse environmental impact and to present their client with recommended alternatives for them to consider for implementation to prevent or minimize the potential environmental impacts which have been identified.

This module is separated into two major parts; Part A—Nutrients and Part B—Pesticides. Although they are presented separately, many of the concepts are the same. As you read through each part consider the similarities between pesticides and nutrients in the environment.

Module 2, Part A—Nutrients and the Environment

Supporting Objectives

Upon completion of this part, you will be able to:

- List and define the three processes that determine pollutant delivery.
- List three processes that influence the availability of nutrients in the environment.
- Define eutrophication and generally describe the process of eutrophication.
- Describe phosphorus cycling in a lake and stream system.
- List two negative impacts that each nutrient (C, N, P, K and S) can have on the environment.
- Describe two problems that excess salts can cause in soils, and list two practices that can be used to manage these problems.
- List two sources of heavy metals and describe the primary concern for heavy metals in the environment.
- List five adverse effects of eutrophication.
- Define environmental risks and list the key components related to nutrients in the environment.
- Explain the responsibility of resource planners when they become aware of environmental risks.
- List three ways nitrogen moves in the environment.

Introduction

The landowner's goal of producing an economical crop yield is a primary consideration. Achieving these economic yield goals is the main reason for using fertilizer, manure, and other nutrient sources on cropland. Environmental considerations are important as well. The risk of adverse off-site impacts must be taken into account when developing recommendations for nutrient management.

This part of Module 2 will review the major nutrient elements associated with agriculture that can have adverse impacts on water quality and other resources. These elements are carbon, nitrogen, phosphorus, potassium, and sulfur. Other substances associated with agriculture, which can create an environmental concern include salts and heavy metals (many heavy metals are also micronutrients). This module will begin by covering:

- pollutant delivery;
- the fate of the nutrient element in the environment; and
- the impacts of nutrients once they are delivered to a receiving waterbody.

This information is a review of subject matter previously covered in the NEDC course, Introduction to Water Quality with an emphasis on nutrients.

Pollutant Delivery

The impact of nutrients on water quality is ultimately dependent on pollutant delivery. The *three processes that determine pollutant delivery* are *availability, detachment, and transport.* A pollutant can be defined in this context as a nutrient out of place. Conservation practices act on one or more of these pollutant delivery processes to prevent nutrients from moving off-site and causing adverse environmental impacts.

Availability is the presence of a nutrient (or other material) in quantities and forms capable of being moved off-site. *Processes that affect the availability* of nutrients include *adsorption, precipitation,* and *transformation* (changes in chemical form). You will notice that these processes are similar to the processes that impact a pesticide's fate in the environment.

Adsorption is the attraction of compounds to the surface of soil materials. For example, a positive ion like the ammonium form of nitrogen (NH_4^+) is adsorbed to the negatively charged soil cation exchange capacity (CEC) sites. However, the nitrate form of nitrogen (NO_3^-), which is negatively charged, is not adsorbed and therefore can be readily leached from the soil (figure 2.3 and 2.4, page 19 and 20, Module 2, Part A).

Precipitation is the chemical combination of soluble species to form an insoluble compound. For example, at low pH, certain soils contain high levels of soluble iron and aluminum, which react with soluble phosphorus to form relatively insoluble iron and aluminum phosphates. At high pH soluble phosphates react with soluble calcium to form relatively insoluble calcium phosphates. Formation of these insoluble precipitates reduces the probability of phosphorus leaching and runoff of soluble phosphorus. However, if soils containing these precipitates are eroded the phosphorus can be carried to waters on sediment where the precipitates can dissolve to release bio-available phosphorus.

Transformation is the change in chemical form of a compound. These transformations, which can be either chemical or biological, are important because different forms of a nutrient have varying degrees of environmental risk. For example, urea nitrogen in manure can be transformed to ammonia nitrogen when applied to soil. If this transformation takes place at the soil surface, the ammonia, which is a gaseous form of nitrogen, can be lost into the atmosphere.

Detachment is the mobilization of nutrients (or other materials) allowing them to become available for transport. Examples of detachment are wind blown suspended particles, nutrients dissolving in water or soil particles detached by raindrop impact. Detachment results in dissolved particles, suspended particles, and sediment attached particles.

Transport is the physical movement of *a nutrient or nutrient source (i.e. animal waste)* from one place to another. Transport is significant whenever a nutrient is moved beyond the edge of the field or below the root zone. For example, even though very high soil phosphorus levels may exist, the environmental risk of this phosphorus depends on its transport to surface waters.

Factors that affect the potential for transport to surface water include:

- distance to waterbody
- slope
- direction of flow
- surface roughness
- soil texture and permeability

Factors that affect the potential for transport to ground water include:

- soil factors (permeability, organic matter, and texture);
- subsurface geology or material; and
- depth to water.

These factors are discussed further in Module 5.

Control of most pollutants can be assessed in terms of the capability to impact one or more of the pollutant delivery processes. For example, nutrient management limits the amount of nutrients applied based on crop needs, thus reducing nutrient *availability*. Erosion control practices control detachment of soil particles and subsequent sedimentation. A filter strip intercepts *transport* of sediments and nutrients to a waterbody.

Impacts of Nutrients on Receiving Waterbodies

Nutrients that leach to ground water have the potential to increase the nutrient concentration. Typically, elevated nitrate concentrations are of greatest concern because of the potential impact to drinking water quality. In some areas where ground and surface waters are interconnected, elevated phosphorus concentrations in ground water may be a concern if these ground waters discharge into a sensitive surface waterbody such as a lake or stream.

Eutrophication Process

One of the most common impairments of surface waters is accelerated *eutrophication* (nutrient enrichment) caused by excess nutrient inputs, especially phosphorus and nitrogen. Impaired waters are those waters that no longer support one or more of the designated uses such as drinking, recreation, or fisheries. Eutrophication of water bodies occurs naturally over time as these water bodies gradually accumulate plant material and lose dissolved oxygen. Human activities in a watershed can lead to increased sediment and nutrient delivery to a waterbody greatly accelerating this process. In the U.S. eutrophication is estimated to account for about half of the impaired lake area, 60% of the impaired river reaches and for much of the impairment to estuaries and coastal waters.

Generally either phosphorus or nitrogen is limiting in an aquatic ecosystem and whichever is limiting will control the eutrophication process (figure 2.1). Phosphorus is typically the limiting nutrient in most freshwater systems, especially lakes, while nitrogen is typically the limiting nutrient in most estuary or coastal ecosystems. However, exceptions to this general rule can occur and the nutrient that is most limiting will control primary production and therefore eutrophication. The eutrophication process involves several steps that are listed below:

- Nutrients enter the lake or stream through surface runoff and precipitation. Sediment, dissolved nutrients, and organic materials enter the waterbody.

  The waterbody experiences an increase in biological productivity. Aquatic plant and algae growth increases when climatic conditions (temperature, dissolved oxygen content and light) are favorable. Excess plant and algae growth can be a nuisance to lake users. Three common aquatic growth infestations for eutrophied waters are:

  — floating or rooted large plants (macrophytes)

  — algal mats (filamentous)

  — phytoplankton (commonly seen as a pea soup appearance in highly infested waters)

- As plants and algae die, the biomass is decomposed by microbes. Sediment and organic materials begin to collect on the lake bottom. Increased turbidity, odor, and taste problems may become an issue.

- The decomposition process removes dissolved oxygen from the water. Microbes use carbon as an energy source, and through respiration remove the dissolved oxygen faster than it can be replaced by plants. This can lead to oxygen depletion (hypoxia).

- Some species such as trout, pike, and walleye avoid low oxygen water. Prolonged exposure to low oxygen conditions can lead to the death of these species. These conditions tend to favor such fish species as carp and suckers, which are more tolerant of reduced oxygen levels. This can lead to a reduction in species diversity. The loss of species diversity is undesirable for both economic and ecological reasons. The loss of sport fish from an aquatic system may constitute a major economic loss to local businesses dependant upon fishing.

- Ultimately, the lake fills with sediment and organic materials and becomes a wetland.

Perhaps the most serious adverse impact of eutrophication results from the explosive growth of nuisance algae that commonly occurs. These algae can produce chemicals that are harmful to other organisms, including livestock and humans. In freshwater ecosystems, blooms of blue-green algae (now called cyanobacteria) are a common symptom of eutrophication. These blooms can contribute to a wide range of water quality related problems including:

— fish kills

— foul odor

— unpalatable tastes in drinking water

— impaired recreational and aesthetic values

— livestock kills

— serious health risk to humans

Furthermore, when eutrophic waters are processed in water treatment facilities, the high organic load may react with chlorine to form carcinogens known as trihalomethanes.

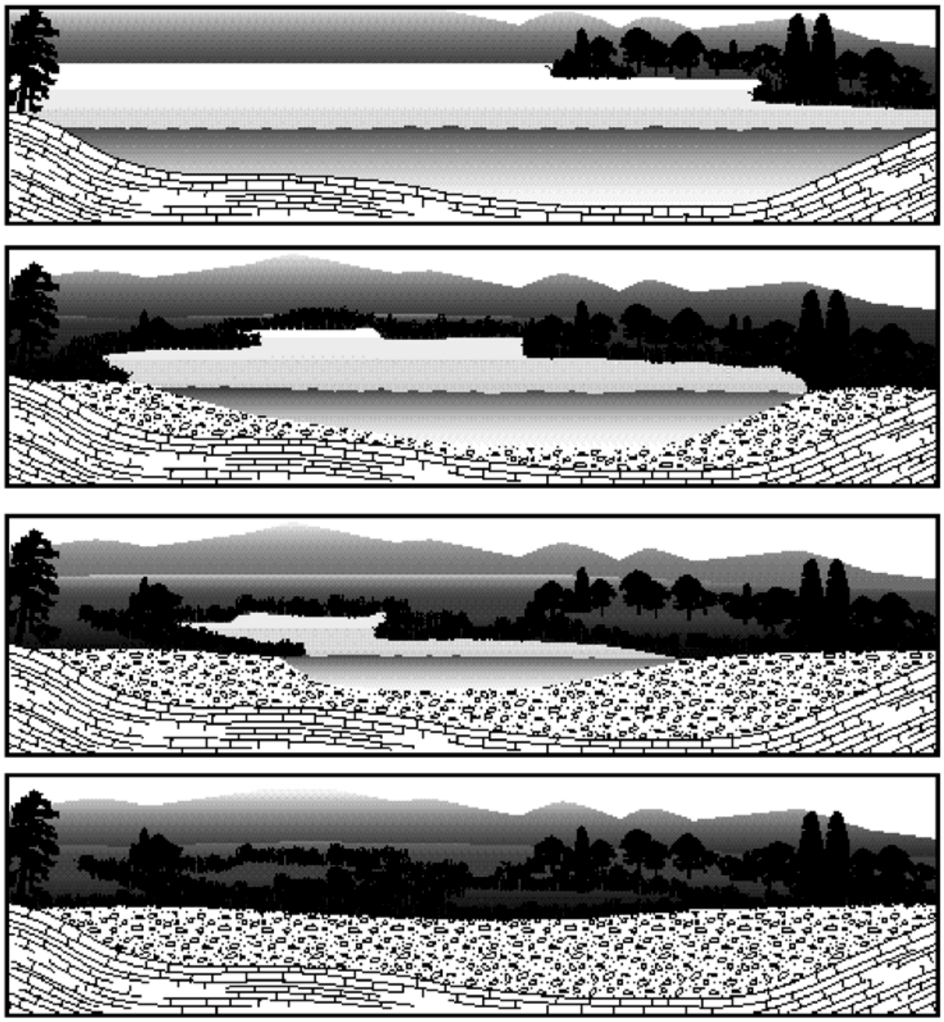


Figure 2.1. Eutrophication or natural aging process of a lake is depicted from top to bottom. Aquatic plants grow, decay, and settle to the bottom as the lake slowly fills in. This process is greatly accelerated by the increased inputs of nutrients such as nitrogen and phosphorus.

Eutrophication can also result in the loss of aquatic habitats such as plant beds in fresh and marine systems and coral reefs along tropical coast.

In marine ecosystems, algal blooms called red or brown tides cause widespread problems from the release of toxins and low oxygen conditions when they die and decompose. Coastal algae blooms have increased in recent years having severe negative impacts on aquaculture and shell fisheries. They can cause shellfish poisoning in humans, and have caused large mortality in marine mammals.

Pfiesteria (http://www.nal.usda.gov/wqic/pfiest.html), a toxic dinoflagellate, has recently been associated with mortality of finfish in the Chesapeake Bay. Outbreaks of Pfiesteria have been linked in part to elevated nutrient loads and impaired water quality. This dinoflagellate produces a highly toxic, volatile chemical that can cause neurological damage to people who come in contact with it.

Student Activity 1

1. List and define the three parts of the pollutant delivery process.

2. List, define, and provide an example of three processes that influence the availability of nutrients in the environment.

3. Define eutrophication and generally describe the process of eutrophication.

4. Of the many potential adverse impacts of eutrophication, provide five examples of potential adverse effects of eutrophication.

5. What is environmental risk, what are the key components to consider related to nutrients in the environment, and why is environmental risk important to resource planning and management?

6. When working with our clients, what is our responsibility as resource planners when we become aware of an important environmental risk?

Nutrients of Concern and Environmental Risk

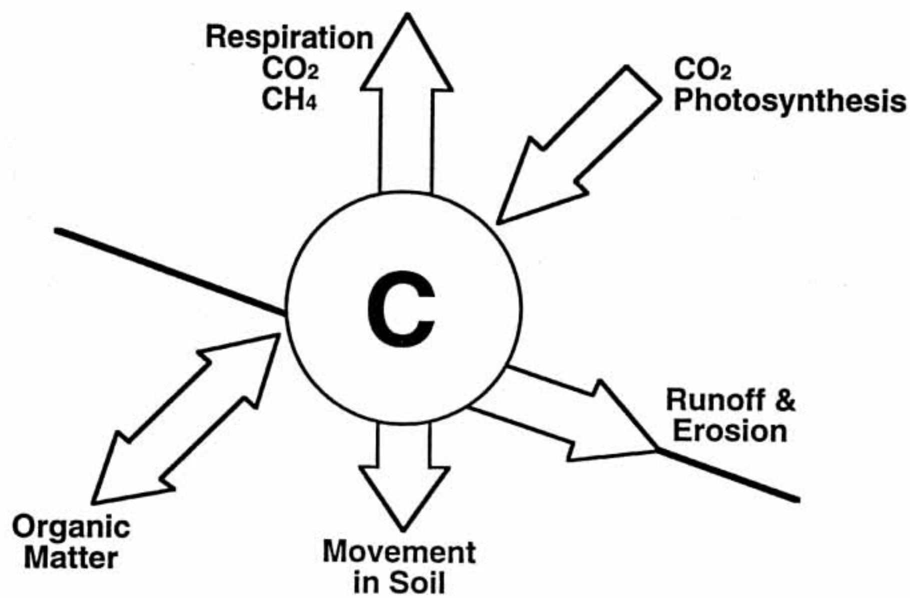


Figure 2.2 Simple carbon cycle.

Carbon (C) is the major building block of plants and animals. As a plant nutrient, carbon is taken up by the plant from the atmosphere as carbon dioxide (CO_2). Carbon dioxide is also a by-product of plant and animal respiration.

Methane (CH_4) is a by-product of anaerobic respiration. Both carbon dioxide and methane are gases that can potentially create the greenhouse effect (warming of the earth's atmosphere and changes in global climates).

The major carbon pool in soils is organic matter. As illustrated in figure 2.2, carbon moves back and forth between the organic matter complex in the soil and the other carbon pathways. Organic matter includes both living and dead plant and animal materials. Nutrients like nitrogen and phosphorus are assimilated into organic compounds by plants and animals. Thus major pools of nitrogen and phosphorus are associated with carbon compounds in the soil organic matter. Carbon complexes, like organic matter, also have an affinity for many agricultural inputs. For example, pesticides may be significantly bound to organic matter. Carbon can cycle these agrichemicals through various chemical and biological processes. The fate of nutrients and pesticides in the environmental system is therefore, closely related to the fate of carbon. For example, movement of soluble carbon to lower portions of the soil profile may provide a source of energy for microbial conversion of nitrates to nitrogen gas (denitrification).

Once they enter water bodies via erosion, runoff, and leaching carbon compounds contribute to eutrophication. Sources of carbon are:

- sediment
- organic matter
- manure and other biosolids

Once in the water body, the presence of carbon creates a demand for oxygen by organisms using the carbon as an energy source to decompose the organic matter. This high biological oxygen demand (BOD) can create an oxygen deficiency in the water great enough to cause fish kills and may also cause oxygen limitations to other aquatic organisms.

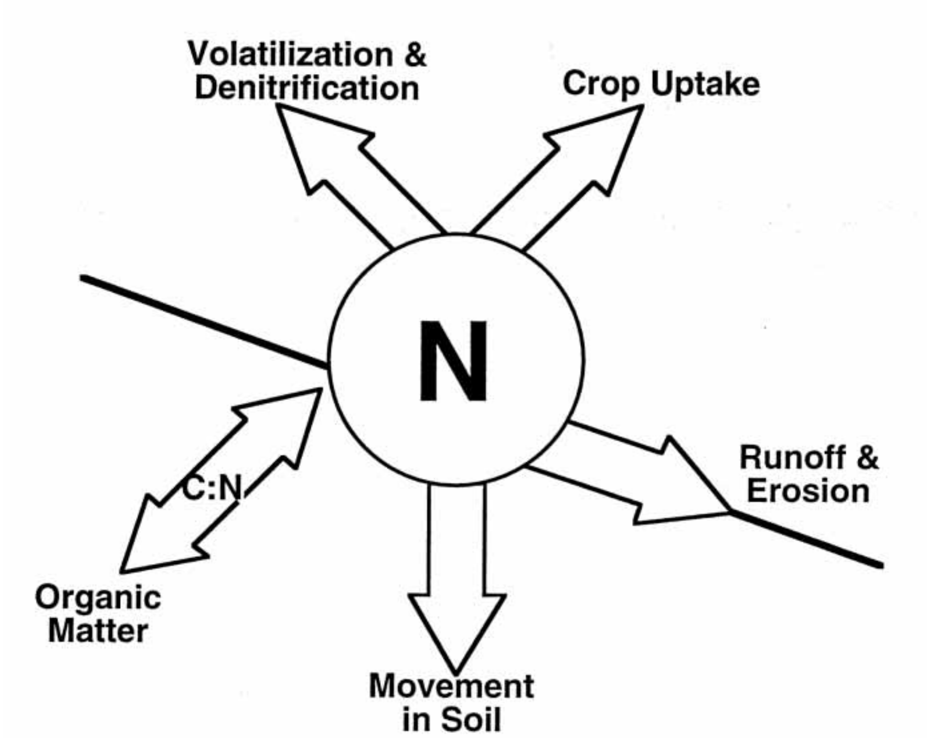


Figure 2.3 Simple nitrogen cycle.

Nitrogen is usually the most limiting nutrient in crop production systems and is typically added to the soil environment in the greatest amount of any of the plant nutrients. Under favorable conditions, increases in nitrogen content of the soil and plant uptake generally leads to higher nitrogen and protein content of the plant as well as greater crop yield.

Ammonium nitrogen is a cation (NH_4^+) and is adsorbed to the soil on the cation exchange sites. It is also fixed (trapped or locked up) in place between clay layers, becoming relatively unavailable for plant uptake, and is only slowly released over time as the soil bonds are broken (figure 2.4).

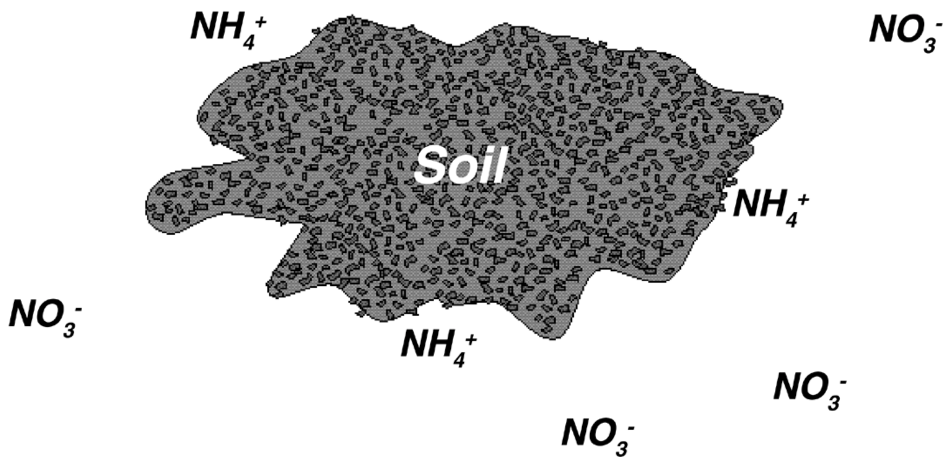


Figure 2.4 Ammonmium nitrogen (NH_4^+) and Nitrate nitrogen (NO_3^-).

Ammonia (NH_3) can react with soil organic matter to form compounds that resist decomposition. In affect, the ammonia can also become fixed by the organic matter. Fixed ammonia is subject to subsequent slow release over time as the organic matter eventually decomposes. Ammonia is soluble in water and is used as a source of nitrogen by aquatic plants, including algae. Ammonia can be detrimental to fish in two ways: by direct toxicity and by removing oxygen from the water. Ammonia and ammonium are in a dynamic equilibrium in water. When ammonia dissolves in water, a portion reacts to form ammonium ions (NH_4^+) with the balance remaining as ammonia. The concentration of ammonia increases with increasing pH and temperature. Current criteria for fresh water aquatic life is 0.02 mg/L of ammonia. Since ammonia is not routinely measured in water, the criterion is based on the total of ammonium and ammonia in the water. Levels higher than this are toxic to fish, especially cold water fish like trout (figure 2.5). Higher levels are also toxic to aquatic plants; however, if the concentration is gradually increased, plants can thrive at these higher ammonium levels. Total ammonium nitrogen can also exert a significant oxygen demand on the water. Oxygen is required by bacteria to nitrify ammonium nitrogen to nitrate nitrogen.

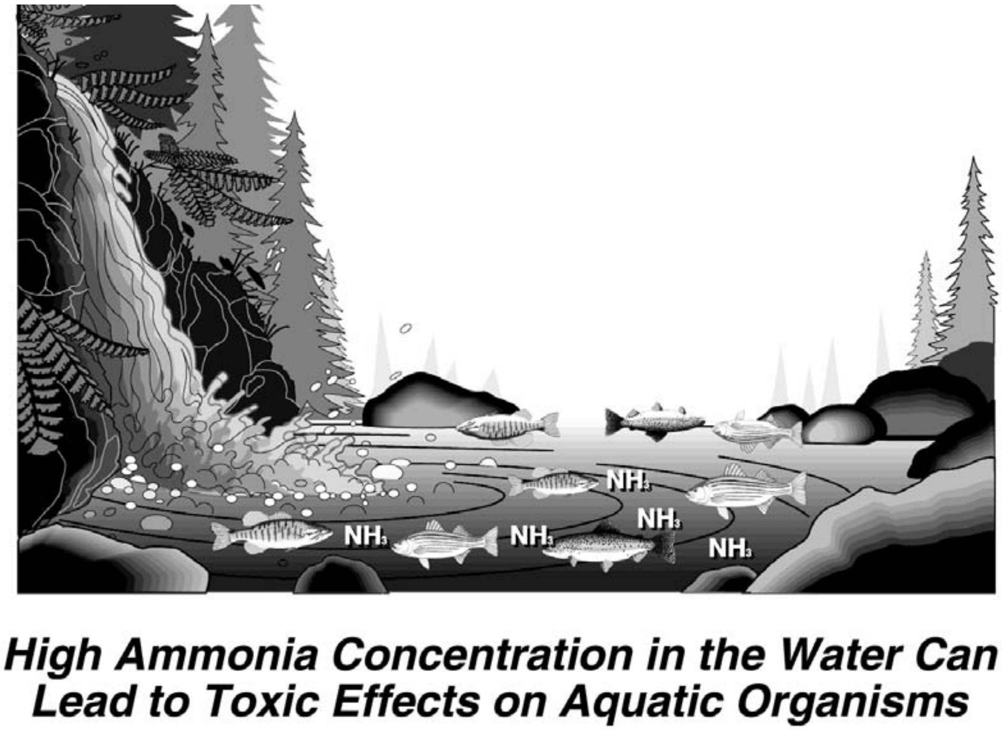


Figure 2.5 Potential effects of high ammonia concentrations in water. As illustrated, elevated ammonia concentrations in water may lead to fish kills, especially cold water fish such as trout or other sensitive species.

Surface application of ammonium to the soil can result in significant volatile loss as ammonia to the atmosphere (volatilization). Under specific soil environmental conditions, nitrogen may be lost to the atmosphere as gaseous nitrogen and nitrogen oxide. This will be discussed in more detail in Module 3. These additions of nitrogen to the atmosphere can contribute to environmental problems. Nitrogen oxide is a gas that contributes to the greenhouse effect and is considered to be detrimental to the ozone layer. Ammonia volatilized to the atmosphere may increase the nitrogen content of rainfall in localized areas. This gaseous loss of nitrogen to the atmosphere may have a positive impact on some ecosystems. Many wetlands, riparian areas, and grasslands receive much of their nitrogen nutrition from rainfall.

The ammonium ion combines with water within the soil to form aqueous ammonia which, at high concentrations, is toxic to biological life. Seed germination and root growth are severely reduced in the presence of ammonia. Such plants as rice, azaleas, and blueberries have adapted to grow in high ammonium environments where little nitrification takes place.

Nitrate nitrogen (NO_3^--N) is an important plant nutrient, but it is not essential for animal nutrition. Nitrate nitrogen is very mobile in the soil. Since it is negatively charged and thus does not bind to the negatively charged clay surfaces, it is subject to leaching. Leaching occurs when precipitation or irrigation supplies water in excess of soil storage capacity. Once the nitrate is transported below the root-zone there is no opportunity for plant uptake and less opportunity for chemical/biological transformation. Continued leaching can move the nitrate to the ground water. Public health drinking water standard (US EPA) for nitrate nitrogen is 10 mg/L (10 ppm). High levels of nitrate in drinking water can cause a potentially fatal blood disorder called blue baby syndrome (*methemoglobanemia*). This illness occurs in children less than 6 months old. Extreme cases can result in death. The critical nitrate nitrogen concentration in livestock drinking water supplies is 40 mg/L. Concentrations greater than this amount can lead to reduced feed consumption and reproductive problems. Table 2.1 gives some general guidelines for the use of water with known nitrate content.

Table 2.1 Use of water with known nitrate content.

Reported as: nitrate nitrogen (NO_3^-N)	**Reported as: nitrate (NO_3^-)**	**Interpretation**
<0.3 ppm[2]	<1.32 ppm[3]	Recommended level to prevent accelerated eutrophication. 0-10 ppm1
0-10 ppm[1]	0-44 ppm	Safe for all animals and humans.
10-20 ppm	44-88 ppm	Safe for livestock unless feed has high nitrate levels.
20-40 ppm	88-176 ppm	Might cause problems for livestock. If feed contains more than 1,000 ppm, total nitrate is likely to exceed safe levels.
40-100 ppm	176-440 ppm	Risks for livestock. Feed should be low in nitrates, well balanced, and fortified with vitamin A.
100-200 ppm	440-880 ppm	Should not be used. General symptoms such as poor appetite likely.

[1] ppm (parts per million) is the same as mg/L (milligram per liter).
[2] Concentration of all inorganic nitrogen including nitrate, nitrite and ammonium. Generally nitrate is predominant component.
[3] 1 ppm NO_3^-N is the same as 4.4 ppm NO_3^-.

Some evidence suggests that nitrates in the digestion tract of animals give rise to nitrosamines, which have been implicated as carcinogens. This connection, however, has not been fully established.

Certain conditions, such as drought and over application, can cause a buildup of nitrate levels in the soil, which can lead to uptake in excess of plant requirement. High levels of nitrate in livestock feed can also lead to animal health problems. Nitrate toxicity in animals, particularly dairy cattle, has sublethal effects such as slow growth, loss of milk production, and deficiencies of vitamin A and iodine. Nitrate toxicity in dairy cattle can be brought about by ingestion of drinking water higher than 100 mg/L nitrate nitrogen concentration or feed that has higher than 0.5 percent total nitrate (0.1 percent nitrate nitrogen). Forage plants accumulate nitrates at varying rates. Plant uptake of nitrate increases rapidly in high nitrate soils with the first rains following a long drought. High nitrate accumulations have been reported in sudan grass, sorghum-sudan, pearl millet, corn, wheat, and oats. Weeds, too, can accumulate nitrates. Examples of high nitrate accumulators are pigweed, smartweed, ragweed, lambsquarter, goldenrod, nightshade, bindweed, canada thistle, and nettle. Guidelines for nitrate levels in feeds are given in table 2.2.

Table 2.2 Nitrates in feed.

Nitrate in feed [1/] **(dry matter basis)**		**Comments**
Percent	**ppm**	
0.00 - 0.25	0 - 2,500	Generally considered safe.
0.25 - 0.5	2,500 - 5,000	Generally safe when fed with a balanced ration. Water for livestock should be low in nitrates. Be cautious with pregnant and young animals.
0.50 - 1.50	5,000 - 15,000	Limit ration high in nitrate. Ration should be well fortified with energy, minerals, and vitamin A. May experience milk production problems and possible reproduction problems.
>1.50	>15,000	Toxic. Do not use in free choice feeding program. Feed containing these levels must be mixed and limited to 15% of total ration.
[1/] Feed nitrates are generally expressed as nitrate (NO_3^-). Nitrates in water are generally expressed as nitrate-nitrogen (NO_3^-N)		
(Source: University of Wisconsin)		

Student Activity 2

1. List three negative impacts that nitrogen can have on the environment.

2. List two negative impacts that carbon can have on the environment.

3. Why is nitrate nitrogen subject to leaching from the soil profile and when is leaching most likely to occur?

4. Considering the nitrogen cycle, list three ways nitrogen moves in the environment.

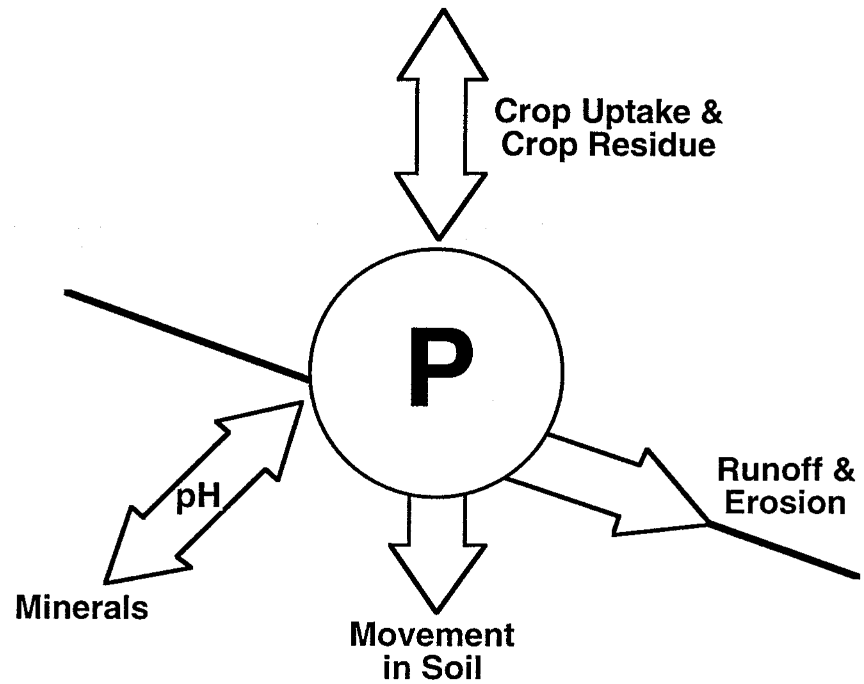


Figure 2.6 Simple Phosphorus Cycle.

Phosphorus is an essential nutrient for plant growth. Phosphorus occurs in the soil primarily as inorganic and organic compounds. Inorganic forms of phosphorus include clay complexes with iron, aluminum and calcium, and phosphorus-containing minerals. Organic forms are primarily associated with organic matter. Plants take up phosphorus in the orthophosphate forms ($H_2PO_4^-$ and HPO_4^{-2}). Although the total amount of phosphorus in the soil is large, the quantity of plant-available phosphorus in the soil solution as orthophosphate is small, ranging from 0.25 to 3.00 pounds per acre. *To meet crop requirements the soil solution must be continually replenished*. There exists a dynamic equilibrium in the soil between the adsorbed phosphorus of mineral and organic components and the soil solution.

There are no known direct harmful effects of phosphorus on plants or animals. Evidence of excess phosphorus in the soil solution for plant growth is rare and little evidence can be found for support of toxic conditions to plants. However, at high soil test P levels, some crops such as dry beans and citrus may not be able to acquire sufficient zinc and copper.

The fate of phosphorus in the soil system is outlined in figure 2.6. Historically, phosphorus has been added to soil to meet crop uptake. Phosphorus is applied to the soil in the form of commercial fertilizer or organic amendments like animal manure. The phosphate ion (PO_4^{-3}) contained in these materials is rapidly adsorbed to soil particles or combined to form a slightly soluble chemical compound. In most soils these processes prevent leaching of phosphorus below the root-zone. However in some environments such as sandy soils, soils that have high soil-test phosphorus levels, organic soils, soils that have shallow water tables, and in high rainfall area phosphorus leaching can occur. This phosphorus does not pose a risk to drinking water, but it may have a significant water quality impact where ground water interfaces/discharges to surface water.

The major loss of phosphorus from land surfaces is through the process of surface runoff and erosion. Approximately 90 percent of phosphorus load are carried in the sediment. Generally, phosphorus lost in runoff amounts to less than 5 percent of that applied to agricultural land. From a crop production standpoint, this amount is considered to be insignificant, however, even this seemingly small amount can lead to degradation in water quality due to eutrophication. Most of the phosphorus is lost in only one or two storms or runoff events. Phosphorus applied to the surface, either as manure or commercial fertilizer, is subject to loss/transport in runoff. Soluble phosphorus, though only 10 percent of the total runoff P from cropland, is highly bioavailable and can contribute significantly to eutrophication even at the low levels. In soils that are not tilled, such as hay land, pastureland and no-tillage, the ratio of sediment-bound P to soluble P is reversed. In these soils 90 percent of the total runoff P is in the soluble form.

Some soils remain relatively low in phosphorus and need to be supplemented by phosphorus additions. However, many regions of the country, especially in areas of confined animal operations, are experiencing elevated levels of soil test phosphorus above those required for optimum production. These elevated soil test levels increase the risk of greater phosphorus transport to surface waters and accelerated eutrophication. (See table 2.3.)

Cattle and other ruminants convert plants and grains phosphorus into dietary phosphorus that are important in their metabolism. Monogastric animals (non-ruminants) like poultry and swine have a more difficult time breaking down the phosphorus contained in the plant material for dietary purposes. The phosphorus is tied up as phytic acid, which is almost impossible for poultry and swine to metabolize. Addition of the enzyme phytase to the feed helps in the conversion of phytate to dietary P. Sufficient supplements of dietary P are added to the feed to ensure a balance diet. Much of this dietary and plant P is passed through the digestion system, therefore both poultry manure and swine manure has a high concentration of P. Manure is a significant source of phosphorus regardless of the animal source, and if mismanaged can create water quality and other resource problems (table 2.3). Compare the percent of phosphorus in the various animal waste (percent P content based on total waste produced) to that of diammonium phosphate, which has a phosphorus content of 22 percent.

Table 2.3 Phosphorus production and content of various animal waste.

Animal	Phosphorus (lb) per AU/year		Animal Weight (lb)	Total P (lb) per animal per year	Annual total P production as a % of animal weight	% P content[2] based on total solids produced
	Total P	Ortho P				
Dairy	34.3	22.3	1400	48.0	3.4	0.8
Beef	33.6	11.0	1000	33.6	3.4	1.1
Sheep	31.8	11.7	200	6.4	3.2	0.8
Horse	25.9	6.9	1200	31.1	2.6	0.5
Swine	65.7	43.8	300	19.7	6.6	1.6
Layers	109.5	33.6	4	0.4	11.0	1.9
Broilers	109.5	Unavailable	3	0.3	11.0	1.4
Turkeys	84.0	Unavailable	14	1.2	8.4	1.9
Duck	197.1	197.1	4	0.8	19.7	0.7
Humans[1]	28.4	Unavailable	160	4.5	2.8	0.5

[1] Per person based on domestic household water use (includes toilet, kitchen, laundry).
[2] Dry weight basis.

Phosphorus entry into surface waters can lead to accelerated eutrophication. Phosphorus is often the limiting nutrient in freshwater plant systems. Phosphorus is needed by aquatic plants at amounts that are far greater than what is typically available in most aquatic systems. Note the ratio of required nutrient concentrations relative to what is typically available as found in table 2.4. Aquatic plants generally require about 80,000 times more phosphorus than what is commonly available in most aquatic systems. Although this is also true for nitrogen (30,000:1), nitrogen tends to be amply supplied to fresh water by atmospheric deposition and symbiotic fixation. When fresh water systems are enriched with phosphorus, the plants in water, aquatic vegetation responds dramatically with increased growth. Controlling the input of phosphorus into water is one of the most efficient and effective ways of reducing water quality related problems.

Phosphorus enters the aquatic system from the soil solution, runoff from the landscape, and direct discharge from point sources. Phosphorus enters the water column via overland flow in both the dissolved and sediment attached forms and can be released from bottom sediment (figure 2.7). Over time algae and other aquatic plants can readily uptake dissolved phosphorus from the water column. Therefore the two major sinks of phosphorus in an aquatic system are sediment-bound in the bottom sediment and that which is assimilated into aquatic plants. As mentioned previously, the amount of dissolved phosphorus in the water column of an aquatic system is small.

Table 2.4 Proportions of essential elements for growth in living tissues of freshwater plants (requirements), in the mean world river water (supply), and the approximate ratio of concentrations required to those available.

Element	Average water plant content (%)	Average supply in water (%)	Ratio of required vs. available
Phosphorus	0.08	0.000001	80,000
Nitrogen	0.70	0.000023	30,000
Carbon	6.50	0.0012	5,000
Silicon	1.30	0.00065	2,000
Potassium	0.30	0.00023	1,300
Calcium	0.40	0.0015	<1,000
Magnesium	0.07	0.0004	<1,000
Chlorine	0.06	0.0008	<1,000
Sulfur	0.06	0.0004	<1,000
Iron	0.02	0.00007	<1,000
Boron	0.001	0.00001	<1,000
Manganese	0.0007	0.0000015	<1,000
Zinc	0.0003	0.000001	<1,000
Copper	0.0001	0.000001	<1,000
Molybdenum	0.00005	0.0000003	<1,000
(Source: Weltz, 1983)			

Under certain situations (e.g. lake turnover) dissolved phosphorus can be redistributed from the lake sediment back into the water column and become available for uptake. If water at the surface of a lake cools more quickly than the bottom water (as it does in the winter), then surface water sinks to the bottom (cool water is more dense and heavier than warm water) and the warm water rises bringing phosphorus up into the photic (light) zone. A shallow or wind-mixed lake can also redistribute phosphorus in the water. These processes influence the phosphorus level in the water column.

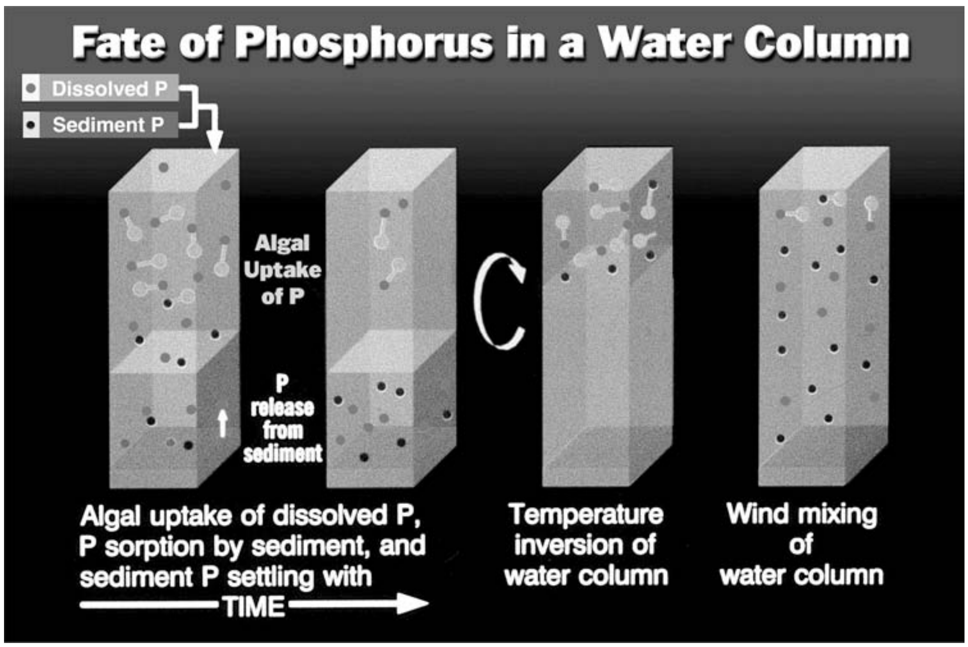


Figure 2.7 Phosphorus dynamics in the water column.

In streams and rivers (lotic or flowing systems) similar interactions occur. However, because water is typically moving at a faster rate through these systems, phosphorus cycling occurs as a process often referred to as phosphorus spiraling. Dissolved and sediment phosphorus levels change during transport in streamflow (spiral) via interaction with suspended sediments, streambank and stream bed material, and aquatic plants. These interactions all influence the relative amounts of dissolved and sediment phosphorus in a stream.

When sediment enters a river or lake, phosphorus may be adsorbed from solution or desorbed (released) from the sediment, depending on the concentration of phosphorus in solution. Soil eroded from a heavily fertilized field may release phosphorus to solution when it enters a stream or lake. Conversely, erosion of subsoil or streambank material that has low phosphorus and high clay content may adsorb phosphorus from the solution and lower the dissolved phosphorus concentration during transport in a river.

Although all contributing factors and their interactions are not completely known, recent research indicates that high level of phosphorus and nitrogen in estuary and marine systems correlate with increases in undesirable aquatic organisms such as pfiesteria and red algae. These organisms can be toxic to other aquatic life. Humans exposed to these toxins have reported ill health effects.

Student Activity 3

1. The form of phosphorus that is readily available from plant uptake and use is ______________________________.

2. The major part of the phosphorus load in surface runoff is typically carried by sediment. ______________ (true or false)

3. Cattle manure has more phosphorus per pound than chicken manure. ______________ (true or false)

4. Name the two major sinks of phosphorus in an aquatic system.

   ____

   ____

5. Describe the process of phosphorus cycling in an aquatic system.

   ____

   ____

   ____

   ____

6. Briefly describe how excess phosphorus can impact the water quality of a pond?

   ____

   ____

   ____

   ____

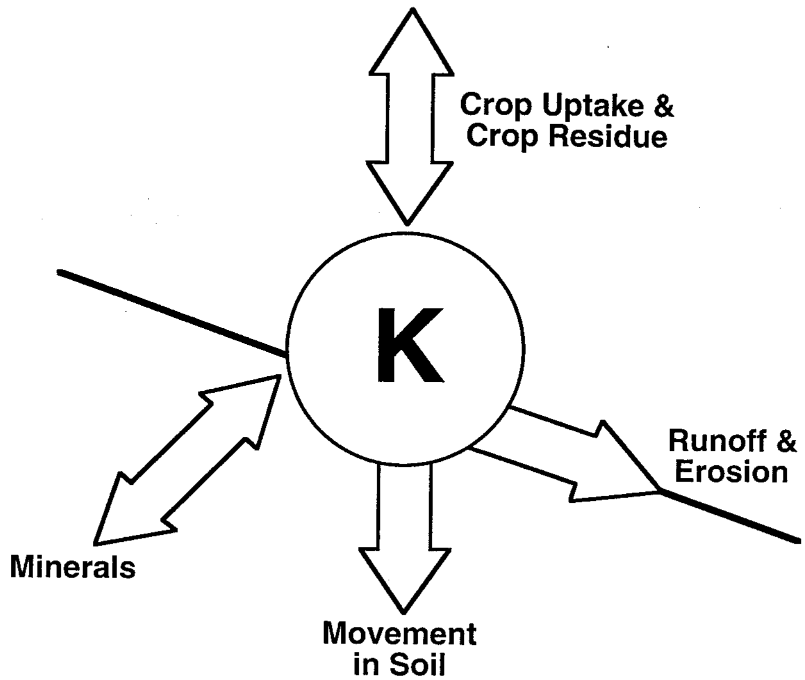


Figure 2.8 Simple potassium cycle.

Potassium (K) is utilized in relative large quantities by plants. Tissue concentrations range from 1.0 to 2.0 percent. Potassium plays an important role in plant hardiness and disease tolerance. The potassium ion (K^+) regulates the water status in plants. It also works in the ion transport system across cell membranes and activates many plant enzymes. Potassium is a cation (K^+) that is held on the soil cation exchange sites.

Excess potassium in the soil can lead to conditions of grass tetany in livestock. Grass tetany is a serious disorder in lactating ruminant animals caused by low magnesium content in forage, especially grasses. When high levels of potassium are present in the soil solution, plants will take up the potassium at the expense of magnesium, leading to luxury consumption of potassium and an imbalance of potassium and magnesium in the plant. Lactating ruminants that eat this forage do not get enough magnesium in their diet. The concern comes from using high rates of manure and other organic material on forages. This situation is more common when forages receive organic material high in nitrogen and potassium early in the growing season. Although legumes are better balanced with magnesium, pastures with a mixture of grasses and legumes may still have problems early in the season when legumes are typically growing much slower than grasses. Early season application of organic material to forages should be avoided until the slower-growing legume has an opportunity to flourish. Grazing can be delayed until the legumes provide a good balance in the pasture with the grasses.

The effects of high K levels in soil and long-term sustainability are poorly understood. Although nutrient imbalances will likely occur, the effects on plant nutrient uptake, growth and production have not been well documented. Recent research suggest that excessive levels of soil K may have a negative effect on sustainability. However, little data is available and critical levels have not been established. There are no known deleterious effects of K in fresh or saline waters except to increase the salt content and electric conductivity.

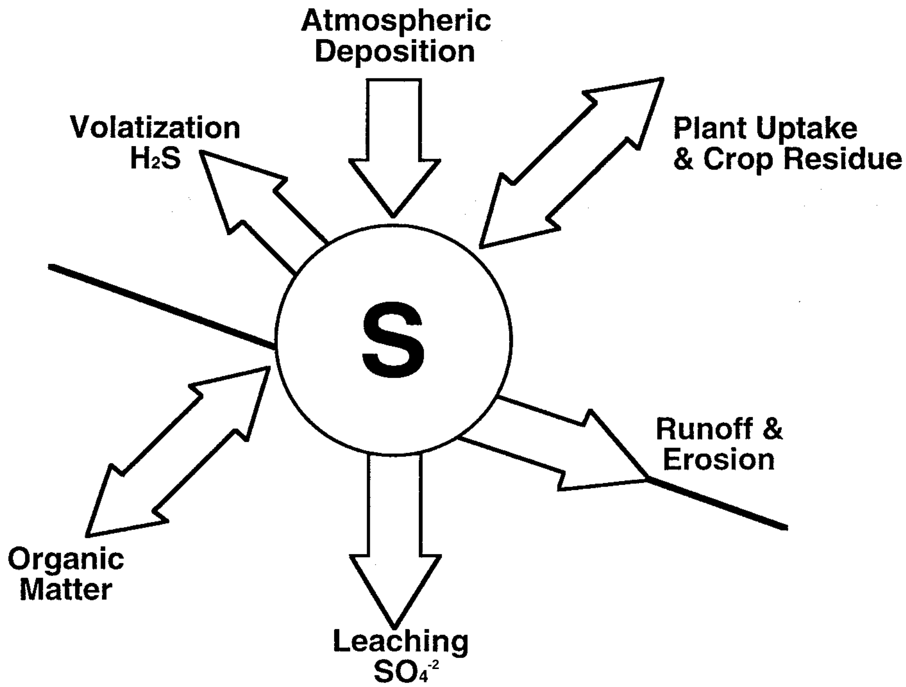


Figure 2.9 Simple sulphur cycle.

The sulfur (S) cycle is similar to the nitrogen cycle. Sulfur sulfate (SO_4^{-2}), a divalent (having a valence or degree of combining power of an element or chemical group of two) anion, is less leachable than nitrate. There is no drinking water standard for sulfate, however sulfur products can impart a bad taste to drinking water. Sulfur can be removed from the landscape through erosion and runoff. However, few surface water bodies are impacted by sulfur additions. A major natural source of sulfur to the soil comes from atmospheric deposition. Sulfur is one of the major components in acid rain. The source of the deposition is burning of high sulfur fossil fuels.

Student Activity 4

1. List two potential effects of excess potassium in soil?

2. Describe the effect of high soil potassium levels on forages, especially grasses?

3. What are the two negative effects of excess sulfur in the environment?

4. What is a major source of sulfur in/to the soil?

Salts

Excess salt in agricultural soil can lead to decreased productivity. Salt accumulation occurs when salts are not removed from the soil by crop uptake or leaching. High salt concentrations are often found in conjunction with inadequate drainage, low quality irrigation water, and insufficient soil moisture. Animal manure may also be a significant source of salts. Drainage water from salt-affected soil can contribute to salt loading of surface water.

Excessive or imbalanced concentrations of dissolved salts can cause four types of problems for agriculture:

- *General yield declines*—Dissolved salts create *osmotic forces*. Essentially, osmotic forces act in the same manner as the water holding forces that the soil structure creates (termed *matrix forces*). They tend to hold water back from the plant. Effectively, excessive dissolved salts reduce the amount of available water in the soil. This affects plant germination and nutrient and water uptake, which prevents the crop from reaching its yield potential.

- *Soil structure problems*—Sometimes it is not the total amount of dissolved salts that is important, rather it is the relative amount of different types of salts. If the different types of salts are out of proportion, soil structure problems can result. The imbalance occurs if there is too much sodium in relation to magnesium and calcium in the soil water. The type and amount of clay in the soil determines the extent of the problem. Problems are generally manifested as impeded movement of water, air and roots. It becomes difficult for water to infiltrate the ground causing poor root penetration and expansion.

- *Specific toxicity*—Some salts, while necessary for crop growth in proper amounts, are toxic in excessive amounts. The prime example is boron. A benchmark of poor irrigation water quality for many growers is water that is tested at 1.0 part per million of boron or above. Crops have varying sensitivities to salts (figures 2.10 through 2.12). Therefore, crop selection is an important consideration when soils are determined to be salt affected.

- *Corrosion and other miscellaneous problems*—Salts can cause excessive corrosion of some irrigation system equipment. Because of this, certain waters may require special handling to prevent problems such as clogging of drip irrigation systems.

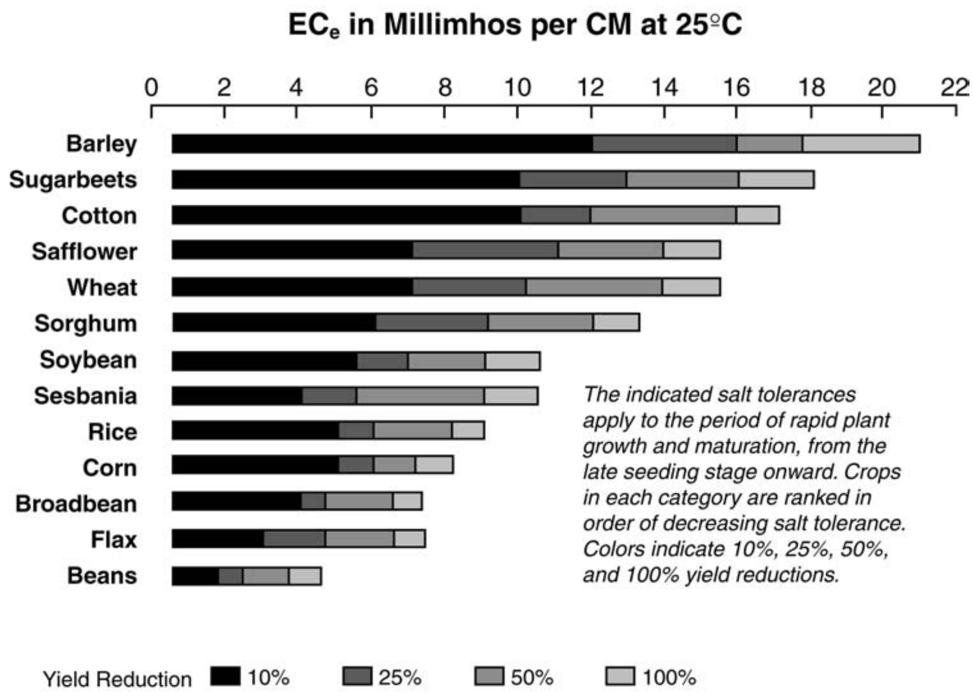


Figure 2.10 Salt tolerance of field crops.

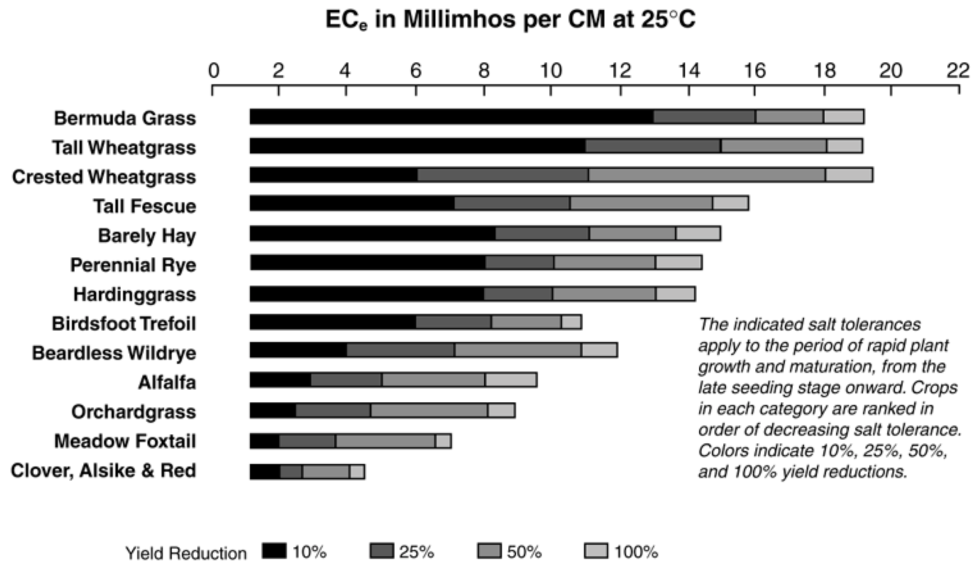


Figure 2.11 Salt tolerance of forage crops.

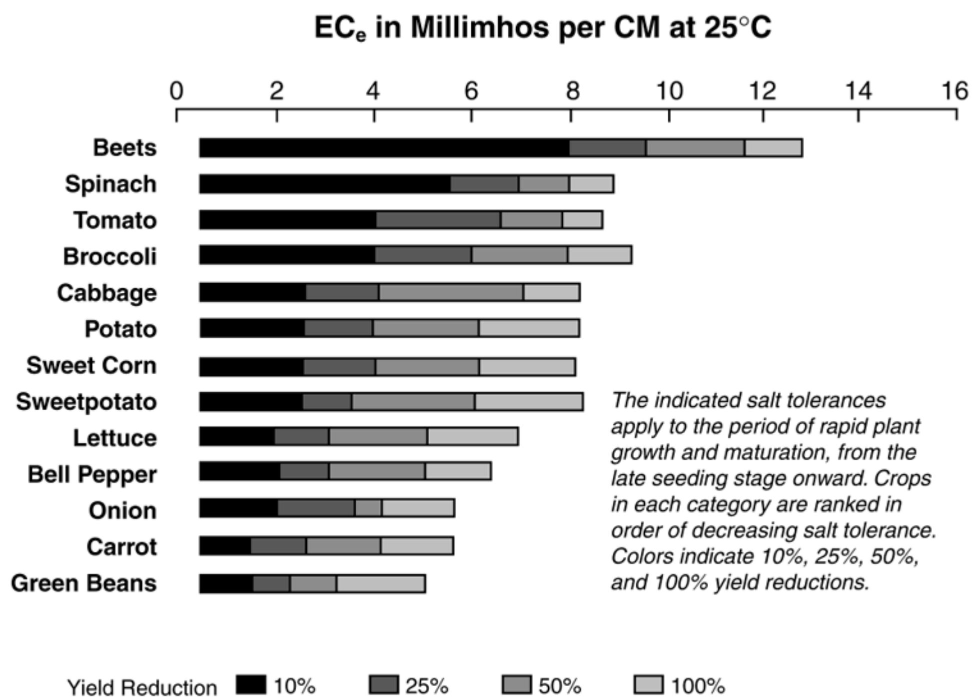


Figure 2.12 Salt tolerance of vegetable crops.

Management Techniques

Specific management techniques are available for dealing with salinity problems. Practices that can be used to manage these problems include the following:

- Selection of crops or crop varieties that have salt tolerance.
- Use of irrigation water to leach salts out of the crop root zone.
- Establishment of proper surface and subsurface drainage.
- In some cases, soil amendments can be used to improve soil structure.
- Use of planting techniques like elevated bedding.
- Use of ground water for first irrigation and surface water for later applications if possible.

Student Activity 5

1. List four conditions that may lead to salt build-up in soil.

2. List two problems that excess salts can cause in agriculture.

3. Provide two examples of management techniques that can be used to correct a salinity problem.

4. Do you have a potential salt problem in your area? Why or why not?

Heavy Metals

Heavy metals are generally interpreted to include those metals from periodic table groups IIA through VIA (figure 2.13). The semi-metallic elements: boron, arsenic, selenium, and tellurium are often included. Many of these elements are necessary to support life, but are typically found at trace levels. At elevated levels they become toxic to plants or animals, or both, may build up in biological systems, and may become a significant health hazard.

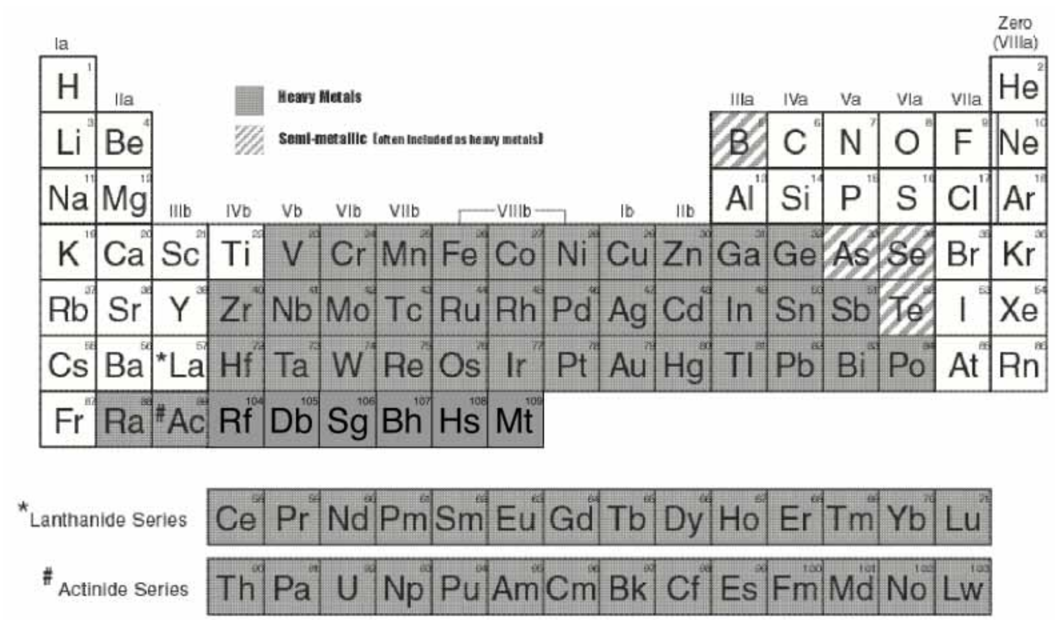


Figure 2.13 Periodic table of the elements.

Heavy metals such as *cadmium, arsenic, chromium,* and *mercury* are extremely poisonous. Less toxic elements include lead and nickel. Others elements, which are also essential nutrients, can be toxic if they occur at high levels in soils. These elements include *boron, copper, zinc, molybdenum,* and *manganese*. Most heavy metals enter the soil by applications of such as organic wastes and biosolids (sewage sludge). Other sources include fertilizer by-products, animal manure, and atmospheric deposition from burning of hydrocarbon fuels by industry and motor vehicles.

Several metals have been targeted by EPA when screening for environmental problems. They are:

- Antimony
- Arsenic
- Beryllium
- Cadmium
- Chromium
- Copper
- Lead
- Mercury
- Nickel
- Selenium
- Silver
- Thallium
- Zinc

The EPA has established standards for cumulative lifetime soil limits when applying organic materials containing these elements to the soil. These loading limits are based on the soil's cation exchange capacity and pH.

Trace elements (both heavy metals and micronutrients) are relatively immobile once they are in the soil. Heavy metals do not leach or volatilize from the soil. The level of plant availability is generally low in relation to the total quantity present in the soil. Soil pH has the greatest influence on availability and subsequent plant uptake. The ability of plants to take up heavy metals increases as soil pH decreases. Maintaining soil pH at a level higher than the optimum range for crops will reduce plant uptake of most trace elements. The one exception is molybdenum. For most agricultural crops a soil reaction pH between 6.0 and 7.0 is optimum. Soil organic matter binds metals and reduces their bio-availability. Soils that have low soil organic matter and a low cation exchange capacity have a high environmental risk for bio-availability of metals to plants.

Plant growth is affected by excess amounts of copper and zinc in the soil. Both are toxic to plants at high soil concentrations. Both are also mutually competitive as well as competitive with other micronutrients and heavy metals at the site on the plant root where these ions are transported across the root cell membrane during uptake. Excessive concentrations of either element in the available form in the soil can induce a plant deficiency of other micronutrients.

A concern with the heavy metals is that they are often not toxic to plants but can be toxic to the animals that eat the plants. Problems with heavy metals are often chronic in nature resulting from cumulative exposure to these metals in food. Heavy metals can be ingested by animals in forage where metals have either been taken up by the plant, or with dust deposition of metals on the plant. The greatest environmental risk is where metals are eroded from the application site by wind or water and transported to receiving water bodies or when plants accumulate metals and are consumed by animals.

Student Activity 6

1. What are three sources of heavy metals to agricultural lands?

2. List three heavy metals that are also essential nutrients.

3. List four heavy metals of major concern that have been identified and targeted by the U.S. Environmental Protection Agency.

4. Why are heavy metals an environmental concern?

5. List two processes that influence the fate of heavy metals in the environment.

Group Activity 1—Optional

Control of most pollutants can be assessed in terms of the capability to impact one or more of the pollutant delivery processes. Discuss the following best management/conservation practices and their impact on one or more of the pollutant delivery processes.

Best management/conservation practice	**Pollutant delivery process(es) impacted**
Residue management	
Terraces	
Banding vs. broadcast fertilizer	
Water and sediment control basin	
Irrigation water management	
Riparian forest buffer	

Module 2, Part B—Pesticides: Human and Environmental Health

Supporting Objectives

Upon completion of this part, you will be able to:

- Describe the processes that affect the fate of pesticides in the environment.
- Explain the ways pesticide use can induce potentially adverse impacts on humans and other non-target organisms.
- Define the elements of pesticide risk assessment.

Introduction

Part B of Module 2 is designed as an introduction to the environmental and human health impacts associated with pesticide use. An understanding of the principles covered in this section should allow natural resource conservationists to assist landowners in making environmentally sound pesticide use decisions as a part of resource conservation planning.

Over 1.20 billion pounds of pesticide active ingredients are used annually in the United States in agriculture, forestry, rights-of-way, and by homeowners. All pesticides are designed to be toxic to living organisms that are of economic or human health importance, but also have unintended effects on non-target organisms and the environment. While advances have occurred in pesticide chemistry, formulation, and application technology since the widespread use in the 1950's, 1960's, and 1970's of persistent organochlorine insecticides, such as DDT, the concern remains regarding the potential risks to human health and the environment associated with pesticide use. Although each pesticide formulation has unique properties that contribute to its inherent toxicity and environmental fate, it is its use practices that ultimately determine a pesticide's benefit and risk. Consequently, pesticide use should be carefully planned, and sole reliance on pesticides should be avoided. Whenever possible, pesticide use should be integrated with other ecologically and environmentally sound control strategies designed to keep pests below economic injury levels.

Part B is presented in four sections. Each section has supporting learning objectives and activities.

Module 2, Part B, Section 1—FIFRA Risk/Benefit Statute

Supporting Objectives

- Describe FIFRA.
- List three requirements for pesticide registration under FIFRA.
- List three components of EPA's risk assessment procedure.
- Explain why, even when a pesticide is used according to the label, there may be significant environmental risk.

Introduction

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) is the primary legislation regulating pesticides in the United States. The Environmental Protection Agency (EPA) is responsible for the administration of this body of laws, which addresses numerous issues including the registration of pesticide products, prescribing conditions for pesticide use, establishing maximum acceptable levels of pesticide residues in foods, labeling requirements, and other aspects of pesticide regulation.

Registration

To register a pesticide, EPA must determine that the pesticide "will perform its intended function without unreasonable adverse effects on the environment; and when used in accordance with widespread and commonly recognized practice, it will not generally cause unreasonable adverse effects on the environment." FIFRA defines "unreasonable adverse effects on the environment" as "any unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of a pesticide."

The basic requirements for pesticide registration are:

- The use of the pesticide must not result in unreasonable adverse effects to human's health or the environment.
- The use of the pesticide will perform its intended function; it must be efficacious (effective at producing a desired effect).
- The benefits of the use of the pesticide must outweigh the risk.

EPA thus uses risk assessment and risk management practices to determine labeling and use conditions for the pesticide. The risk assessment process is a multistage process in which EPA must:

- Consider the toxicological hazard posed by the pesticide.
- Consider the potential for exposure.
- Characterize the risk.

In identifying the hazard, EPA requires the pesticide registrant to conduct animal studies that address the toxicity of the pesticide to humans and wildlife. The data is used to determine the relationship between the pesticide dose and the incidence of an adverse effect, such as nervous system dysfunction, birth defects, or cancer. Once the hazard has been defined through the determination of dose response, the potential for exposure is estimated. Additional studies are required to characterize the fate of the pesticide in the environment. Human exposure assessment considers pesticides in the diet, in water, air, and on surfaces that may come into contact with skin. Special consideration is given to occupational exposure, including applicators and other farm workers. In addition, EPA must consider separately sensitive sub-populations, such as infants and children. Considering similar routes of exposure and numbers, types, distribution, abundance, dynamics, and natural history of non-target organisms, the potential for wildlife exposure is estimated. Hazard and exposure assessments are integrated into risk characterization. This process estimates the incidence and severity of an adverse effect under the various conditions of the exposure assessment. How these components are put into practice constitutes the principles of risk assessment. EPA performs a risk assessment prior to the registration of a pesticide; however, as testing standards are updated pesticides must be reregistered to meet the new requirements. Ultimately, the user determines pesticide risk. Those who provide advice have the opportunity to assist the pesticide user in making sound pest management decisions that further reduce the potential for adverse effects to human health and the environment.

EPA fact sheet on pesticide registration

According to an EPA fact sheet on pesticide registration (www.epa.gov/pesticides/citizens/registration.htm), updated October 18, 2000, 735-F-99-001 January 1999):

> *"EPA's registration program places high priority on registering pesticides that are safer than pesticides currently on the market, those pesticides with public health benefits, and pesticides that are of particular economic importance to producers."*

The same fact sheet states that:

> *"EPA is required by law to reregister pesticides that were originally registered before November 1, 1984, to ensure they meet today's more stringent safety standards."*

In addition, the fact sheet states that:

> *"All label language must be approved by EPA before a pesticide can be sold or distributed in the United States. The overall intent of the label is to provide clear directions for effective product performance while minimizing risks to human health and the environment."*

See also, www.epa.gov/pesticides/trac/factshee.htm updated January 26, 1999, for additional Pesticide Re-registration Facts.

New products must be deemed "safe" by EPA before they can be registered and old products must be deemed "safe" before they can be re-registered, but old products that have not yet been re-registered may not meet current EPA safety standards.

The following paragraph is taken directly from the EPA Re-registration Eligibility Decision (RED) document. It briefly explains how re-registrations are obtained:

> *In evaluating pesticides for re-registration, the pesticide producers submit to EPA a complete set of studies describing the human health and environmental effects of each pesticide. Agency scientists review the submitted studies to determine if the studies are scientifically valid. These studies are the basis for the Agency's risk assessment. The Agency then develops any mitigation measures or regulatory controls needed to effectively reduce each pesticide's risks, and then reregisters those pesticides or uses that can be used without posing unreasonable risks to human health or the environment.*

When a pesticide is eligible for re-registration, EPA explains the basis for its decision in a Re-registration Eligibility Decision (RED) document. Re-registration Eligibility Decision documents include sections devoted to Water Resources Assessment, Ecological Risk Assessment, and Risk Mitigation.

Excerpts from RED document for Alachlor

Water Resources Assessment

The Water Resources Assessment concludes that:

- Alachlor is highly mobile and moderately persistent. These two characteristics are generally observed in chemicals that reach ground water and surface water.
- Alachlor presents a clear hazard to groundwater quality. Reliable monitoring studies have demonstrated that alachlor, even when used according to label directions, results in significant groundwater contamination. Alachlor use also results in groundwater in the use areas being contaminated with degradation products, which are also very mobile and persistent.
- Monitoring studies show that alachlor levels in surface water result in effects on aquatic plants and indirectly on aquatic animals.
- Available information indicates that (surface) drinking water supply systems will usually comply with the SDWA

Ecological Risk Assessment

An evaluation of the risk to nontarget organisms from the use of alachlor products, combining toxicity data with potential exposure, indicates that:

- Alachlor poses a potential risk to terrestrial animals on a chronic basis. Additional information is required to confirm this assessment.
- The granular formulations and high use rate pose the greatest risk to nontarget organisms.
- Alachlor levels observed in surface water monitoring studies could result in extensive adverse effects on aquatic plants.
- Aquatic animals are not at acute risk due to exposure to alachlor, but chronic effects may be observed under certain circumstances.

Risk Mitigation

To lessen the human health, ecological, water and food quality risk posed by alachlor, the registrant has voluntarily agreed to reduce the maximum single application rate from 6 lb to 4 lb ai/acre, and to classify alachlor as a restricted use pesticide (RUP) for groundwater concerns. EPA is requiring additional mitigation measures that will: protect non-target species, control surface water and ground water contamination, and protect workers.

It must be stressed that following the label only minimizes risks to human health and the environment; *it does not eliminate risk*.

Our job is to identify resource concerns, evaluate the environmental risks of proposed pest management alternatives, and then recommend appropriate mitigation techniques that meet FOTG quality criteria. Any pest management alternative may have site-specific risks that need to be mitigated to protect the resource base, but we need to pay special attention to the use of older pesticides that have yet to be re-registered.

Student Activity 7

1. What is FIFRA? How does FIFRA define “unreasonable adverse effect on the environment”?

2. What is the statute that is the basis for pesticide regulation in the U.S.?

3. List three criteria for allowing a pesticide to be registered for use in the United States.

4. What federal agency has the primarily responsibility for regulating pesticides?

5. Although a pesticide has been applied according to the label, explain why there still could be significant environmental risk?

6. When working with our clients, what is our responsibility as resource planners when we become aware of an important environmental risk?

Module 2, Part B, Section 2—Fate of Pesticides in the Environment

Supporting Objectives

- Distinguish between point source and nonpoint source pollution.
- Define and calculate the distribution coefficient (Kd) of a pesticide.
- Define and calculate the sorption coefficient (Koc)
- Describe how each of these four pesticide properties can impact pesticide environmental fate.
  - — Half-life
  - — Sorption
  - — Water solubility
  - — Vapor pressure
- Describe how the following six environmental factors can impact the fate of pesticides in the environment.
  - — Temperature
  - — Soil pH
  - — Soil texture
  - — Sunlight
  - — Organic matter
  - — Soil moisture
- List four pathways for pesticide movement in the environment.

Introduction

This section addresses the potential for pesticides to reach ground water and surface water and is part of a package of training materials designed to assist in making pesticide use decisions that protect water quality, as well as human health and the environment.

Pollution Sources

Pollution is divided into two categories—*point source* and *non-point source.*

Point source pollution occurs from concentrated spills, leaks or discharges at discrete locations. Classic point sources of pollution include sewage treatment plants and industrial facilities. Other examples of point sources include:

- Pesticide spills, caused by improper mixing and loading.
- Improper pesticide storage, including leaky containers or spray apparatus.
- Improper disposal of empty pesticide containers.
- Improper disposal of leftover pesticides.

Non-point source pollution occurs when rainfall, irrigation, or melting snow picks up diffuse contaminants and washes them into ground and surface water. Examples of non-point sources include:

- Pesticide leaching from a field, orchard, or lawn.
- Pesticide runoff from a field, orchard, or lawn.
- Eroded sediment that is delivered to a stream, lake, or pond.

Pest management has the potential to result in both point and non-point source pollution. Summarizing point versus non-point source pollution from pesticides:

Point Source	**Non-point Source**
Mixing/loading	Application
Spills	Runoff
Disposal	Drift

Student Activity 8

1. Determine whether each of the following examples would be considered a point source (PS) or a non-point source (NPS) of pesticide pollution:

		Answer
a.	Pesticide leaving a tile line	___________
b.	Pesticide drift from a tank sprayer	___________
c.	Runoff from a recently sprayed vineyard	___________
d.	Volatilization from a surface application	___________
e.	Pesticide in leachate from an old landfill	___________
f.	Pesticide from a leaking container in a storage facility	___________
g.	Pesticide drift from an aerial application	___________
h.	Volatilization from an airblast application	___________
i.	Pesticide spill during mixing or loading	___________

Environmental Fate: Understanding Pesticide Persistence and Mobility

Many factors govern the potential for pesticide contamination of ground water or surface water. These factors include: pesticide properties, soil properties, such climatic conditions as rainfall distribution and water management, and crop management practices. This section focuses primarily on the properties of pesticides that affect their fate in the environment.

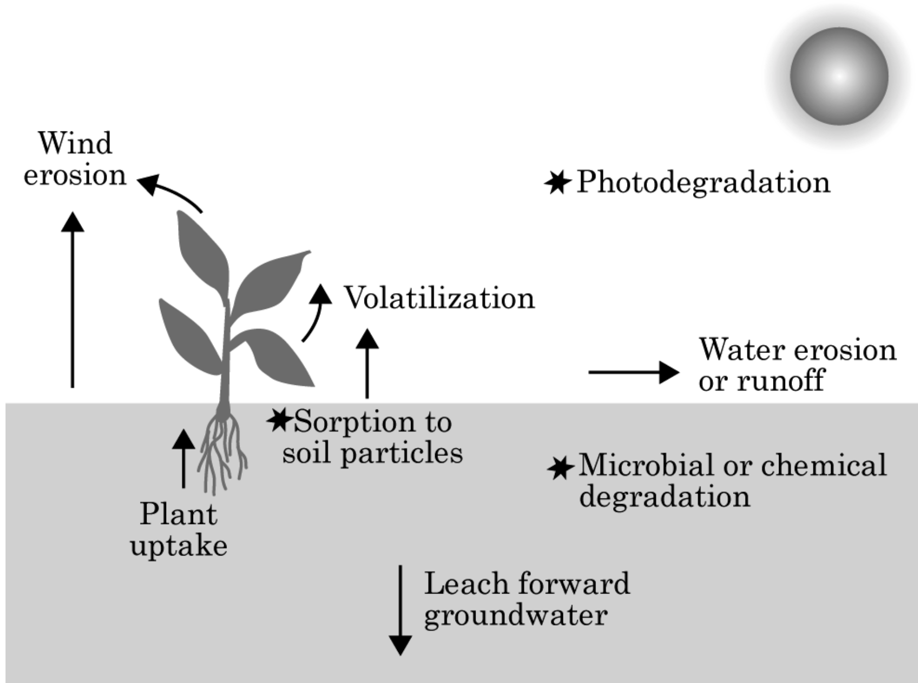


Figure 2.14 Pesticide fate processes.

Many possible fate processes exist for a pesticide (figure 2.14). These processes can be grouped into those that affect *persistence* and those that affect *mobility*.

Processes that affect persistence are:

- Photodegradation (degradation caused by sunlight)
- Chemical degradation
- Microbial degradation

Processes that affect *mobility* are:

- Sorption
- Plant uptake
- Volatilization
- Wind Erosion
- Runoff
- Leaching

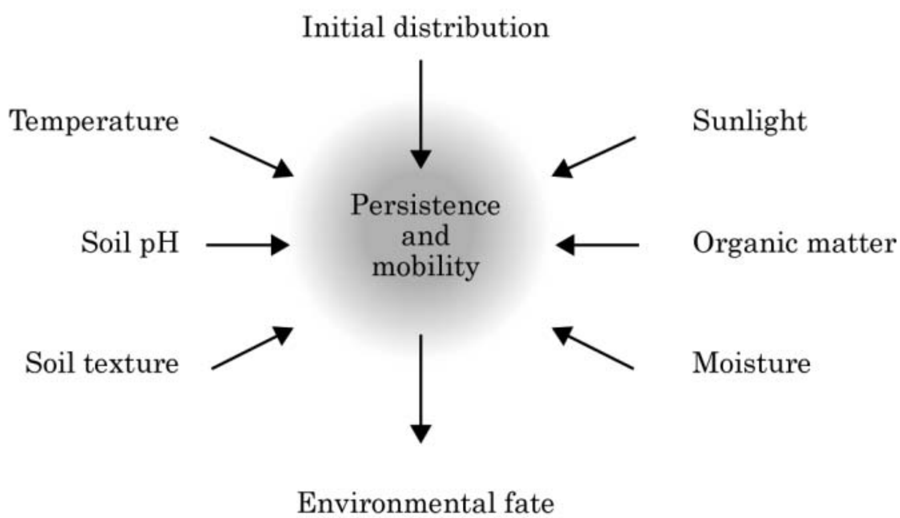
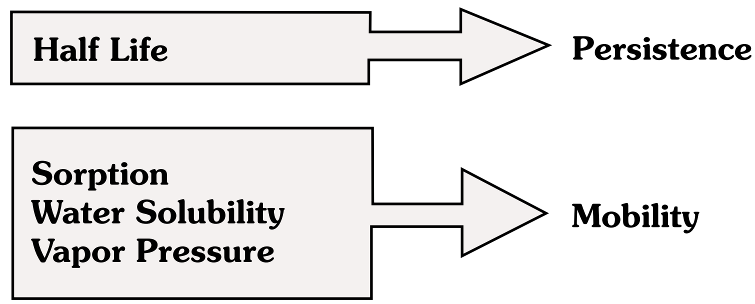


Figure 2.15 Factors affecting pesticide environmental fate.

Pesticide persistence and mobility are also influenced by the properties of the pesticide. The four *pesticide properties* that affect persistence and mobility are:



The soil environment, site conditions, weather, and application method influences the environmental fate of a pesticide (figure 2.15). The six *environmental factors* that impact the fate of pesticides are:

- Temperature (soil and air)
- Soil pH
- Soil texture
- Sunlight
- Soil organic matter
- Soil moisture

Not all of the factors listed above are directly related to pesticide fate in the environment. Soil texture for example, is used as a surrogate, or proxy, for soil characteristics like infiltration rate, hydraulic conductivity (both saturated and unsaturated) and specific surface area (the amount of surface area to which a pesticide can bind). Certain soil properties can be estimated by knowing the texture of a soil. For example, a soil with high clay content would tend to have a very low infiltration rate and low saturated hydraulic conductivity. Unless these soils crack significantly (i.e., shrink and swell causing large surface connected macropores), we would expect theses soils to produce much more runoff than leaching. On the other hand, we would expect sandy and loamy soils to leach more readily than runoff, because of their high infiltration and saturated hydraulic conductivity.

Other environmental factors are more directly related to pesticide fate. Temperature for example effects pesticide fate several ways. One way is to directly increase volatilization. As temperature of air, plant, and soil increase, so does the potential for volatile losses.

Some environmental factors can even interact with each other. Sunlight for instance, can directly breakdown a pesticide by photodegradation (which will be discussed in more detail later in this section). Additionally, sunlight can raise the temperature of both the leaf and soil surfaces, thereby increasing volatile losses.

The fate of a pesticide in the environment is also influenced by the initial pesticide distribution. Initial distribution describes the proportion of pesticide that is on or in the air, soil, water, plants, and animals after application. The formulation, method, and rate of application, as well as topography, amount and type of vegetation and ground cover, and weather conditions determine this. With time, the pesticide may be redistributed within the application site or may move off site—beyond the edge of the target area or the bottom of the root zone. Pesticides that move off site represent an economic loss and may result in adverse effects on the environment.

Pesticide Persistence

Pesticide persistence is often expressed in terms of *half-life*. This is the length of time required for one-half of the original quantity to break down. Pesticides can be divided into three categories based on half-life:

- Non-Persistent—typical soil half-life of less than 30 days
- Moderately Persistent—typical soil half-life of 30 to 100 days
- Persistent—typical soil half-life of more than 100 days.

Figure 2.16 graphically represents the relationship between half-life and pesticide persistence. It takes 8 half-lives for a pesticide to dissipate to 1 percent of the amount applied. For pesticides with half-lives of 1 day, dissipation 99 percent of the applied chemical takes is approximately 8 days. For chemical with a half-life of 90 days, it could take 2 years.

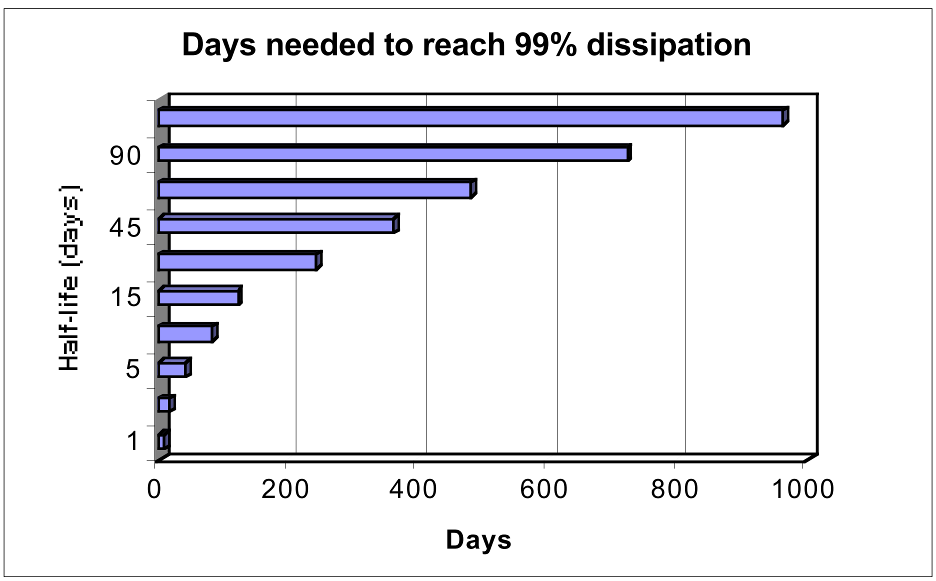


Figure 2.16 Days needed for 99 percent dissipation of amount of pesticide applied, over a range of half-lives.

Table 2.5 compares the half-lives of several pesticides. Half-life can be used, along with sorption, water solubility and vapor pressure, to predict environmental fate of pesticides. We will be examining the other properties in the rest of Module 2B Section 2. The pesticides are organized according to their relative half-lives. Malathion, 1,3-dichloropropene, and dicamba salt are non-persistent. Benomyl and diuron are moderately persistent. Bensulide and prometon are persistent. The half-life values in table 2.5 represent "typical" soil half-life. *Persistence in soil may vary greatly because degradation is influenced by a number of factors, many of which are determined by specific local conditions.*

Ultimately, the degradation products of any organic chemical will be water, carbon dioxide, and minerals. However, intermediate degradation products of some pesticides are of concern for health or environmental reasons. In these cases, half-life values should be determined for the intermediate products.

Table 2.5 Pesticide half-life, ordered from shortest to longest persistence.

Pesticide	**Field half-life (days)**
Malathion	1
1,3 Dichloropropene	10
Dicamba salt	14
Benomyl	67
Diuron	90
Bensulide	120
Prometon	500

Pesticides degrade by *microbial, chemical* or *photo* (sunlight) activity. All three processes may participate in the breakdown of a single pesticide. The rate of degradation depends on pesticide chemistry, as well as on environmental conditions. Distribution between foliage and soil, as well as temperature, soil and water pH, microbial activity, and other soil characteristics may affect pesticide persistence. The half-life values in table 2.5 represent persistence in the field (i.e., on the soil surface). Half-life values for pesticides vary from location to location. In general, pesticide residues on canopy foliage or ground cover tend to be less persistent than pesticide residues in the soil.

Microbial degradation is the breakdown of chemicals by microorganisms. It occurs when fungi, bacteria, and other soil microorganisms use pesticides as food or consume pesticides along with other substances. Soil organic matter, texture, and site characteristics—such as moisture, temperature, aeration, and pH—all affect microbial degradation. Microbial activity is usually greatest in warm, moist, well-aerated soils that have a neutral pH. Enzymes mediate microbial degradation. The rate of most reactions catalyzed by enzymes tends to double for each 10°C increase in temperature between 10 and 45°C (50 to 113°F). Enzyme activity is greatly reduced above and below these temperatures. Microbial degradation occurs at a higher rate in the surface soil horizons, particularly in areas with high organic matter. Usually, the rate decreases with depth in the soil, where conditions such as moisture, temperature, and aeration are less favorable for microbial activity.

Chemical degradation occurs when a pesticide reacts with water, oxygen, or other chemicals in the soil. Chemical degradation can also occur in the air or on foliage. As soil pH becomes extremely acidic or alkaline, microbial activity usually decreases. However, these conditions may favor rapid chemical degradation.

Photodegradation is the breakdown of pesticides by sunlight. All pesticides are susceptible to photodegradation to some degree. The intensity and spectrum of sunlight, length of exposure, and properties of the pesticide affect the rate of photodegradation. Pesticides that are applied to foliage or to the soil surface are more susceptible to photodegradation than pesticides that are incorporated into the soil. Glass filters out much of the *ultraviolet light*, which is that part of the light spectrum that has the greatest potential to photodegrade pesticides. Therefore, pesticides may degrade faster inside plastic-covered greenhouses than inside glass greenhouses.

Pesticide Mobility

Pesticide mobility may result in redistribution within the application site or movement of some amount of pesticide off site. There are five pathways for pesticide movement in the environment:

- attach (sorb) to soil particles and move with eroded soil
- dissolve in water and move in runoff
- dissolve in water and taken up by plants
- dissolve in water and leach downward towards ground water
- volatilize or removed from foliage or soil with wind and become airborne

Pesticide properties including *sorption, water solubility,* and *vapor pressure* affect mobility. Mobility is also influenced by environmental and site characteristics including *weather, topography, canopy,* and *ground cover;* and *soil organic matter, texture,* and *structure.*

Sorption describes the attraction between a chemical and soil, vegetation, or other surfaces. However, sorption most often refers to the binding of a chemical to soil particles (figure 2.17). Sorption includes surface attractions (adsorption) and other physical and chemical mechanisms. Pesticides that are sorbed to soil particles are more likely to remain in the root zone where they may be available for plant uptake and microbial or chemical degradation. However, pesticides that are strongly sorbed to soil are usually less available for microbial degradation and plant uptake. Pesticides that sorb weakly to soil particles are more likely to move through the soil profile with infiltrating water. Sorption is determined by the chemical characteristics of the pesticide. The specific mechanisms for the sorbing of a chemical to the soil are not easily defined. Numerous mechanisms may operate in a particular situation. For pesticides that are weak acids or bases, such as dicamba salt and prometon, sorption is influenced by the pH of the soil. Weak acid or base pesticides may carry a positive or negative charge, or no charge depending on pH.

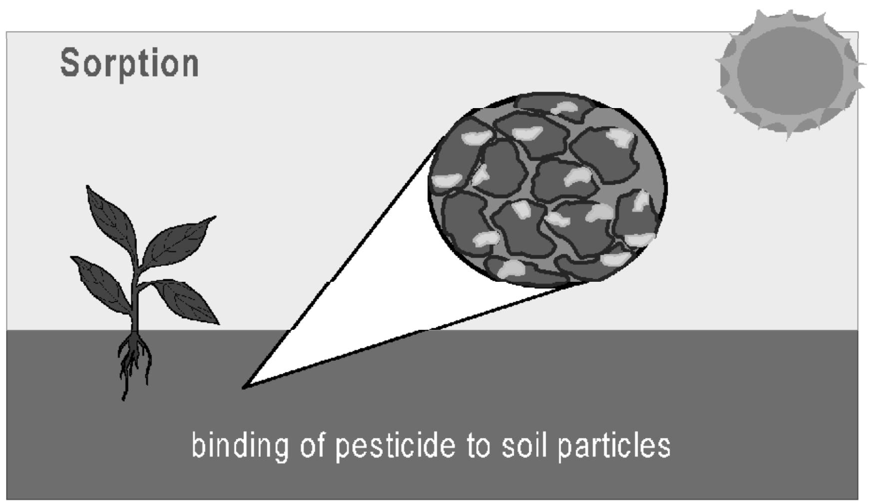


Figure 2.17 Pesticide sorption.

Soil moisture, organic matter content, and texture also influence sorption. Pesticides are more readily sorbed onto dry soil because water competes with pesticides for binding sites in moist soil. Organic matter and clay particles both have plenty of surface area and are chemically active. Soils high in clay or organic matter, or both, have a high potential to sorb pesticides. Organic matter however, is much more important in binding pesticides than clay. Clay content is also important for holding organic matter in the soil. Sand particles provide less surface area for sorption. Pesticides are more likely to move away from the point of application in sandy soils. Soils that have an organic layer, such as crop residue or thatch in turfgrass, may strongly sorb pesticides and reduce their mobility.

The sorption of a particular pesticide to a soil is measured in a laboratory by mixing water, pesticide, and soil. After equilibrium has been reached, the amount of pesticide remaining in solution is measured. The concentration of pesticide sorbed to the soil in the mixture is divided by the pesticide concentration still in solution. This yields the *distribution coefficient, K_d.*

$$\frac{\text{concentration of pesticide sorbed}}{\text{concentration of pesticide in solution}} = K_d\text{, distribution coefficient}$$

A low distribution coefficient indicates that more of the pesticide is in solution; a higher value indicates that the pesticide is more strongly sorbed to that particular soil.

Consider the following two examples:

	Pesticide A	**Pesticide B**
Pesticide adsorbed to soil (ppm)	100	1000
Pesticide concentration in water (ppm)	5	5
Distribution coefficient	$\frac{100}{5} = 20$	$\frac{1000}{5} = 200$

When comparing the distribution coefficients of the above pesticides, more of pesticide A is in solution and more of pesticide B is adsorbed to this particular soil.

Pesticide K_d comparisons are only valid on the same soil. Comparisons of K_d values between soils are not valid because the K_d is as much a function of soil properties as it is pesticide properties. If we assume that most of a soil's pesticide binding capacity is due to the organic matter content of that soil, then we would expect that soils that have different organic matters must have different K_ds.

To remove the effect of soil organic matter content from K_d, divide by the amount of organic carbon in the soil. (Soil organic carbon is directly proportional to soil organic matter, which is primarily responsible for a soil's sorption properties). This produces a measure of the affinity of the pesticide to bind with soil (specifically soil organic matter). This value is the soil organic carbon sorption coefficient (K_{oc}), and is used to compare the relative sorption of pesticides on any type of soil.

To calculate K_{oc}:

$$K_{oc} = \frac{K_d}{\text{Organic carbon content of the soil}}$$

Thus, K_{oc} is the distribution coefficient K_d, corrected for soil organic carbon. The K_{oc} therefore, should be independent of the soil used to determine K_d. The higher the pesticide's K_{oc}, the more strongly the pesticide is sorbed, and therefore less likely to move in solution.

K_{oc} values for seven pesticides are listed in table 2.6. Among these pesticides, dicamba salt has the lowest sorption coefficient (K_{oc} = 2) and benomyl has the highest (K_{oc} = 1900). Therefore, dicamba salt would be the most mobile in solution, and benomyl would be the most tightly bound to soil organic matter.

Table 2.6 Pesticide K_{oc}, ordered form lowest to highest binding capacity.

Pesticide	K_{oc} (ml/g)
Dicamba salt [1/]	2
1,3 Dichloropropene	32
Prometon [1/]	150
Diuron	480
Bensulide	1,000
Malathion	1,800
Benomyl	1,900

[1/] Dicamba is a weak acid; Prometon is a weak base; therefore, sorption and solubility are affected by soil pH.

Water solubility describes the amount of pesticide that will dissolve in a known amount of water. It is usually measured in milligrams per liter of water (mg/L) or parts per million (ppm). Table 2.7 shows that, dicamba salt has the highest solubility, 400,000 mg/L. Benomyl is the least soluble of these seven pesticides. Benomyl's solubility is 2 mg/L. These values are most useful as a means of comparison. How much actually dissolves in the field may differ because temperature and the presence of other chemicals affect solubility. Solubility of those pesticides that are weak acids or bases is also influenced by pH.

Table 2.7 Pesticide solubility in water ordered from most soluble to least soluble.

Pesticide	Solubility in water (mg/L)
Dicamba salt [1/]	400,000
1,3 Dichloropropene	2,250
Prometon [1/]	720
Malathion	130
Diuron	42
Bensulide	5.6
Benomyl	2

[1/] Dicamba is a weak acid; Prometon is a weak base; therefore, sorption and solubility are affected by soil pH.

Highly soluble pesticides are more likely to be quickly moved—within the site or off site—in solution as runoff or, through leaching, but even a pesticide with a relatively low solubility can move into solution with large quantities of soil moisture, rainfall or irrigation.

For example, 1 inch (2.54 cm) of water over a hectare (ha) equals 254,000 liters (L) of water. This is enough to solubilize a typical application of benomyl (0.5 kg active ingredient/ha) which has a low solubility (2mg/L).

Plant Uptake

The degree of plant uptake is partially determined by the pesticide's water solubility. It is also affected by adjuvants (additives) that may enhance uptake. While in solution, a pesticide can move with water on or in the soil and contribute to runoff or leaching. It can also move across cell membranes and be taken up by plants. Plant uptake of pesticides prevents runoff or leaching.

Volatilization

Pesticides may also volatilize or be transported off-site by the wind. Volatilization from foliage is determined by the pesticide's vapor pressure, which is affected by temperature. *Vapor pressure* is the pressure exerted by a vapor when it is in equilibrium with the liquid from which it is derived. Pesticides with a high vapor pressure tend to volatilize. Those with a low vapor pressure are less likely to volatilize. The higher the temperature, the greater the volatilization. Leaf surface temperatures can be much higher than nearby air temperatures, particularly at midday on cloudless days when the greatest amount of solar radiation reaches the leaf. Pesticides on foliage are most susceptible to volatilization immediately after application because over time, pesticides become incorporated into surface waxes or enter the plant.

Volatilization from moist soil is determined by the moisture content of the soil and by the pesticide's vapor pressure, sorption, and water solubility. Because water competes for binding sites, pesticide volatilization is greatest in wet soils. On dry soil surfaces (water contents generally < 2-5%, depending on soil texture), pesticide volatilization is greatly reduced, often below limits of detection in air. Volatilization from moist soil is described by **the Henry's law constant (K_h)**. K_h is defined as the concentration of pesticide in air divided by the concentration in water. This value can be calculated using the pesticide's vapor pressure and solubility. K_h characterizes the tendency for a pesticide to move between the air and the *soil water*. The higher the Henry's law constant, the more likely that a pesticide will volatilize from moist soil. Since sorption will affect the amount of pesticide in the soil water, the tendency to volatilize from moist soil depends on both the Henry's law constant and the distribution coefficient, Kd (figure 2.18). During periods of direct sunlight, temperatures at the soil surface may be much higher than surrounding air. This can increase volatilization at the soil surface.

In general, pesticides with vapor pressure index values of less than 10^{-7} has a low potential to volatilize. Pesticides with vapor pressure index values greater than 10^{-4} have a high potential to volatilize (Table 2.8).

Table 2.8 Pesticide vapor pressure and potential for volatile loss.

Vapor Pressure	Potential for Volatile Loss
Greater than 1.0×10^{-4}	High
1.0×10^{-4} to 1.0×10^{-7}	Medium
Less than 1.0×10^{-7}	Low

The pesticides in table 2.9 are representative of the range of pesticide vapor pressures and Henry's law constants.

Table 2.9 Vapor Pressure and Henry's Law Constant, order by least volatile to most volatile.

Pesticide	Vapor Pressure (mm-Hg)	Henry' s Law Constant
Dicamba salt	0	0
Benomyl	$<1 \times 10^{-10}$	7.8×10^{-10}
Diuron	6.9×10^{-8}	2.1×10^{-8}
Bensulide	8.0×10^{-7}	3.1×10^{-6}
Prometon	7.7×10^{-6}	1.3×10^{-7}
Malathion	8.0×10^{-6}	1.0×10^{-7}
1,3 Dichloropropene	29	77

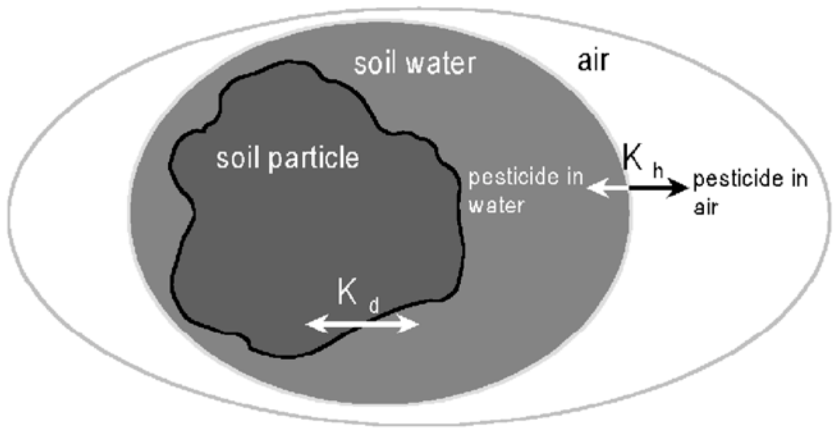


Figure 2.18 Distribution coefficient (K_d) and Henry's Law Constant (K_h).

In general, pesticides with Henry's law values of less than 10^{-7} have a low potential to volatilize from moist soil. Pesticides with Henry's law index values above 10^{-5} have a high potential to volatilize.

Airborne pesticide residues are subject to a variety of degradation processes, including photodegradation, oxidation, and hydrolysis. They are often rapidly degraded in the atmosphere. However, stable airborne pesticide residues and their degradation products may move from the application site and be deposited in dew, rainfall, or in dust. This may result in pesticide redistribution within the application site or movement of some pesticide offsite. The offsite airborne movement of a pesticide is known as *drift*. Drift can be harmful to bees and other nontarget species and may also damage nearby crops, trees or other resources. It is important to consider the weather conditions and the environmental behavior of pesticides before application, so measures to minimize drift can be taken.

Runoff and Leaching

Runoff is the movement of water over a sloping surface. Runoff can carry pesticides dissolved in water and pesticides sorbed to eroding soil. If irrigation or heavy rainfall shortly after application induces runoff, some pesticide may move off site. Heavy rainfall or overhead irrigation soon after application also may dislodge pesticide residues on foliage, creating loss with runoff. With time, residues on foliage are less likely to be washed off as they become incorporated in surface waxes.

Leaching is the removal of soluble material by water passing through the soil. Ground water contamination occurs when pesticides move with infiltrating water through the soil profile to the water table. The closer the water table is to the surface, the greater the likelihood that it may become contaminated. Soil texture can also play a key role in determining the likelihood of a pesticide to leach into ground water.

Pesticides that are highly water soluble, relatively persistent, and not readily sorbed to soil particles (low K_{oc} or low distribution coefficient) have the greatest potential for movement.

Estimating Runoff and Leaching

Using the above mentioned pesticide properties, leaching, runoff and adsorbed loss can be estimated. One tool used by NRCS is the Windows Pesticide Screening Tool (WIN-PST). WIN-PST uses the Soil/Pesticide *I*nteraction *S*creening *P*rocedure version 2, (SPISP II), to rate soil/pesticide interactions for:

- leaching potential
- solution runoff potential
- adsorbed runoff potential

WIN-PST will be discussed in further detail in Module 5, and a hands-on demonstration will be provided in the facilitated session (Module 7).

SPISP is a *qualitative* screening procedure that evaluates the potential loss of pesticides from soil. In other words, ratings are in terms of 'low' 'intermediate or 'high', instead of *quantitative* (part per billion concentration or kg/ha mass loss values). SPSIP is made up of three sets of ratings:

- soil ratings for leaching, runoff and adsorbed losses;
- pesticide ratings for leaching; runoff and adsorbed losses; and
- soil/pesticide interaction ratings based on a combination of soil ratings and pesticide ratings.

Algorithms using soil properties were developed to group soil series into three or four loss potentials for each of the three loss categories. Soil properties considered included texture, hydrologic soil group, organic matter and depth of the first horizon. Table 2.10 shows example soil ratings along with the soil properties used to create the ratings.

Table 2.10 Windows pesticide screening tool soil leaching and runoff sensitivity.

Component	**Texture**	**Hyd**	**K factor**	**Depth**	**% OM**	**SLP**	**SSRP**	**SARP**
Markham	Sil	C	0.37	7"	2.5%	L	H	H
Ayr	Sl	B	0.17	8"	1.5%	H	I	I
Sparta	Ls	A	0.17	8"	1.5%	H	L	L
Legend: Hyd-The hydrologic group assigned to this soil K factor-Soil erodibility factor Depth-Depth of the first soil layer % OM-Percent organic matter in the first horizon				SLP-Soil Leaching Potential SSRP-Soil Solution Runoff Potential SARP-Soil Adsorbed Runoff Potential H-High I-Intermediate L-Low				

Pesticide algorithms were developed to group pesticides into three or four loss potentials for each category of loss. Pesticide properties considered include solubility in water, half-life in soil under field conditions and the soil organic carbon sorption coefficient (K_{oc}). Table 2.11 summarizes tables 2.5-2.7 and 2.9, and provides SPISP II ratings based on data in the table.

Table 2.11 Pesticide properties and SPISP II ratings.

Pesticide	Field 1/2 life (days)	Koc	Solubility in water (mg/L)	Vapor pressure (mm Hg)	Henry's Law Constant (K_h)	Pesticide leaching potential	Pesticide solution runoff potential	Pesticide adsorbed runoff potential
Malathion	1	1,800	130	8.0×10^{-6}	1.0×10^{-7}	Low	Low	Low
1,3 Dichloropropene	10	32	2,250	29	77	Intermediate	Intermediate	Low
Dicamba salt [1/]	14	2	400,000	0	0	High	Intermediate	Low
Benomyl	67	1,900	2	$<1 \times 10^{-10}$	7.8×10^{-10}	Low	High	High
Diuron	90	480	42	6.9×10^{-8}	2.1×10^{-8}	Intermediate	High	Intermediate
Bensulide	120	1,000	5.6	8.0×10^{-7}	3.1×10^{-6}	Intermediate	High	High
Prometon [1/]	500	150	720	7.7×10^{-6}	1.3×10^{-7}	High	High	Intermediate

[1/] Dicamba is a weak acid; Prometon is a weak base; therefore, sorption and solubility are affected by soil pH.
Note: Properties listed in italics are not used to create SPISP II ratings.

Malathion, with a short half-life and high sorption coefficient, has LOW pesticide ratings for all three loss pathways. Prometon has HIGH leaching and solution runoff ratings based on its very long half-life and relatively low sorption. Interestingly, dicamba salt has the same leaching rating as prometon, although the two pesticides have very different half-life and sorption properties. Dicamba's HIGH leaching rating is influenced by its low tendency to bind to soil. SPISP ratings indicate the potential for movement of a pesticide, off the field, through the indicated pathways. SPISP II soil and pesticide groupings are combined in a matrix to give an overall loss potential for each loss category. Table 2.12 shows the soil/pesticide interaction for dicamba.

Table 2.12 Soil/pesticide interaction for dicamba on three soils.

Pesticide	**Loss Pathway**	**Soil**		
		Ayr SL	Sparta LS	Markham SIL
Dicamba	Leaching (IALP)	**H** (H/H)*	**H** (H/H)	**L** (L/H)
	Solution Runoff (ISRP)	**I** (I/I)	**L** (L/I)	**H** (H/I
	Adsorbed (IARP)	**L** (I/L)	**L** (L/L)	**I** (H/L)
* The individual soil rating / pesticide rating respectively.				

WIN-PST modifies 'soil/pesticide interaction' loss ratings (SPISP II), to consider some of the major effects of pesticide management, residue management, water management and climate. WIN-PST then combines the interaction loss ratings, with relative pesticide toxicity to non-target species, to arrive at an overall hazard rating. Modification of the ratings for management and climate are based on investigation with the National Agricultural Pesticide Risk Analysis (NAPRA) process. Statistics of the overall loss potential indicate that the LOW loss potential is pure; that is, it does not contain occurrences that have INTERMEDIATE or HIGH losses. Therefore, there is high level of confidence that there is negligible or no loss with a 'LOW' rating. The INTERMEDIATE loss potential does not contain occurrences of HIGH loss, but does contain occurrences of LOW loss. The HIGH loss potential contains incidences of INTERMEDIATE and LOW loss.

This understanding of pesticide behavior can be used to minimize the risks of contaminating water resources. Table 2.13 demonstrates the importance of linking pesticide behavior information with awareness of water resources in your region.

Table 2.13 Water resources of concern.

Pesticide Use Location	Resource Use	Resource of Concern
Over a sole source aquifer	Drinking water	Ground water
Over a sensitive aquifer	Drinking water	Ground water
Over an aquifer recharge area	Drinking water	Ground water
Over ground water that discharges to surface water	Drinking water Aquatic habitat	Surface Water
Where surface runoff goes to a water supply	Drinking water	Surface Water
Where surface runoff goes to streams, ponds, rivers, or lakes	Aquatic habitat	Surface Water

Student Activity 9

1. Name four environmental factors that impact the fate of pesticides in the environment.

2. List three major degradation pathways and list factors that may contribute to the breakdown of a pesticide under each major pathway.

3. List four pathways for pesticide movement in the environment.

4. Calculate the distribution coefficient (K_d) of a mixture of pesticides in water if the concentration of pesticides adsorbed to the soil is 500 ppm and the pesticide concentration in water solution is 25 ppm.

____

____

____

____

____

5. Pesticide A has a K_{oc} of 1000 and Pesticide B has a K_{oc} of 25. Which one is more sorbed and therefore less mobile?

____

____

____

____

____

6. On a hot, dry day, would you expect the same pesticide to volatilize more readily from a moist soil or a dry soil? Why?

____

____

____

____

____

7. Two pesticide alternatives for controlling a pest. Pesticide A has a K_{oc} of 28. Pesticide B has a K_{oc} of 350. Which pesticide has the higher potential for leaching?

____

____

____

8. List and define the four pesticide properties that impact their fate in the environment.

____

____

____

____

9. A new pesticide ("Kill-All" Herbicide) has come on the market, and you are asked to assess its potential persistence and mobility. Given the following pesticide properties, is the pesticide highly persistent? Is it highly mobile? Why?

Half-life = 150 days

K_{oc} = 1200

Solubility = 4 mg/L

Vapor pressure = 2.5×10^{-5}

____

____

____

____

____

10. A pesticide may reside in air, soil, or water. What pesticide properties would you use to determine where a pesticide is most likely to be found in the environment?

____

____

____

____

____

11. Define the following terms and describe what the environmental consequences might be:

Drift ____

____

____

Leaching _____________________________________

____

____

Runoff _______________________________________

____

____

Sorption _____________________________________

____

____

Module 2, Part B, Section 3—
Pesticide Toxicity

Supporting Objectives

- Define “poison” and “toxicity.”
- List the two most common types of toxicity and provide examples of each.
- Define four terms commonly used to describe dose-effect relationships in toxicological studies.
- Describe the strengths and weaknesses of laboratory toxicity testing and epidemiology studies.
- List three pesticide groupings by their modes of action. Give and example of a pesticide in each grouping.
- List two standards commonly used to establish units of pesticide residues in drinking water.
- Describe three pesticide exposure scenarios.

Introduction

As we discussed in Section 1 of Module 2B, a primary concern of pesticide use is that the chemicals should not pose an undue risk to human health when used according to label directions. Pesticide users must always keep in mind that these chemicals may pose a risk to human health or to the environment if proper precautions are not taken to minimize exposure to the chemicals during mixing, loading and application, or if they are misused. The risks to human health will be discussed in this Section of Module 2B. The methods of assessing risk to human health will be covered.

Poisons and Toxicity

Physical, chemical or biological agents that put stress on the body can upset the normal functions of a human body. The body's reaction to prolonged stress depends on the nature of the agent, the degree of stress, and the duration of stress. When the stress is too strong or too long, and the body's regulation mechanisms cannot be maintained or restored, disease occurs. Poisoning by chemical agents is nothing more than chemically induced disease, and the symptoms of chemical poisoning often are the same as symptoms caused by biological agents such as bacteria or viruses. To better understand how disease is caused by exposure to toxic chemicals, we must first understand how poisons work within the body.

A *poison* can be defined as a chemical that kills, injures, or impairs humans or other organisms. Poisons work by changing the rate of different body functions, increasing them (for example, increasing the heart rate or sweating), or decreasing them (sometimes to the point of stopping them entirely, like breathing). For example, people poisoned by parathion (an insecticide) may experience increased sweating. This reaction occurs in the following sequences: The first step is the biochemical inactivation of an enzyme. This (1) biochemical change leads to a (2) cellular change (in this case an increase in nerve activity). The cellular change is then responsible for (3) physiological changes, which are the symptoms of poisoning that are seen or felt in particular organ systems (in this case the sweat glands). The basic progression of effects from biochemical to cellular to physiological occurs in most cases of poisoning.

Depending on the specific biochemical mechanism of action, a poison may have widespread effects throughout the body or may cause a limited change in physiological functioning in a particular region or organ. Parathion causes a simple inactivation of an enzyme, which is involved in communication between nerves. The enzyme that parathion inactivates, however, is widespread in the body, and thus many varied effects on a number of body systems are seen besides sweating.

Toxicity is a general term used to indicate adverse effects produced by poisons. These adverse effects can range from slight symptoms like headaches or nausea, to severe symptoms like coma and convulsions and death.

Toxicity is normally divided into two types, based on the number of exposures to a poison and the time it takes for toxic symptoms to develop. The two types most often referred to are acute and chronic. *Acute toxicity* is due to short-term exposure and happens within a relatively short period of time. *Chronic toxicity* is due to long-term exposure and happens over a longer period. Examples of an acute response are dizziness, nausea, and headaches associated with excessive exposure to a cholinesterase inhibitor such as an organophosphate. (We will be discussing this example later in the Module.) The development of tumors or certain types of cancer have been associated with exposure to certain industrial chemicals over many years. This is an example of a chronic response.

The science of *toxicology* is based on the principle that there is a relationship between a toxic reaction (the response) and the amount of poison received (the dose). An important assumption in this relationship is that there is almost always a dose below which no response occurs or can be measured. A second assumption is that once a maximum response is reached, any further increases in the dose will not result in any increased effect. Knowing the *dose-response relationship* is a necessary part of understanding the cause and effect relationship between chemical exposure and illness. Keep in mind that toxicity is an inherent quality of the chemical and cannot be changed without changing the chemical to another form. The toxic effects on an organism are related to the amount of exposure and the sensitivity of the organism.

Exposure to poisons can be intentional or unintentional. The effects of exposure to poisons vary with the amount of exposure, which is another way of saying *the dose*. Usually when we think of dose, we think in terms of taking one vitamin capsule a day or two aspirin every 4 hours, or something like that. Contamination of food or water with chemicals can also provide doses of chemicals each time we eat or drink. Some commonly used measures for expressing levels of contaminants are listed in table 2.14. These measures tell us how much of the chemical is in food, water, or air and are typically expressed in terms for concentration like milligrams of chemical per liter of water (mg/L). The amount we eat, drink, or breathe determines the actual dose we receive and is typically expressed in terms of milligrams of chemical per kilograms of body weight (mg/kg).

Concentrations of chemicals in the environment are most commonly expressed as parts per million (ppm) and parts per billion (ppb). Regulatory or established tolerance limits for various chemicals usually use these abbreviations. Remember that these are extremely small quantities. For example, if you put 1 teaspoon of salt in 2 gallons of water the resulting salt concentration would be approximately 1,000 ppm, and it would not even taste salty!

Table 2.14 Common exposure measurements.

Dose	Abbreviation	Metric equivalent	Abbreviation	Approximate amount in water
Parts per million	ppm	Milligrams per kilogram or milligrams per liter water	mg/kg mg/L	1 teaspoon per 1,000 gallons
Parts per billion	ppb	Micrograms per kilogram or micrograms per liter water	µg/kg µg/L	1 teaspoon per 1,000,000 gallons

Dose-Response Relationships

The dose of a poison is going to determine the degree of effect it produces. The following example illustrates this principle. Suppose 10 goldfish are in a 10-gallon tank, and we add 1 ounce of 100-proof whiskey to the water every 5 minutes until all the fish get drunk and swim upside down. Probably none would swim upside down after the first 2 or 3 shots. After 4 or 5, a sensitive fish might. After 6 or 8 shots another 1 or 2 might. With a dose of 10 shots, 5 of the 10 fish might be swimming upside down. After 15 shots, there might be only 1 fish swimming properly, and it too would turn over after 17 or 18 shots.

The effect measured in this example is swimming upside down. Individual sensitivity to alcohol varies, as does individual sensitivity to other poisons. There is a dose level at which none of the fish swim upside down (any observed effect). There is also a dose level at which all of the fish swim upside down. The dose level at which 50 percent of the fish have turned over is known as the *ED_{50}, which means effective dose for 50 percent of the fish tested*. The ED_{50} of any poison varies depending on the effect measured. In general, the less severe the effect measured, the lower the ED_{50} for that particular effect. Obviously, poisons are not tested in humans in such a fashion. Instead, animals are used to predict the toxicity that may occur in humans.

One of the more commonly used measures of toxicity is the LD_{50}. The *LD_{50} (the lethal dose for 50 percent of the animals tested)* of a poison is usually expressed in milligrams of chemical per kilogram of body weight (mg/kg). The LD_{50} is a measure of acute (lethal) toxicity in a sensitive population of animals. A chemical with a small LD_{50} (like 5 mg/kg) is highly toxic. A chemical with a large LD_{50} (1,000 to 5,000 mg/kg) is practically non-toxic. The LD_{50} says nothing about non-lethal toxic effects, though. A chemical may have a large LD_{50} but may produce illness at very low exposure levels. It is incorrect to say that chemicals with low LD_{50}s are more dangerous than chemicals with large LD_{50}s. They are simply more toxic. The danger, or risk of adverse effect of chemicals, is mostly determined by how they are used (i.e., the risk of exposure), not by the inherent toxicity of the chemical itself. These same principles apply if we are concerned about the concentration of a toxicant in an aquatic environment or in air. In these situations, the *LC_{50} (median lethal concentration)* is used rather than LD_{50}.

The LD_{50}s of different chemicals may be easily compared. However, it is always necessary to know which species was used for the tests. It is also important to know how the chemical was administered (the route of exposure), and the way exposure occurs. Some chemicals may be extremely toxic if swallowed (oral exposure) but only slightly toxic at all if splashed on the skin (dermal exposure). Studies have shown that more pesticide can be absorbed through the skin on the forearm than through skin on the hands. This is why it is important to wear long, waterproof gloves, and long-sleeved shirts when mixing pesticides.

In aquatic systems the terms EC_{50} (Effective Concentration) and LC_{50} are used. These are the concentrations in water that will affect 50 percent of the aquatic organisms being tested and kill 50 percent of the aquatic organisms being tested, respectively.

The designation *toxic dose (TD)* is used to indicate the dose (exposure) that will produce signs of toxicity in a certain percentage of animals. The *TD_{50} is the toxic dose for 50 percent of the animals tested*. The larger the TD, the more poison it takes to produce signs of toxicity. The toxic dose does not give any information about the lethal dose because toxic effects (for example, nausea and vomiting) may not be directly related to the way that the chemical causes death. The toxicity of a chemical is an inherent property of the chemical itself. It is also true that chemicals can cause different types of toxic effects, at different dose levels, depending on the animal species tested. For this reason, when using the toxic dose designation, it is useful to precisely define the type of toxicity measured, the animal species tested, and the dose and route of administration.

The potency of a poison (chemical) is a measure of its strength compared to other poisons (chemical). The more potent the poison, the less it takes to kill. the less potent the poison, the more it takes to kill. The potencies of poisons are often compared using signal words or categories as shown in table 2.15. Table 2.15 also lists EPA's rating scale and labeling requirements for pesticides.

Table 2.15 Toxicity rating scale and labeling requirements for pesticides.

Category	Signal word required on label	Characteristic acute toxicity in experimental animals LD_{50} and LC_{50}	Skin/eye irritation	Probable oral lethal dose
Highly toxic	DANGER-POISON	Oral: 0-50 mg/kg Dermal: 0-200 mg/kg Inhalation: 0-0.2 mg/l	Severe	A few drops to a teaspoon
Moderately toxic	WARNING	Oral: >50-500 mg/kg Dermal: >200-2000 mg/kg Inhalation: >0.2-2.0 mg/l	Moderate	Over a teaspoon to 1 ounce
Slightly toxic	CAUTION	Oral: >500-5000 mg/kg Dermal: >2000-20,000mg/kg Inhalation: >2.0-20 mg/l	Slight	Over 1 ounce
Practically non-toxic	None required	Oral: >5000 mg/kg Dermal: >20,000 mg/kg Inhalation: >20 mg/l	None	
Source: 40 CFR 156.10 (1994)				

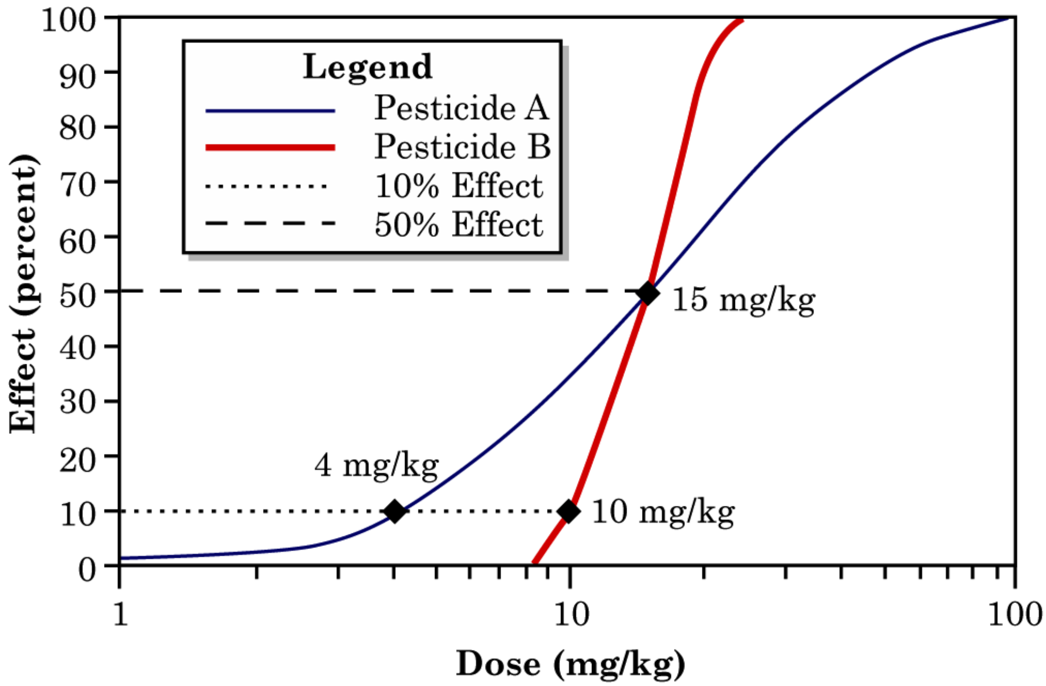
The *NOEL (no observable effect level)* is the highest dose or exposure level of a poison that produces no noticeable toxic effect on animals. From our previous fish example, we know that there is a dose below which no effect is seen. In toxicology, residue tolerance levels of poisons that are permitted in food or in drinking water, for instance, are usually set from 100 to 1,000 times less than the NOEL to provide a wide margin of human safety.

The *TLV (threshold limit value)* for a chemical is the airborne concentration of the chemical (expressed in ppm) that produces no adverse effects in workers exposed for 8 hours per day, 5 days per week. The TLV is usually set to prevent minor toxic effects like skin or eye irritation.

Often people compare poisons based on their LD_{50}s and base decisions about the safety of a chemical based on this number. This is an over-simplified approach to comparing chemicals because the LD_{50} is simply one point on the dose-response curve that reflects the potential of the compound to cause death. What is more important in assessing chemical safety is the threshold dose and the slope of the dose-response curve, which shows how fast the response increases as the dose increases. Figure 2.19 shows examples of dose-response curves for two different chemicals that have the same LD_{50}. Which of these chemicals is more toxic?

For doses below the LD_{50}, chemical A is more toxic; at the LD_{50} they are the same, and above the LD_{50}, chemical B is more toxic. While the LD_{50} can provide some useful information, it is only one component of risk assessment because the LD_{50} only reflects information about the lethal effects of the chemical. It is quite possible that a chemical will produce an undesirable toxic effect (reproductive toxicity or birth defects) at doses that cause no deaths at all.

Figure 2.19 Dose-response curve.



Toxicity assessment is quite complex; many factors can affect the results of toxicity tests. Some of these factors include variables like temperature, food, light, and stressful environmental conditions. Other factors related to the animal itself include age, sex, health, and hormonal status.

A true assessment of chemical toxicity involves comparisons of numerous dose-response curves covering many different types of toxic effects. Refer to the EPA registration requirements listed in Section 1 of Module 2B, to see the types of testing required for pesticide registration. These include acute and chronic toxicity.

Long-term reproductive studies are conducted to look for the risk of birth defects or sterility. These and other studies are assessed to arrive at overall pesticide registration and label restrictions.

The determination of which pesticides will be *Restricted Use Pesticides (RUP)* involves this approach. A Restricted Use Pesticide, because of its human health and environmental concern, is one that can only be purchased and used by certified applicators. Recordkeeping is mandated for both applicators and dealers. There may be a number of different reasons why a pesticide is registered as RUP. Some Restricted Use Pesticides have very small LD_{50}s (high acute oral toxicity). Others may have low acute toxicity but may be very strong skin or eye irritants and thus require special handling. Pesticides that have been shown to cause tumors in laboratory animals or which are highly persistent in the environment may also be labeled RUP.

The knowledge gained from dose-response studies in animals is used to set standards for human exposure and the amount of chemical residue that is allowed in the environment. As mentioned previously, numerous dose-response relationships must be determined in many different species. Without this information, it is impossible to accurately predict the health risks associated with chemical exposure. With adequate information, we can make informed decisions about chemical exposure and work to minimize the risk to human health and the environment.

Table 2.16 summarizes several threshold used to characterize toxicity.

Table 2.16 Several thresholds used to characterize toxicity.

Abbreviation	Threshold	End Point	Typical Units
ED_{50}	Effective dose for 50 percent of test population (terrestrial)	Any effect such as swimming upside down, lethargy, improved vigor or increase in growth rate	mg/kg body weight
EC_{50}	Effective concentration for 50 percent of test population (aquatic)	Any effect such as swimming upside down, lethargy, improved vigor or increase in growth rate	mg/L
LD_{50}	Lethal dose for 50 percent of test population (terrestrial)	Death	mg/kg body weight
LC_{50}	Lethal concentration for 50 percent of test population (aquatic)	Death	mg/L
TD_{50}	Toxic dose for 50 percent of test population	Adverse (toxic) effect such as swimming upside down, lethargy, decline in vigor or stunting	mg/kg body weight
NOEL	No observable effect level	No noticeable toxic effect	Depends on type of exposure
TLV	Threshold limit value for human workers expose 8 hours a day, five days a week (airborne)	Minor toxic effects such skin or eye irritation	mg/L air (ppm)

For more toxicity thresholds see, later in this section, under heading *Pesticide Drinking Water Standards* including sidebar: *Human Toxicity thresholds: NRCS pesticide screening tools*. Also see *Aquatic Toxicity thresholds: NRCS pesticide screening tools*, in section 4 *Ecological effects, Module 2 Part B.*

Manifestations of Toxic Effects

Most toxic effects are reversible and do not cause permanent damage, but complete recovery may take a long time. However, some poisons cause irreversible (permanent) damage. Poisons can affect just one particular organ system or they may produce generalized toxicity by affecting a number of systems. Usually the type of toxicity is subdivided into categories based on the major organ systems affected. Some of these are listed in table 2.17.

Because the body only has a certain number of responses to chemical and biological stresses, it is a complicated business sorting out the signs and symptoms and determining the actual cause of human disease or illness. In many cases, it is impossible to determine whether an illness was caused by chemical exposure or by a biological agent (like a flu virus). A history of exposure to a chemical is one important clue in helping to establish the cause of illness, but such a history does not constitute conclusive evidence that the chemical was the cause. To establish this cause/effect relationship, it is important that the chemical be detected in the body (such as in the blood stream) at levels known to cause illness. If the chemical produces a specific and easily detected biochemical effect (like the inhibition of the enzyme acetylcholinesterase), the resulting biochemical change in the body may be used as conclusive evidence.

Table 2.17 General toxicity categories.

Category	System affected	Common symptoms
respiratory	nose, trachea, lungs	irritation, coughing, choking, tight chest
gastrointestinal	stomach, intestines	nausea, vomiting, diarrhea
renal	kidney	back pain, urinating more or less than usual
neurological	brain, spinal cord, behavior	headache, dizziness, confusion, depression, coma, convulsions
hematological	blood	anemia (tiredness, weakness)
dermatological	skin, eyes	rashes, itching, redness, swelling
reproductive	ovaries, testes, fetus	infertility, miscarriage

People who handle chemicals frequently in the course of their jobs and become ill and need medical attention should tell their physicians about their previous exposure to chemicals.

Although both natural and synthetic chemicals may cause a variety of toxic effects at high enough doses, the effect that is of most concern in the United States is cancer. This is not surprising considering the high incidence of this disease, its often-fatal outcome, and the overall cost to society. Unfortunately, the incidence of this disease seems to increase with age so that as people live longer, there will be more and more cases of cancer in our country. Scientists do not yet understand exactly how cancer occurs or why some chemicals seem to cause cancer and others do not.

Chemicals that are known to cause cancer are called *carcinogens*, and the process of cancer development is called carcinogenesis. Up to now, scientists have identified about two dozen chemicals or occupational exposures that appear to be definitely carcinogenic to humans. Some of the most familiar are tobacco smoke and asbestos. In addition, there are a number of chemicals that cause cancer in animals and are suspected of being human carcinogens. Because not all chemicals have been tested at present, it is possible that the number of known and suspect human carcinogens will increase in the future.

Remember that as with all toxic effects, the dose or amount of exposure is critical. Just as a small enough amount of cyanide will not lead to death, smoking one cigarette will not lead to lung cancer. Thus to decide on the risk that a particular carcinogen poses, it is important to determine how much of the chemical will cause how many cases of cancer in a specified population. This value can then be compared to what is considered an acceptable risk. Currently, the commonly accepted increase in risk of cancer is one additional cancer in one million people. A few exceptions to this criterion are made in the cases of food additives, including pesticides that are considered as food additives, in which no amount of carcinogen is allowed (the Delaney Clause, as documented in the Federal Food, Drug and Cosmetic Act), and drinking water where a goal of zero contamination for carcinogens has been set.

Carcinogen Testing

Once an acceptable risk for a carcinogen has been established (usually by the Environmental Protection Agency for environmental contaminants), there remains the problem of determining what dose or amount of chemical will lead to this risk. There are two types of studies that are used to make this determination: (1) investigations of human populations (*epidemiology*) and (2) experiments on laboratory animals. Each of these types of studies has its advantages and disadvantages, and both have some degree of uncertainty, no matter how much evidence is gathered.

Epidemiological studies in human populations

Investigations of human populations, in an attempt to establish the relationship between environmental factors and health, are called epidemiological studies. Scientists examine selected populations to single out particular exposures that might be related to toxic effects; in this case, cancer. Occupational groups, such as factory workers in a particular industry, are often studied for two reasons. One is that their exposures to the toxic compounds are generally higher than other people's so that a higher incidence of cancer is expected, if it occurs. A higher incidence is obviously easier to detect. The second reason is that their exposure to a specific chemical is often unique and can more easily be distinguished from exposures to many other chemicals that are used in daily life.

Through epidemiological studies among industrial worker populations, it was possible to show that asbestos is linked to lung cancer, vinyl chloride to a rare form of liver cancer, and benzene to leukemia. There have also been suggestions that pesticide exposure to farmers might lead to cancer, but the results are not clear cut, and there is still much controversy about the epidemiological studies that have been performed on these populations. Even in well-documented cases, it is not possible to use epidemiology to establish the exact risk of exposure to specific levels (concentrations) of these chemicals.

Laboratory animal studies

Laboratory studies have several advantages over epidemiological studies. Studies on laboratory animals are often easier to interpret because chemicals can be studied one at a time; very high doses can be administered; other chemicals and environmental factors can be eliminated or controlled; and animals can be sacrificed during the course of the study. The disadvantages are that it is not known how to apply these high dose results to much lower dose exposures that happen in the real world. Equally perplexing is how animal results can be applied to human populations. In extrapolating from high to low doses and from animals to humans, regulatory agencies have taken the approach of trying to be as conservative as possible, that is of trying to leave a large margin of safety so that even if the studies are in error, human health (usually of the most sensitive groups in the population such as young children and pregnant women) will be protected.

As a result, the acceptable exposure levels (published in the Federal Register for each carcinogen) usually represent what is called the *worst case* exposure. An assumption made in the calculation of worst-case exposure levels is that humans will be exposed to the same concentration of the chemical every day of their lives for 70 years. As a result, the published acceptable risk level does not necessarily represent the “safe level” but rather a target level with the expectation that the true risk to exposure is less than the published value. Remember that the exposure criteria are guidelines for the protection of sensitive elements of the population and are calculated with many factors of uncertainty (the relationship of animal toxicity to human toxicity for instance).

Student Activity 10

1. Define poison by chemical agents and list four symptoms of someone who may have been poisoned by a chemical.

2. Define toxicity, list the two types of toxicity and give an example of each.

3. Define the following terms:

LD_{50}

TD_{50}

NOEL

TLV

4. What is the difference between LC_{50} and LD_{50}?

____

____

____

____

____

____

____

5. What is the difference between mg/kg and mg/l in describing amounts of exposure?

____

____

____

____

6. What are the relative strengths and weaknesses of:

Laboratory toxicity testing ___________________________

____

____

____

Epidemiology studies ________________________________

____

____

____

7. Are chemical with small LD_{50}s always more dangerous than those with large LD_{50}s? Why or why not?

Acute Toxicity: Effects of Exposure to Cholinesterase-Inhibiting Pesticides

A common form of acute toxicity to pesticides is the illness that occurs when people are exposed to cholinesterase inhibiting pesticides. Human exposure to cholinesterase inhibiting chemicals can result from inhalation, ingestion, or eye or skin contact during the mixing or application of these pesticides.

Cholinesterase (ko-li-nes-ter-ace) is one of many important enzymes needed for the proper functioning of the nervous systems of humans, other vertebrates, and insects. Certain chemical classes of pesticides, such as organophosphates (OPs), carbamates, and chlorinated derivatives of nicotine (imidacloprid) work against undesirable bugs by interfering with or inhibiting cholinesterase. While the effects of cholinesterase-inhibiting products are intended for insect pests, these chemicals can also be poisonous, or toxic, to humans in some situations.

Mode of Action

Electrical switching centers, called synapses, are found throughout the nervous systems of humans, other vertebrates, and insects. Muscles, glands, and nerve fibers called neurons are stimulated or inhibited by the constant firing of signals across these synapses. A chemical called acetylcholine (a-see-till-ko-leen) usually carries stimulating signals. A specific type of cholinesterase enzyme, *acetylcholinesterase*, which breaks down the acetylcholine, discontinues stimulating signals. These important chemical reactions are usually going on all the time at a fast rate, with acetylcholine causing stimulation and acetylcholinesterase ending the signal. If cholinesterase-affecting insecticides are present in the synapses, however, this situation is thrown out of balance. The presence of cholinesterase-inhibiting chemicals prevents the breakdown of acetylcholine. Acetylcholine can then build up, causing a “jam” in the nervous system. If acetylcholinesterase is unable to breakdown or remove acetylcholine, the muscle can continue to move uncontrollably.

Electrical impulses can fire away continuously unless the number of messages being sent through the synapse is limited by the action of cholinesterase. Repeated and unchecked firing of electrical signals can cause uncontrolled, rapid twitching of some muscles, paralyzed breathing, convulsions, and in extreme cases, death.

Any pesticide that can bind or inhibit cholinesterase, making it unable to breakdown acetylcholine, is called a *cholinesterase inhibitor*. The two main classes of cholinesterase inhibiting pesticides are the organophosphates (OPs) and the carbamates. Such newer chemicals as the chlorinated derivatives of nicotine can also affect the cholinesterase enzyme.

Table 2.18 includes a list of some of the most commonly used organophosphate insecticides. Carbamates, like organophosphates, vary widely in toxicity and work by inhibiting plasma cholinesterase. Table 2.19 includes some examples of carbamates.

Table 2.18 Common organophosphate insecticides.

acephate (Orthene)	fenthion (Baytex, Tiguvon)
azinphos-methyl (Guthion)	fonofos (Dyfonate)
carbofuran (Furadan)	isofenfos (Oftanol, Amaze)
carbophenothion (Trithion)	malathion (Cythion)
chlorfenvinphos (Birlane)	methamidophos (Monitor)
chlorpyrifos (Dursban, Lorsban)	methidathion (Supracide)
crufomate (Ruelene)	methyl parathion
demeton (Systox)	naled (Dibrom)
diazinon (Spectracide)	phorate (Thimet)
dicrotophos (Bidrin)	phosalone (Zolonc)
dimethoate (Cygon, De-Fend)	phosmet (Imidan, Prolate)
disulfoton (Di-Syston)	phosphamidon (Dimecron)
ethion	temephos (Abate)
ethoprop (Mocap)	tetrachlorvinphos (Rabon, Ravap)
fenamiphos (Nemacur)	trichlorfon (Dylox, Neguvon)

Table 2.19 Common carbamate insecticides.

aldicarb (Temik)	methiocarb (Mesurol)
bendiocarb (Ficam)	methomyl (Lannate, Nudrin)
bufencarb	oxamyl (Vydate)
carbaryl (Sevin)	pirimicarb (Pirimor)
carbofuran (Furadan)	propoxur (Baygon)
formetanate (Carzol)	methidathion (Supracide)

Chlorinated derivatives of nicotine: imidacloprid

Like nicotine, imidacloprid, a recently introduced synthetic insecticide, mimics the action of acetocholine by binding to the postsynaptic nicotinic receptor. However, nicotine and imidacloprid are insensitive to the action of acetocholinesterase and therefore bind persistently to the receptor that leads to nerve overstimulation, resulting in hyperexcitation, convulsions, paralysis, and death. Because the nicotinergic neuronal pathway is more abundant in insects, these compounds are selectively more toxic to insects than mammals.

Effects of overexposure to cholinesterase inhibiting pesticides

Overexposure to organophosphate and carbamate insecticides can result in cholinesterase inhibition. Signs and symptoms of cholinesterase inhibition from exposure to carbamates, OPs or chlorinated derivatives of nicotine include the following:

- In mild cases (within 4–24 hours of contact): tiredness, weakness, dizziness, nausea, and blurred vision;
- In moderate cases (within 4–24 hours of contact): headache, sweating, tearing, drooling, vomiting, tunnel vision, and twitching;
- In severe cases (after continued daily absorption): abdominal cramps, urinating, diarrhea, muscular tremors, staggering gait, pinpoint pupils, hypotension (abnormally low blood pressure), slow heartbeat, breathing difficulty, and possibly death, if not promptly treated by a physician.

Unfortunately, some of the above symptoms can be confused with influenza (flu), heat prostration, alcohol intoxication, exhaustion, hypoglycemia (low blood sugar), asthma, gastroenteritis, pneumonia, and brain hemorrhage. This can cause problems if the symptoms of lowered cholinesterase levels are either ignored or misdiagnosed as something more or less harmful than they really are.

The types and severity of cholinesterase inhibition symptoms depend on:

- toxicity of the pesticide
- amount of pesticide involved in the exposure
- route of exposure
- duration of exposure

Although the signs of cholinesterase inhibition are similar for both carbamate and organophosphate poisoning, blood cholinesterase returns to safe levels much more quickly after exposure to carbamates than after OP exposure. Depending on the degree of exposure, cholinesterase levels may return to pre-exposure levels after a period ranging from several hours to several days for carbamate exposure, and from a few days to several weeks for organophosphates. Therefore, blood tests for OP are an important diagnostic tool to determine whether a person has been poisoned by a cholinesterase inhibitor or not, and whether the inhibitor was a carbamate or organophosphate. Blood samples are drawn regularly from pesticide applicators to monitor their comparative levels of cholinesterase over time.

Endocrine Disrupters

Recently there has been a great deal of controversy into whether pesticides and other synthetic materials used in industry cause adverse impacts on the reproductive health of wildlife. EPA defines endocrine disrupters as compounds that “interfere with the synthesis, secretion, transport, binding, action, or elimination of natural hormones in the body that are responsible for the maintenance of homeostasis (normal cell metabolism), reproduction, development, and/or behavior.” Many endocrine disrupters are thought to mimic hormones, such as estrogen or testosterone. They have chemical properties similar to hormones that allow binding to hormone specific receptors on the cells of target organs.

Many studies on the relationship between chemical exposure and reproductive problems in wildlife have shown that exposure to high doses can result in malformed reproductive organs, consistent with sex hormone imbalance at a critical stage of fetal development. The dramatic results of these high dose studies has lead to speculation that the risk to reproductive success, associated with exposure to much lower levels of some chemicals in the environment, may be unacceptable.

The World Wildlife Fund published a list of pesticides, which they allege to be endocrine disrupters. Many pesticides that act as endocrine disrupters have a primary mode of action unrelated to the endocrine system. In other words, endocrine disruption is not specific to any one class of pesticides (e.g., insecticides, herbicides, and fungicides). Such chemicals as PCB's or the heavy metals, cadmium, lead and mercury are thought to have endocrine disrupting effects. At this point in time, controlled laboratory studies have been unable to demonstrate endocrine disruption by pesticides at the low doses typically found in the environment. Further research is ongoing on this issue. More information on endocrine effects can be found at the EPA Endocrine Home Page at http://www.epa.gov/endocrine/.

Student Activity 11

1. List three groups of pesticides that can cause cholinesterase inhibition.

2. How and why is cholinesterase used to monitor exposure to pesticides?

Exposure Pathways: Humans

Chemicals, including pesticides, are widely distributed in the environment. Therefore, many sources are possible for exposure to these chemicals for humans. Substances that are in ambient and indoor air may be inhaled into the lungs while those in water or food may be ingested or inhaled through mist or steam (such as in the shower). Direct contact with the chemical is the most prevalent way environmental chemicals can penetrate the skin, but exposure through the skin may also occur as a result of contact with chemical contaminants in air and water (for example bathing or swimming).

A single chemical can enter the body through all three routes of exposure-oral/ingestion, respiratory/inhalation, and dermal/skin penetration (dermal exposure). A compound, such as chloroform, which evaporates readily and which may be found in drinking water, illustrates this point. When this water is used for drinking, ingestion is the route of exposure. When it is used for showering, exposure may occur because of inhalation of the steam or mist and from direct contact through the skin. Similarly, pesticide use can involve more than one route of exposure if precautions are not taken. A pesticide that is sprayed can be inhaled during use; penetrate through the skin during mixing and application; and be ingested through food if not washed off hands or food before eating.

Dietary exposure to chemicals may occur through eating contaminated food items or drinking contaminated water. The EPA has established guidelines for pesticides levels in agricultural commodities that are designed to protect public health. Before a pesticide can be approved for use on food or animal feed, EPA must establish a tolerance (or an exemption from tolerance requirements) for each of the product's active and inert ingredients. A *tolerance* is the maximum permissible residue level of a pesticide that may legally be present on raw agricultural commodities, processed commodities, rotational crops, and livestock. The Food and Drug Administration regulates pesticide residues in processed foods.

Pesticide Drinking Water Standards

EPA has set standards for pesticide residues in drinking water for approximately 200 organic chemicals, many of which are pesticides. These standards include *Health Advisories (HAs)* in mg/L (ppm) for 1-day, 10-day, and longer-term exposures for children and longer-term exposure to adults.

The HA is the concentration of a chemical in drinking water that is not expected to cause adverse effects over a lifetime of exposure. HAs are determined separately for pesticides that have not been shown to cause cancer in laboratory animals and for those that have.

Following a more thorough evaluation, EPA has established *Maximum Contaminant Levels (MCLs)* and *Maximum Contaminant Level Goals (MCLGs)* for many, but not all, pesticides. MCLs are the maximum permissible level of a contaminant in water that is delivered to any user of a public water system. MCLGs are non-enforceable concentrations of a drinking water contaminant that are protective of adverse human health effects and allow an adequate margin of safety.

EPA's Office of Water also establishes *Drinking Water Equivalent Levels (DWELs)*. The DWEL is a lifetime exposure concentration protective of adverse, non-cancer health effects that assumes all of the exposure to a contaminant is from a drinking water source.

EPA also establishes a *reference dose (RfD)* in mg/kg body weight/day for each registered pesticide. The RfD represents the level of daily exposure to a pesticide (through all possible routes of exposure) that is not expected to result in appreciable risks over a human lifetime. This value is based on studies with laboratory animals and usually incorporates a safety factor of 100 to compensate for differences in species sensitivity and sensitive sub-populations. Table 2.20 lists drinking water standards and health advisories for four example pesticides.

Table 2.20 EPA drinking water standards and guidelines (summer 2000).

Pesticide	Water quality standards		Health advisories				
			10-kg child		70-kg adult		
	MCLG (mg/L)	MCL (mg/L)	1 day (mg/L)	10 day (mg/L)	RfD (mg/kg/day)	DWEL (mg/L)	Lifetime (mg/L)
Atrazine	0.003	0.003	—	—	0.035	1	0.2
2, 4-D	0.07	0.07	1.0	0.3	0.01	0.4	0.07
Glyphosate	0.7	0.7	20	20	0.1	4	0.7
Methoxychlor	0.04	0.04	0.05	0.05	0.005	0.2	0.04

Aquatic Toxicity thresholds used in NRCS pesticide screening tools will be further discussed in Module 5. A brief description of the thresholds, are shown in the sidebar Human Toxicity thresholds: NRCS pesticide screening tools.

Human Toxicity thresholds: NRCS pesticide screening tools

Chronic Human Carcinogen Level* (calculated; CHCL*;* denotes that the value is calculated) Threshold created by NAPRA team for WIN-PST and NAPRA. The concentration at which there is a 1 in 100,000 probability of contracting cancer over a lifetime exposure. It is calculated using an EPA algorithm and is based on the cancer slope from animal studies. CHCL provides a concentration comparable to an MCL.

Health Advisory (HA) Health Advisory is determined by EPA' s Office of Water (OW). It is the concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic effects over a lifetime exposure with a margin of safety. In accordance with OW policy, Health Advisories are not calculated for chemicals that are known or probable human carcinogens (EPA Cancer Class A and B).

Health Advisory* (HA*; *denotes that the value is calculated) Derived using the EPA method for calculating HA based on Reference Dose (RFD). RFD values are from the EPA Office of Pesticide Programs (OPP), EPA, or World Health Organization (WHO). In accordance with OW policy, Health Advisories are not calculated for chemicals that are known or probable human carcinogens (EPA Cancer Class A and B).

Maximum Contaminant Level (MCL) Set by EPA, it is the maximum permissible long-term pesticide concentration allowed in a public water source. MCL is always used as a drinking water standard for any pesticide for which EPA has an assigned MCL value. In the absence of an MCL, the HA, HA* or CHCL* are used, in that order.

Inhalation Exposure

The mammalian lung has an impressive surface area through which airborne pollutants may be taken into the body. Carbon monoxide poisoning and chemical warfare agents are dramatic examples of how some chemicals may rapidly enter the body and produce toxic reactions. During the mixing, loading, and application of pesticides, the lungs may be a potential route of exposure. It is important to know about a pesticide's vapor pressure and conditions appropriate for use, as climate and atmospheric pressure play a important role in the behavior of many chemicals. Always be aware of label precautions for handling, application, and re-entry to treated areas.

Dermal Exposure

During mixing, loading, and application of pesticides, the skin is the most likely body surface to come into contact with the product. Many pesticides can be absorbed through the skin into the blood and can cause toxic effects. The amount of pesticide absorbed through the skin may be enough to produce severe toxic reactions, including death. In addition, pesticides can also injure the skin directly, a process known as cutaneous toxicity. Cutaneous toxic reactions account for approximately 1/3 of all pesticide related occupational problems.

Dermatitis is one reaction that can result from exposure to pesticides. Dermatitis means literally inflammation of the skin. Most often dermatitis is referred to as a skin rash; however, this term is non-specific. There are many different types of rashes, and they differ in the way they appear and in how they are produced. Determining what has caused the dermatitis may involve "patch testing" in which the patient's skin is exposed to small patches containing dilute solutions of the suspect agents. In this way, the offending chemical can be identified and measures taken to prevent or minimize future exposure. Some of the more frequently encountered dermatitis problems in humans and food animals are primary irritant dermatitis and allergic contact dermatitis.

Primary Irritant Dermititis

Chemical substances that directly irritate the skin (like caustic acids or bases) cause primary irritant dermatitis. The symptoms may be similar to a slight burn (redness, itching, and pain) or as severe as blisters, with peeling and open wounds (ulceration). The areas of direct contact are usually the most affected, and this is one of the ways it is recognized. When exposure to the irritant is prevented, the irritation cannot occur. Thus, the use of appropriate protective equipment can completely prevent the development of primary irritant dermatitis.

Table 2.21 Plants and pesticides that may cause primary irritant dermatitis.

Plants			
Tomatoes	Dieffenbachia	Rubber Tree	Carrot
Castor Bean	Fig Tree	Sap Mushroom	Daffodil
Cucumber	Buttercup	Parsnip	Foxglove
Turnip	Tulip bulb	Parsley	Narcissus bulb
Celery	Cowslip	Milkweed	
Pesticides			
Sulfur	Captafol	Endosulfan	Omite
Folpet	Lindane	TOK	Ziram
Toxaphene	Choropicin	Thiram	Methomyl
Kelthane	Zineb	Dinoseb	Triazine
Maneb	Dinitro	Benomyl	Captan
Glyphosate	Weed Oil	Dacthal	Chlorothalonil
Organophophates			

Allergic Contact Dermatitis

One particular instance in which the dose-response relationship does not hold true is in a true allergic reaction. Allergic reactions are special kinds of changes in the immune system; they are not really toxic responses. The difference between allergies and toxic reactions is that a toxic effect is directly the result of the toxic chemical acting on cells. Allergic responses are the result of a chemical stimulating the body to release natural chemicals, which are, in turn, directly responsible for the effects seen. Thus, in an allergic reaction, the chemical acts merely as a trigger, not as the bullet.

The best example of allergic contact dermatitis (ACD) is poison oak and poison ivy dermatitis. This cutaneous toxic reaction is a true allergic response because the skin must be sensitized by exposure to the chemical (once or many times), and the result is a localized allergic reaction. Not everyone will develop ACD after exposure, and some workers may handle a potentially allergenic substance for years before ACD develops, or it may develop after a single exposure. The symptoms of ACD are exactly those of poison ivy or poison oak dermatitis and vary from redness, itching, and small blisters to widespread blisters that overlap, forming large, fluid filled blisters.

Table 2.22 Plants and pesticides that may cause allergic contact dermatitis (ACD).

Pesticides		
Captan	Captafol	Benomyl
Triazines	Dichlorvos	Parathion
Malathion	Naled	Thiram
PCNB	Zineb	Maneb
Some natural pyrethroids	Cresol	Formaldehyde
Plants	**Flowers**	**Trees**
Poison ivy	Primrose	Cedar
Poison oak	English ivy	Pine
Poison sumac	Tulip bulbs	Cashew
Liverwort	Chrysanthemum	Lichens
Onions	Narcissus bulbs	
Garlic		
Celery		

Worker Protection Standard

Worker Protection Standards are standards established by EPA to reduce farmworker exposure to pesticides. As part of these efforts EPA has developed *Restricted-Entry Intervals (REIs)*. REIs are periods of time that farmworkers must remain away from a site after a pesticide has been applied. Table 2.23 demonstrates REIs for pesticides that contain only one active ingredient. It should be noted, however, that many pesticides contain more than one active ingredient. For additional information, a video on worker protection standards should be available through your local State Department of Agriculture.

Table 2.23 Restricted-entry intervals.

Toxicity category	REIs
I	48 hours
II	24 hours
III	12 hours
IV	12 hours

What is a MSDS?

A Material Safety Data Sheet (MSDS) is designed to provide both workers and emergency personnel with the proper procedures for handling or working with that substance. MSDS will include information such as physical data (melting point, boiling point, flash point etc.), toxicity, health effects, first aid, reactivity, storage, disposal, protective equipment, and spill/leak procedures. These are of particular use if a spill or other accident occurs. An example MSDS for AATREX 4L is included at the end of Module 2. The following web site is a good source for MSDS information: http://www.cdms.net/manuf/manuf.asp.

Pesticide Information Profiles

Pesticide Information Profiles (PIPs) are documents, which provide specific pesticide information relating to health and environmental effects. PIPs are not based on an exhaustive literature search. The information does not in any way replace or supersede the information on the pesticide product labeling or other regulatory requirements. These documents can be accessed through EXTOXNET. The web address is: http://ace.orst.edu/info/extoxnet/pips/searchindex.html.

The best way to prevent cutaneous toxicity is the appropriate and correct use of protective clothing and the practice of safe handling and application procedures.

Student Activity 12

1. EPA has set standards for pesticide residue in drinking water. List and define two of the most common terms used by EPA.

2. List the three most likely routes of exposure for a toxicant.

3. Define the following terms.

   Worker Protection Standard

   Restricted entry intervals

Group Activity 2—Optional

1. Discuss the implementation of pesticide usage and cancer. Give your opinion on the role of pesticides in cancer development in humans.

Module 2, Part B, Section 4— Ecological Effects

Supporting Objectives

- Define ecosystem, population, and community
- List three examples of adverse effects toxic pollutants may have on an ecosystem or a community.
- Describe the differences among microcosm, mesocosm, and field trials.
- Define bioaccumulation, bioconcentration, and biomagnification.
- List three pesticide characteristics that can influence its uptake and storage in wildlife.
- Describe the concept of dynamic equilibrium

Introduction

Chemicals released into the environment may have a variety of adverse ecological effects ranging from fish and wildlife kills to more subtle effects on reproduction or fitness that also can result in population decline. Ecological effects can be long-term or short-lived changes in the normal functioning of an ecosystem, resulting in economic, social, and aesthetic losses. These potential effects are an important reason for regulation of pesticides, toxic substances, or other sources of pollution.

An ecosystem is the physical environment along with the organisms (biota) inhabiting that space. Some typical examples of ecosystems include a farm pond, a mountain meadow, and a rain forest. An *ecosystem* follows a certain sequence of processes and events through the days, seasons, and years. The processes include not only the birth, growth, reproduction, and death of biota in that particular ecosystem, but also the interactions between species and physical characteristics of the geological environment. From these processes, the ecosystem gains a recognizable structure and function, and matter and energy are cycled and flow through the system. Over time, better adapted species come to dominate; entirely new species may change, perhaps in a new or altered ecosystem.

The Organization of Ecosystems

The basic level of ecological organization is with the individual, a single plant, insect, or bird. The definition of ecology is based on the interactions of organisms with their environment. In the case of an individual, it would entail the relationships between that individual and numerous physical (rain, sun, wind, temperature, nutrients) and biological (other plants, insects, diseases, animals) factors. The next level of organization is the *population*. Populations are simply a collection of individuals of the same species within an area or region. We can see populations of humans, birch trees, or sunfish in a pond. Population ecology is concerned with the interactions of the individuals with each other and with their environments.

The next, more complex, level of organization is the *community*. Communities are made up of different populations of interacting plants, animals, and microorganisms also within some defined geographic area. Different populations within a community interact more among themselves than with populations of the same species in other communities; therefore, there are often genetic differences between members of two different communities. The populations in a community have evolved together so those members of that community provide resources (nutrition, shelter) for each other.

The next level of organization is the *ecosystem*. An ecosystem consists of different communities of organisms associated within a physically defined space. For example, a forest ecosystem consists of animal and plant communities in the soil, forest floor, and forest canopy, along the stream bank and bottom, and in the stream. A stream bottom community, for example, will have various fungi and bacteria living on dead leaves and animal wastes, protozoan and microscopic invertebrates feeding on these microbes, and larger invertebrates (worms, crayfish) and vertebrates (turtles, catfish). Each community functions somewhat separately, but they are also linked to the others by the forest, rainfall, and other interactions. For example, the stream community is heavily dependent on leaves produced in the surrounding trees falling into the stream, feeding the microbes and other invertebrates. In addition, the rainfall and ground water flow in a surrounding forest community greatly affect the amount and quality of water entering the stream or lake system.

Terrestrial ecosystems can be grouped into units of similar nature, termed biomes (such as a deciduous forest, grassland, or coniferous forest), or into a geographic unit, termed landscapes, containing several different types of ecosystems. Aquatic ecosystems are commonly categorized on the basis of whether the water is moving (streams, river basins) or still (ponds, lakes, large lakes) and whether the water is fresh, salty (oceans), or brackish (estuaries). Landscapes and *biomes* (and large lakes, river basins, and oceans) are subject to global threats of pollution (acid deposition, stratospheric ozone depletion, air pollution, the greenhouse effect) and human activities (soil erosion, deforestation).

Adverse Effects on Ecosystems

While natural forces such as drought, fire, flood, frost, or species migration may affect an ecosystem, it usually continues to function in a recognizable way. A pond ecosystem may go through flood or drought, but it continues to be a pond. This natural resilience allows ecosystems to resist change and recover quickly from disruptions.

On the other hand, toxic pollutants and other non-natural phenomena can overwhelm the natural stability of an ecosystem and result in irreversible changes and serious losses, as illustrated by the following examples:

- decline of forests, caused by air pollution and acid deposition.
- loss of fish production in a stream, due to death of invertebrates from copper pollution.
- loss of timber growth, because of nutrient losses caused by mercury poisoning of microbes and soil insects.
- decline and shift in age of eagle and hawk (and other top predator) populations, because of the effects of DDT in their food supply on egg survival.
- losses of numbers of species (diversity) in ship channels subjected to repeated oil spills.
- loss of commercially valuable salmon and endangered species (bald eagle, osprey) from forest applications of DDT.

Each of these pollutant-caused losses has altered ecosystem processes and components and affected the aesthetic and commercial value of an ecosystem. Usually, adverse ecological effects take place over long periods or even at some distance from the point of chemical release. For example, DDT, though banned for use in the United States for over 20 years, is still entering the Great Lakes ecosystem through rainfall and dust from sources half way around the world. The long-term effects and overall impacts of new and existing chemicals on ecosystems can only be partially evaluated by current laboratory testing procedures. Nevertheless, field studies and careful monitoring of chemical use and biological outcomes, make it possible to evaluate the short-term and long-term effects of pesticides and other chemicals.

Adverse Ecological Effects on Communities

Scientists are most concerned about the effects of chemicals and other pollutants on communities. Short-term and temporary effects are more easily measured than long-term pollution effects on ecosystem communities. Understanding the impact of effects requires knowledge of the time course and variability of these short-term changes. Pollutants may adversely affect communities by disrupting their normal structure and delicate interdependencies. The structure of a community includes its physical system, usually created by the plant life and geological processes, as well as the relationships between its populations of biota.

For example, a pollutant may eliminate a species essential to the functioning of the entire community; it may promote the dominance of undesirable species (weeds, trash fish); or it may simply decrease the numbers and variety of species present in the community. It may also disrupt the dynamics of the food webs in the community by breaking existing dietary linkages between species. Most of these adverse effects in communities can be measured through changes in productivity in the ecosystem. Under natural stresses (such as unusual temperature and moisture conditions), the community may be unable to tolerate chemical effects that would otherwise cause no harm.

An important facet of biological communities is the number and intensity of interactions between species. These interactions make the community greater than simply the sum of its parts. The community is stronger than its populations, and the ecosystem is more stable than its communities. A seriously altered interaction may adversely affect all the species dependent on it. Even so, chemicals without apparent effects on populations or communities can alter some ecosystem properties or functions (such as nutrient dynamics). Thus, an important part of research in ecological effects is concerned with the relative sensitivity of ecosystems, communities, and populations to chemicals and to physical stresses. Consider the effects of spraying an orchard with an insecticide when bees and other beneficial insects may be present and vulnerable to the toxicant. This practice is both economically and ecologically unsound, since it would deprive all plants in the area of pollinators and disrupt control of plant pests by their natural enemies. Advanced agricultural practices, such as integrated pest management (IPM), avoid these adverse effects through appropriate timing and selection of sprays in conjunction with non-chemical approaches to insect control.

Effects of chemicals on communities can be measured in a laboratory model ecosystem, or *microcosm*. Intermediate-sized systems are called *mesocosms* and may be engineered field systems, open-top plant chambers, or field pens. In addition, researchers conduct full field trials. They then evaluate the data they gather about effects of chemicals on processes and species in complex situations that reflect the real world.

Adverse Effects on Species

Most information on ecological effects has been obtained from studies on single species of biota. These tests have been performed in laboratories under controlled conditions and chemical exposures, usually with organisms reared in the laboratory representing inhabitants of natural systems. Most tests are short-term, single exposures (acute toxicity assays), but long-term (chronic) exposures are used as well. Although such tests reveal which chemicals are relatively more toxic and which species are relatively more vulnerable to their effects, these tests do not disclose much about either the important interactions noted above or the role of the range of natural conditions faced by organisms in the environment.

Generally, the effects observed in these toxicity tests include reduced rates of survival or increased death rates; reduced growth and altered development; reduced reproductive capabilities, including birth defects; changes in body systems, including behavior; and genetic changes. Any of these effects can influence the ability of species to adapt and respond to other environmental stresses and community interactions.

Environmental toxicology studies performed on species in the laboratory provide the basis for much of the current regulation of pollutants and have allowed major improvements in environmental protection. However, these tests yield only a few clues to effects on more complex systems. Long-term studies and monitoring of ecological effects of new and existing chemicals released into the environment are needed in order to better understand potential adverse ecological effects and their consequences.

Exposure Scenarios: Wildlife

Wildlife may be exposed to pesticides via oral, inhalation, and dermal routes of exposure (and in the case of fish, some amphibians, and many aquatic macroinvertebrates, through the gill). Because pesticides are widespread in the environment and are found in both aquatic and terrestrial ecosystems, there are numerous ways in which wildlife may be exposed.

Water quality toxicity thresholds for wildlife will be referenced later in Module 5. They include the LOC, MATC, and STV. See sidebar Aquatic Toxicity threshold: NRCS pesticide screening tools. Exposure routes (solution versus sorbed) and duration of exposure (acute versus chronic) will determine which threshold value will be appropriate.

Aquatic Toxicity thresholds: NRCS pesticide screening tools

Level of Concern (LOC) An acute fish toxicity threshold defined as half of the 96-hour LC50. It' s endpoint is base on lethal dosage. At this concentration, there is significant disruption of the aquatic species of concern, but does not kill 50% of the test population. This concentration may still kill a significant proportion of the population. LOC is used by EPA for aquatic risk assessment.

Maximum Acceptable Toxicant Concentration* (MATC*; * denotes that the value is calculated) MATC is the long-term toxicity value for fish that represents a life cycle (chronic) concentration between a long term No Observable Effect Concentration (NOEC) and Lowest Observed Effect Concentration (LOEC). At this concentration, a very small percentage of a population may be adversely affected. MATC can be determined empirically by performing long-term or early life-stage toxicity tests. MATC* can be calculated two ways: by determining the geometric mean of the NOEC and LOEC when NOEC and LOEC are available and, if NOEC and LOEC are not available, MATC* can be extrapolated from the 96-hour LC_{50}.

Sediment Toxicity Value* (STV*; * denotes that the value is calculated) Threshold created by NAPRA team for WIN-PST and NAPRA. STV provides a toxicity threshold of pesticides sorbed to detached soil leaving the field. The STV estimates the pesticide concentration in sediment pore water. STV = Fish MATC x K_{oc}. Fish MATC is used because toxicity data for sediment dwelling animals are limited. The STV is derived from a method by Di Torro et al., (1991) that estimated short-term toxicity of nonionic pesticides. It was modified to estimates long-term toxicity by using the MATC instead of the 96-hour LC_{50}. STV also evaluate ionic pesticide, by using estimated K_{oc}s for ionic species.

Bioaccumulation

Bioaccumulation is an important process through which chemicals can affect living organisms. Bioaccumulation means an increase in the concentration of a chemical in a biological organism over time, compared to the chemical's concentration in the environment. Compounds accumulate in living things any time they are taken up and stored faster than they are broken down (metabolized) or excreted. Understanding the dynamic process of bioaccumulation is important in protecting human beings and other organisms from the adverse effects of chemical exposure, and it has become a critical consideration in the regulation of chemicals.

A number of terms are used in conjunction with bioaccumulation. Uptake describes the entrance of a chemical into an organism—such as by breathing, swallowing, or absorbing it through the skin—without regard to its subsequent storage, metabolism, and excretion by that organism.

Storage, a term sometimes confused with bioaccumulation, means the temporary deposit of a chemical in body tissue or in an organ. Storage is just one facet of chemical bioaccumulation. (The term also applies to other natural processes, such as the storage of fat in hibernating animals or the storage of starch in seeds.)

Bioconcentration is the specific bioaccumulation process by which the concentration of a chemical in an organism becomes higher than its concentration in the air or water around the organism. Although the process is the same for both natural and manufactured chemicals, the term bioconcentration usually refers to chemicals foreign to the organism. For fish and other aquatic animals, bioconcentration after uptake through the gills (or sometimes the skin) is usually the most important bioaccumulation process.

Biomagnification describes a process that results in the accumulation of a chemical in an organism at higher levels than are found in its food. It occurs when a chemical becomes more and more concentrated as it moves up through a food chain—the dietary linkages between single-celled plants and increasingly larger animal species.

A typical food chain includes algae eaten by the water flea eaten by a minnow eaten by a trout and, finally, consumed by an osprey (or human being). If each step results in increased bioaccumulation, that is, biomagnification, then an animal at the top of the food chain, through its regular diet, may accumulate a much greater concentration of chemical than was present in organisms lower in the food chain. Table 2.24 summarizes the terms used in conjunction with bioaccumulation.

Table 2.24 Summary of terms used in conjunction with bioaccumulation.

Term	Definition	Relationship to bioaccumulation
Bioaccumulation	An increase in the concentration of a chemical in a biological organism over time.	
Storage	Temporary deposit of a chemical in body tissue or an organ.	One facet of bioaccumulation
Bioconcentration	The process by which the concentration of a chemical in an organism becomes higher than its concentration in the air or water around the organism.	A specific process of bioaccuculation
Biomagnification	A process that results in the accumulation of a chemical in an organism at higher levels than are found in its food.	A consequence of bioaccumulation through the food chain
Uptake	The movement of a chemical from the environment into an organism's cells.	A mechanism by which bioaccumulation occurs
Elimination	Excretion or metabolism of a chemical that removes it from the body of an organism.	Reduction in bioaccumulation

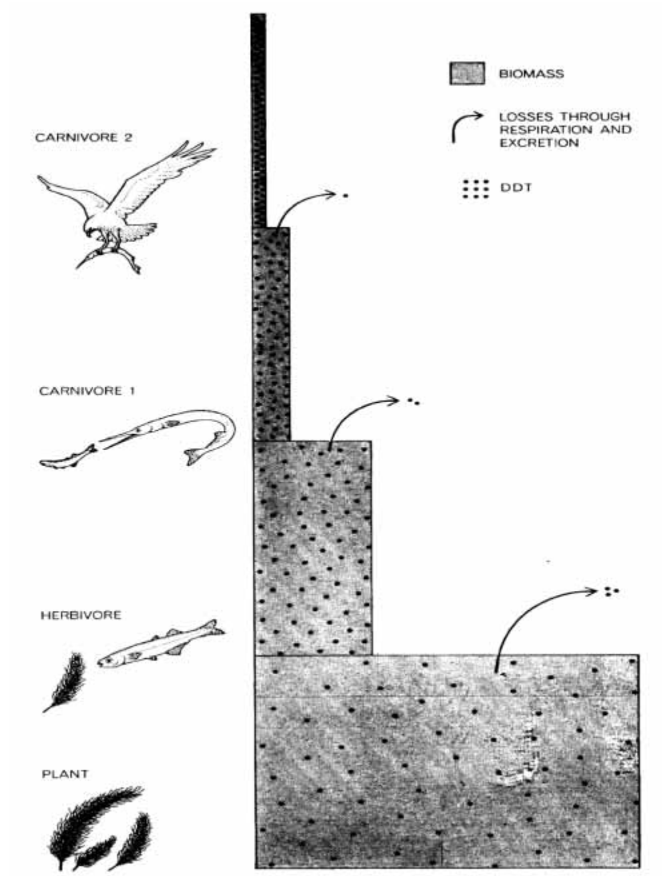


Figure 2.20 Schematic illustration of DDT biomagnification in a simple food chain.

Biomagnification is illustrated by a study of DDT that showed that where soil levels were 10 parts per million (ppm), DDT reached a concentration of 141 ppm in earthworms and 444 ppm in robins. Through biomagnification, the concentration of a chemical in the animal at the top of the food chain may be high enough to cause death or adverse effects on behavior, reproduction, or disease resistance and thus endanger that species, even when levels in the water, air, or soil are low. Fortunately, bioaccumulation does not always result in biomagnification. The bioaccumulation process is normal and essential for the growth and nurturing of organisms. All animals, including humans, daily bioaccumulate many vital nutrients, such as vitamins A, D, and K, trace minerals, and essential fats and amino acids. What concerns toxicologists is the bioaccumulation of substances to levels in the body that can cause harm. Because bioaccumulation is the net result of the interaction of uptake, storage and elimination of a chemical, these parts of the process will be examined further.

Uptake

Bioaccumulation begins when a chemical passes from the environment into an organism's cells. Uptake is a complex process, which is still not fully understood. Scientists have learned that chemicals tend to move, or diffuse, passively from a place of high concentration to one of low concentration. The force or pressure for diffusion is called the chemical potential, and it works to move a chemical from outside to inside an organism.

A number of factors may increase the chemical potential of certain substances. For example, some chemicals do not mix well with water. They are called *lipophilic*, meaning fat loving, or *hydrophobic*, meaning water hating. In either case, they tend to move out of water and enter the cells of an organism, where there are lipophilic microenvironments.

Storage

The same factors affecting the uptake of a chemical continue to operate inside an organism, hindering a chemical's return to the outer environment. Some chemicals are attracted to certain sites, and by binding to proteins or dissolving in fats, they are temporarily stored. If uptake slows or is not continued, or if the chemical is not tightly bound in the cell, the body can eventually eliminate the chemical.

One factor important in uptake and storage is water solubility—the ability of a chemical to dissolve in water. Usually, compounds that are highly water soluble have a low potential to bioaccumulate and do not leave water readily to enter the cells of an organism. Once inside, they are easily removed unless the cells have a specific mechanism for retaining them.

Heavy metals like mercury and certain other water-soluble chemicals are such an exception, because they bind tightly to specific sites within the body. When binding occurs, even highly water-soluble chemicals can accumulate. This is illustrated by cobalt, which binds tightly and specifically to sites in the liver and accumulates there despite its water solubility. Similar accumulation processes occur for mercury, copper, cadmium, and lead.

Many fat-loving, or lipophilic chemicals, pass into organisms' cells through the fatty layer of cell membranes more easily than water-soluble chemicals. Once inside the organism, these chemicals may move through numerous membranes until they are stored in fatty tissues and begin to accumulate.

The storage of toxic chemicals in fat reserves serves to detoxify the chemical, or at least removes it from harms way. However, when fat reserves are called upon to provide energy for an organism, the material stored in the fat may remobilize within the organism and may again be potentially toxic. If appreciable amounts of a toxin are stored in fat and fat reserves are quickly used, significant toxic effects may be seen from the remobilization of the chemical.

Elimination

Another factor affecting bioaccumulation is whether an organism can break down or excrete a chemical, or both. The biological breakdown of chemicals is termed *metabolism*. This ability varies among individual organisms and species and also depends on characteristics of the chemical itself. Chemicals that dissolve readily in fat but not in water tend to be more slowly eliminated by the body and thus have a greater potential to accumulate.

Many metabolic reactions change a chemical into more water-soluble forms (called metabolites) that are readily excreted. There are exceptions, however. Natural pyrethrins, insecticides that are derived from the chrysanthemum plant, are highly fat-soluble pesticides, but they are easily degraded and do not accumulate. The insecticide chlorpyrifos, which is less fat-soluble but more poorly degraded, tends to bioaccumulate. Factors affecting metabolism often determine whether a chemical achieves its bioaccumulation potential in a given organism.

During constant environmental exposure to a chemical, the amount of a chemical accumulated inside the organism and the amount leaving reach a state of dynamic equilibrium. To understand this concept of *dynamic equilibrium*, imagine a tub filling with water from a faucet at the top and draining out through a pipe of smaller size at the bottom. When the water level in the tub is low, little pressure is exerted on the outflow at the bottom of the tub. As the water level rises, the pressure on the outflow increases. Eventually, the amount of the water flowing out will equal the amount flowing in, and the level of the tub will not change. If the input or outflow is changed, the water in the tub adjusts to a different level.

The same concept holds for living organisms. An environmental chemical will at first move into an organism more rapidly than it is stored, degraded, and excreted. With constant exposure, the concentration inside the organism gradually increases. Eventually, the concentration of the chemical inside the organism will reach equilibrium with the concentration of the chemical outside the organism, and the amount of chemical entering the organism will be the same as the amount leaving. Although the amount inside the organism remains constant, the chemical continues to be taken up, stored, degraded, and excreted.

If the environmental concentration of the chemical increases, the amount inside the organism will increase until it reaches a new equilibrium. Exposure to large amounts of a chemical for a long period; however, may overwhelm the equilibrium (for example, overflowing the tub), potentially causing harmful effects.

Likewise, if the concentration in the environment decreases, the amount inside the organism will also decline. Should the organism move to a clean environment, so that exposure ceases, then the chemical eventually will be eliminated from the body.

Factors Affecting Bioaccumulation

This simplified explanation does not take into account the many factors that affect the ability of organisms to bioaccumulate chemicals. Some chemicals bind to specific sites in the body, prolonging their stay; others move freely in and out. The time between uptake and eventual elimination of a chemical directly affects bioaccumulation. Chemicals that are immediately eliminated, for example, do not bioaccumulate.

Similarly, the duration of exposure is also a factor in bioaccumulation. Most exposures to chemicals in the environment vary continually in concentration and duration, sometimes including periods of no exposure. In these cases, equilibrium is never achieved, and the accumulation is less than expected.

Bioaccumulation varies between individual organisms as well as between species. Large, fat, long-lived individuals or species with low rates of metabolism or excretion of a chemical will bioaccumulate more than small, thin, short-lived organisms. Thus, an old lake trout may bioaccumulate much more than a young bluegill in the same lake.

Table 2.25 Categories of ecotoxicology.

Toxicity category	Birds acute oral LD_{50} (mg/kg)	Bird dermal LC_{50} (ppm)	Fish water LC_{50} (mg/l)
very highly toxic	<10	<50	<0.1
highly toxic	10-50	50-500	0.1 - 1
moderately toxic	> 50 – 500	>500 - 1000	>1 - 10
slightly toxic	> 500 – 2000	>1000 - 5000	>10 - 100
practically non-toxic	> 2000	>5000	>100
After: Meister, R. Ed. Farm Chemicals Handbook, Meister Publishing, Willoughby, OH			

Bioaccumulation results from a dynamic equilibrium between exposure from the outside environment and uptake, excretion, storage, and degradation within an organism. The extent of bioaccumulation depends on the concentration of a chemical in the environment, the amount of chemical coming into an organism from the diet, water, or air, and the time it takes for the organism to acquire the chemical and then excrete, store, and/or degrade it. The nature of the chemical itself, such as its solubility in water and fat, affects its uptake and storage. Equally important is the ability of the organism to degrade and excrete a particular chemical. When exposure ceases, the body gradually metabolizes and excretes the chemical.

Bioaccumulation is a normal process that can result in injury to an organism only when the equilibrium between exposure and bioaccumulation is overwhelmed, relative to the harmfulness of the chemical. The toxicity of a chemical will also determine the overall effects of bioaccumulation. Table 2.25 list EPA's rating scale and labeling requirements for pesticides. Remember that in aquatic systems the term LC_{50} is used. This is the concentration in water that will result in death for 50 percent of the organisms being tested.

Student Activity 13

1. Give three examples of how a pesticide could adversely impact an ecosystem.

2. Give three examples of how a pesticide could adversely impact a community.

3. Give three examples of how a pesticide could adversely impact an individual within a species.

4. Define the following terms and give an example of each:

   Bioaccumulation

   Bioconcentration

Biomagnification ____

____

____

5. Define the following terms.

Hydrophilic ____

____

____

Lipophilic ____

____

____

Elimination ____

____

____

6. Define *ecosystem*, population and community.

____

____

____

7. Describe the concept of dynamic equlibrium.

____

____

____

8. Describe the differences among microcosm, mesocosm, and field trials.

References

Kamrin, M. A., Ed. 1997. *Pesticide Profiles: Toxicity, Environmental Impact, and Fate*. Lewis Publishers, Boca Raton, Fl., 676 p.

Ware, G. W. 1991. *Fundamentals of Pesticides, 3rd Ed*. Thompson Publications, Fresno, CA. 307 pp.

Ware, G. W. 1994. *The Pesticide Book, 4th Ed*. Thompson Publications, Fresno, CA. 385 pp.

Water Quality Indicators Guide: Surface Waters. 1994. USDA SCS-TP-161. 129 pp.

The EXtension TOXicology NETwork (EXTOXNET) infobase on the Internet (www.ace.orst.edu/info/extoxnet/), a cooperative effort of University of California-Davis, Oregon State University, Michigan State University, and Cornell University.

Activity Answers

Student Activity 1

1. List and define the three parts of the Pollutant Delivery Process.

   Availability*—The presence of a nutrient (or other material) in quantities and forms capable of being moved offsite.*

   Detachment*—The mobilization of nutrients (or other materials) allowing them to become available for transport.*

   Transport*—The physical movement of a nutrient from one place to another.*

2. List, define, and provide an example of three processes that influence the availability of nutrients in the environment

   Adsorption *is the attraction of compounds to the surface of soil materials. For example, a positive ion like the ammonium form of nitrogen (NH_4^+) is adsorbed to the negatively charged soil cation exchange capacity (CEC) sites.*

   Precipitation *is the chemical combination of soluble species to form an insoluble compound. At high pH soluble phosphates react with soluble calcium to form relatively insoluble calcium phosphates.*

   Transformation *is the change in chemical form of a compound. These transformations, which can be either chemical or biological, are important because different forms of a nutrient have varying degrees of environmental risk. For example, urea nitrogen in manure can be transformed to ammonia nitrogen when* *applied to soil. If this transformation takes place at the soil surface, the ammonia, which is a gaseous form of nitrogen, can be lost into the atmosphere.*

3. Define eutrophication and generally describe the process of eutrophication.

Eutrophication is defined as the natural aging process of lakes, rivers, or ocean systems. Human activities in a watershed can lead to increased sediment and nutrient delivery to a waterbody greatly accelerating this process. The eutrophication process involves several steps:

- *Nutrients enter the lake or stream through surface runoff and precipitation. Sediment, dissolved nutrients and organic materials enter the waterbody.*
- *The waterbody experiences an increase in biological productivity. Aquatic plant and algae growth increases when climatic conditions (temperature, dissolved oxygen content and light) are favorable. Excess plant and algae growth can be a nuisance to lake users.*
- *As plants and algae die, decay sets in. The biomass is decomposed by microbes. Sediment and organic materials begin to collect on the lake bottom. Increased turbidity, odor, and taste problems may become a problem.*
- *The decomposition process removes dissolved oxygen from the water. Microbes use carbon as an energy source, and use up the dissolved oxygen faster than it can be replaced by plants. This can lead to oxygen depletion (hypoxia). Water temperatures rise during the decomposition process.*
- *The increased temperature and decreased oxygen can lead to the death of sensitive fish species such as trout. Low oxygen, warm temperatures, and turbidity favor more tolerant fish species such as carp. This*

leads to a reduction in species, diversity and populations.

- *Ultimately, the lake fills with sediment and organic materials and becomes a wetland.*

4. Of the many potential adverse impacts of eutrophication, provide five examples of potential adverse effects of eutrophication.

   - *Fish kills*
   - *Foul odor*
   - *Unpalatable tastes in drinking water*
   - *Impaired recreational and aesthetic values*
   - *Livestock kills*
   - *Serious health risk to humans*
   - *Trihalomethanes (carcinogens) from water treatment facilities*
   - *Loss of aquatic habitats, such as plant beds in fresh and marine systems and coral reefs along tropical coast*
   - *Red or brown tides in coastal waters and the release of toxins and low oxygen conditions when they die and decompose*
   - *Negative impacts on aquaculture and shellfisheries*
   - *Shellfish poisoning in humans and mortality in marine mammals*
   - *Pfiesteria and resulting mortality of finfish*
   - *Neurological damage to people who come in contact with toxins produced by dinoflagellates.*

5. What is environmental risk, what are the key components to consider related to nutrients in the environment and why is environmental risk important to resource planning and management?

   Environmental risk *can be defined as the probability of undesirable or adverse impact of a nutrient on a sensitive population or resource because of the presence of the nutrient in concentrations great enough to cause the adverse impact.*

   The key components to consider related to nutrients in the environment are the ***presence*** *of the nutrient; the* ***concentrations*** *present; and the* ***sensitivity*** *or susceptibility of the resource or species at risk.*

   Environmental risk is important to resource planning and management because everything that takes place on the landscape in any given watershed or hydrologic unit has the potential to create an environmental risk. By linking the consequences of various land management actions to resulting environmental risk, appropriate conservation practices can be put in place across the landscape to minimize or eliminate adverse resource impacts.

6. When working with our clients, what is our responsibility as resource planners when we become aware of an important environmental risk?

   Resource planners should strive to help their clients better understand the nature of the environmental risk, how the actions or the circumstances related to the client's operation may be contributing to an adverse environmental impact and to present their client with recommended alternatives for them to consider for implementation to prevent or minimize the potential environmental impacts which have been identified.

Student Activity 2

1. List three negative impacts that nitrogen can have on the environment.

   - *Ammonia toxicity to fish*
   - *NO_3^--N toxicity to infants*
   - *Eutrophication of water bodies*
   - *Nitrogen oxide gas contributes to the greenhouse effect and is considered to be detrimental to the ozone layer*
   - *Ammonia volatilized to the atmosphere is a component of acid rain.*

   (Other answers are possible.)

2. List two negative impacts that carbon can have on the environment.

   Greenhouse effects from increased methane and carbon dioxide in the atmosphere.

   Increased Biological Oxygen Demand (BOD) created from the consumption of oxygen by organisms using carbon as an energy source. This increased oxygen demand can create an oxygen deficiency in water sufficient enough to cause fish kill by suffocation and may also cause oxygen limitations to other aquatic organisms.

3. Why is nitrate nitrogen subject to leaching from the soil profile and when is leaching most likely to occur?

   Nitrate nitrogen is negatively charged and does not bind to the negatively charged cation exchange sites in the soil. Leaching is most likely to occur when precipitation or irrigation supplies water in excess of the soil storage capacity.

4. Considering the nitrogen cycle, list three ways nitrogen moves in the environment.

   Volatilization, denitrification, runoff, erosion, and leaching (movement in the soil).

Student Activity 3

1. The form of phosphorus that is readily available from plant uptake and use is *Orthophosphates*.

2. The major part of the phosphorus load in surface runoff is typically carried by sediment. *True*

3. Cattle manure has more phosphorus per pound than chicken manure. *False*

4. Name the two major sinks of phosphorus in an aquatic system.

   The two major sinks of phosphorus in an aquatic system are sediment-bound in the bottom sediment and that which is assimilated into aquatic plants. Usually the amount of dissolved phosphorus in the water column of an aquatic system is very small.

5. Describe the process of phosphorus cycling in an aquatic system.

   Phosphorus enters the aquatic system from the soil solution, runoff from the landscape, and direct discharge from point sources. Phosphorus enters the water column via overland flow in both the dissolved and sediment attached forms and can be released from bottom sediment. Over time algae and other aquatic plants can readily uptake dissolved phosphorus from the water column. Therefore the two major sinks of phosphorus in an aquatic system are sediment-bound in the bottom sediment and that which is assimilated into aquatic *plants. Usually the amount of dissolved phosphorus in the water column of an aquatic system is very small.*

Under certain situations (e.g. lake turnover) dissolved phosphorus can be redistributed back into the water column and become available for uptake. If water at the surface of a lake cools more quickly than the bottom water (as it does in the winter), then surface water sinks to the bottom (cool water is more dense and heavier than warm water) and the warm water rises bringing phosphorus into the photic (light) zone. A shallow or wind mixed lake can also redistribute phosphorus the water. These processes influence the phosphorus level in the water column.

In streams and rivers systems (flowing, or lotic, systems) similar interactions occur. However, because water is typically moving at a faster rate through these systems, phosphorus cycling occurs as a process often referred to as phosphorus spiraling. Dissolved and sediment phosphorus levels change during transport in streamflow (spiral) via interaction with suspended sediments, streambank and stream bed material, and aquatic plants. These interactions all influence the relative amounts of dissolved and sediment phosphorus in a stream.

When sediment enters a river or lake, phosphorus may be adsorbed from solution or desorbed (released) from the sediment, depending on the concentration of phosphorus in solution. Soil eroded from a heavily fertilized field may release phosphorus to solution when it enters a stream or lake. Conversely, erosion of subsoil or streambank material with low phosphorus and high clay content may adsorb phosphorus from the solution and lower the dissolved phosphorus concentration during transport in a river.

6. Briefly describe how excess phosphorus can impacts the water quality of a pond?

   Phosphorus can result in excess aquatic plant growth. When these plants die, their decomposition exhausts the oxygen in the pond. Aerobic organisms are no longer able to survive.

Student Activity 4

1. List two potential effects of excess potassium in soil?

   Nutrient imbalances in forages; loss of long-term sustainability

2. Describe the effect of high soil potassium levels on forages, especially grasses? Describe what can be done to prevent this.

   Early season application of organic material high in nitrogen and potassium can cause increased uptake of these nutrients by the forage. This can result in an imbalance of potassium to magnesium in the plant tissue that leads to grass tetany problem. Legume crops are better balanced with magnesium, but legumes start growing slower in the early season, especially if the grasses in the picture have an excess of nitrogen nutrition. Early season application of organic material to forages should be avoided until the slower growing legume has an opportunity to flourish. Grazing can be delayed until the legumes provide a good balance with the grasses in the pasture.

3. What are the two negative effects of excess sulfur in the environment?

   Taste and odor problems in drinking water Acid rain

4. What is a major source of sulfur in/to the soil?

   Atmospheric deposition

Student Activity 5

1. List four conditions that may lead to salt build-up in soil.
   - *Insufficient soil moisture*
   - *Inadequate drainage to leach salt from the soil profile.*
   - *Poor quality irrigation water*
   - *Low crop uptake*
2. List two problems that excess salts can cause in agriculture.
   - *Yield decline*
   - *Poor soil structure*
   - *Toxicity corrosion*
3. Provide two examples of management techniques that can be used to correct a salinity problem.
   - *Selection of crops or crop varieties that have salt tolerance;*
   - *Use of irrigation water to leach salts out of the crop root zone;*
   - *Establishment of proper surface and subsurface drainage;*
   - *In some cases, soil amendments can be used to improve soil structure.*

- *Use of planting techniques such as elevated bedding.*
- *Use of ground water for first irrigation and surface water for later applications if possible.*

4. Do you have a potential salt problem in your area? Why or why not?

   Varies with location. Most salt problems are due to insufficient soil moisture or inadequate drainage to leach the salts from the soil profile.

Student Activity 6

1. What are three sources of heavy metals to agricultural lands?
   - *Fertilizer by-products*
   - *Sewage sludge*
   - *Animal wastes*
   - *Atmospheric deposition from burning of hydrocarbon fuels by industry and motor vehicles*
2. List three heavy metals that are also essential nutrients
   - *Copper*
   - *Boron*
   - *Zinc*
   - *Molybdenum*
   - *Manganese*

3. List four heavy metals of major concern that have been identified and targeted by the U.S. Environmental Protection Agency.

    - *Cadmium*
    - *Copper*
    - *Nickel*
    - *Lead*
    - *Zinc*

4. Why are heavy metals an environmental concern?

    Plant growth is affected by excess amounts of some heavy metals in the soil. At high soil concentrations heavy metals can be toxic to plants. Excessive concentrations of zinc or copper in the available form in the soil can induce a plant deficiency of other micronutrients.

    The primary concern with heavy metals is that they are often not toxic to plants but can be toxic to the animals that eat the plants. Problems with heavy metals are often chronic in nature resulting from cumulative exposure to these metals in food. Direct ingestion by animals of forage where metals have been applied or soils with dust deposition of metals is an environmental risk. The greatest environmental risk is where metals are eroded from the application site by wind or water and transported to receiving water bodies or when plants accumulate metals and are consumed by animals.

5. List two processes that influence the fate of heavy metals in the environment.

    - *Plant uptake*
    - *Ingestion by animals*

- *Dust deposition*
- *Erosion by wind or water*

Group Activity 1

1. Control of most pollutants can be assessed in terms of the capability to impact one or more of the pollutant delivery processes. Discuss the following best management/ conservation practices and their impact on one or more of the pollutant delivery processes.

Best management/conservation practice	**Pollutant delivery process(es) impacted**
Residue Management	Reduced sheet and rill erosion and *detachment* of sediment, nutrients, and pesticides. Reduced runoff volumes and *transport* of sediment, nutrients, and pesticides.
Terraces	Controlling runoff velocities and *transport* of sediment, nutrients, and pesticides.
Banding vs. Broadcast Fertilizer	Reducing the amount of nutrient *availability*.
Water and Sediment Control Basin	Controlling runoff velocities and allowing some sediment deposition, and *transport* of sediment, nutrients, and pesticides.
Irrigation Water Management	Controlling irrigation applications and *detachment* and *transport* of sediment, nutrients, and pesticides.
Riparian Forest Buffer	Intercepting runoff and reducing the *transport* of sediment, nutrients, and pesticides.

Student Activity 7

1. What is FIFRA? How does FIFRA define "unreasonable adverse effect on the environment"?

   FIFRA, the Federal Insecticide, Fungicide, and Rodenticide Act, is the primary legislation regulating pesticides in the United States. FIFRA defines "unreasonable adverse effect on the environment" as any unreasonable risk to man or the environment, taking into account the economic, social, social, and environmental costs and benefits of the use of a pesticide.

2. What is the statute that is the basis for pesticide regulation in the U.S.?

   Federal Insecticide Fungicide and Rodenticide Act (FIFRA)

3. List three criteria for allowing a pesticide to be registered for use in the United States.

   - *Its use must not result in unreasonable adverse effects to human health and the environment.*
   - *It must be efficacious.*
   - *The benefits of use must outweigh the risks.*

4. What federal agency has the primarily responsibility for regulating pesticides?

   U.S. Environmental Protection Agency (EPA)

5. Although a pesticide has been applied according to the label, explain why there still could be significant environmental risk?

   There are three potential reasons why there may be significant risk:

   a. *The chemical has not been re-registered using current safety requirements that are more stringent than those that have been in place for products that were registered before November 1, 1984. Products that have not been re-registered may pose significant environmental risk even when used according to label instructions.*

   b. *When EPA registers a pesticide, they evaluate all of its proposed uses for "unreasonable adverse effects on the environment." EPA defines this as "unreasonable risk to man or the environment, taking into account the economic, social, and environmental costs and benefits of the use of a pesticide." Therefore, pesticides uses that have significant environmental risks may still be registered if they have important economic and/or social benefits and there are no effective lower risk alternatives.*

   c. *It is impractical for EPA to evaluate every individual site on which a proposed pesticide use may occur. Some sites are much more sensitive to pesticide losses than others. Although a particular pesticide use may be legal in an entire geographic area, sensitive sub-areas may pose significant environmental risks locally. Producers who understand local site sensitivity can voluntarily manage accordingly to protect the resource base and eliminate the need for more stringent label restrictions in the future.*

6. When working with our clients, what is our responsibility as resource planners when we become aware of an important environmental risk?

   Resource planners should strive to help their clients better understand the nature of the environmental risk, how the actions or the circumstances related to the client's operation may be contributing to an adverse environmental impact and to present their client with recommended alternatives for them to consider for implementation to prevent or minimize the potential environmental impacts which have been identified.

Student Activity 8

1. Determine whether each of the following examples would be considered a point or a nonpoint source of pesticide pollution:

		Answers
a.	Pesticide leaving a tile line.	*NPS*
b.	Pesticide drift from a tank sprayer.	*PS (debatable)*
c.	Runoff from a recently sprayed vineyard.	*NPS*
d.	Volatilization from a surface application.	*NPS*
e.	Pesticide in leachate from an old landfill.	*PS*
f.	Pesticide from a leaking container in a storage facility.	*PS*
g.	Pesticide drift from an aerial application.	*NPS*
h.	Volatilization from an airblast application.	*NPS*
i.	Pesticide spill during mixing or loading.	*PS*

Student Activity 9

1. Name four environmental factors that impact the fate of pesticides in the environment:

   - *Temperature*
   - *Soil pH*
   - *Soil texture*
   - *Sunlight*
   - *Organic matter*
   - *Soil moisture*

2. List three major degradation pathways and list factors that may contribute to the breakdown of a pesticide under each major pathway.

   Microbial degradation*—Soil organic matter, texture, and site characteristics such as moisture, temperature, aeration, and pH, all affect microbial degradation.*

   Chemical degradation*—extreme pH, water oxygen, and other chemicals pH, all affect chemical degradation.*

   Photo degradation*—intensity and spectrum of sunlight, length of exposure, pesticide properties, all affect photo degradation. Pesticides that are applied to foliage or to the soil surface are more susceptible to photodegradation than pesticides that are incorporated into the soil. Glass filters out much of the ultraviolet light, which has the greatest potential to photodegrade pesticides.*

3. List four pathways for pesticide movement in the environment.

   - *attach (sorb) to soil particles and move with eroded soil*
   - *dissolve in water and move in runoff*
   - *dissolve in water and taken up by plants*
   - *dissolve in water and leach downward towards groundwater*
   - *volatilize or removed from foliage or soil with wind and become airborne*

4. Calculate the distribution coefficient (K_d) of a mixture of pesticides in water if the concentration of pesticides adsorbed to the soil is 500 ppm and the pesticide concentration in water solution is 25 ppm.

   500/25 or 20

5. Pesticide A has a K_{oc} of 1000 and Pesticide B has a K_{oc} of 25. Which one is more sorbed and therefore less mobile?

   Pesticide A

6. On a hot, dry day, would you expect the same pesticide to volatilize more readily from a moist soil or a dry soil? Why?

   From a moist soil. There would be a larger difference between the moisture content of a wet soil and dry air than between the moisture content of a dry soil and dry air (that is, the moisture gradient would be steeper). Vapors tend to follow steeper moisture gradients.

7. Two pesticide alternatives for controlling a pest. Pesticide A has a K_{oc} of 28. Pesticide B has a K_{oc} of 350. Which pesticide has the higher potential for leaching?

   Pesticide A

8. List and define the four pesticide properties that impact their fate in the environment.

   Half-life *is the length of time required for one-half of the original quantity of a substance to break down.*

   Sorption *can be the binding of a chemical to soil particles, vegetation, or other surfaces, but usually refers to the binding of a chemical to soil particles.*

   Vapor pressure *is the pressure exerted by a vapor when it is in equilibrium with the liquid from which it is derived.*

   Water solubility *is the amount of a substance that will dissolve in a known amount of water.*

9. A new pesticide ("Kill-All" Herbicide) has come on the market, and you are asked to assess its potential persistence and mobility. Given the following pesticide properties, is the pesticide highly persistent? Is it highly mobile? Why?

   Persistent because it has a high half-life of 150 days (>100 days)

   Not mobile and not likely to leach because it has a high K_{oc} *and a low solubility*

   Medium risk of volatilization because its vapor pressure of 2.5×10^{-5} *is in the medium risk range between* 1.0×10^{-4} *to* 1.0×10^{-7}*.*

10. A pesticide may reside in air, soil or water. What information would you use to determine where a pesticide is most likely to be found in the environment?

    Pesticide properties such as solubility, sorption coefficient, and vapor pressure will determine in which part of the environment the pesticide is likely to reside. For example, a pesticide that has a high solubility is likely to reside in water, while one that has a high vapor pressure is likely to reside in air. Furthermore, a pesticide that has a high *sorption coefficient would be strongly adsorbed in the soil and would therefore reside in the soil or soil particles if they are eroded.*

11. Define the following terms:

Drift—*offsite airborne movement, or the movement of a chemical including pesticides in air from the site of application offsite.*

The chemical might be inhaled by a human or animal. The chemical may cause crop damage offsite. The chemical might be deposited in a nearby waterbody.

Leaching—*the movement of water through the soil or the removal of soluble material including pesticides by water passing or percolating through the soil.*

Soluble material may be leached to ground water. Soluble material may be leached and discharged to surface water.

Runoff—*the movement of water over a sloping surface. This occurs when precipitation or irrigation inputs exceed the infiltration rate of the soil.*

Eroded sediment, sorbed chemicals to eroded sediment and dissolved chemical in water may runoff and be carried to a receiving water body.

Sorption—*the attraction between a chemical including pesticides and soil, vegetation, or other surfaces. It is most often referred to as the binding of a chemical to soil particles.*

If chemicals are sorbed to soil particles they are more likely to remain in the root zone where they may be available for plant uptake and microbial or chemical degradation. Chemicals that are weakly sorbed to soil particles are more likely to move through the soil with infiltrating water or to move with runoff water.

Student Activity 10

1. Define poison by chemical agents and list four symptoms of someone who may have been poisoned by a chemical.

   Chemical poisoning is a chemically induced disease. The symptoms of someone who has been poisoned by a chemical may be:

   - *Headaches*
   - *Diarrhea*
   - *Fever*
   - *Increased heart rate*
   - *Nausea*
   - *Dizziness*
   - *Induced sweating*
   - *Convulsions*
   - *Vomiting*
   - *Death in extreme cases*

     (This is only a partial list. Many other symptoms could be identified.)

2. Define toxicity, list the two types of toxicity, and give an example of each.

   Toxicity *is the adverse effects produced by poisons.*

   Acute toxicity*—dizziness, nausea, vomiting, headache, fever.*

   Chronic toxicity*—cancer, leukemia, organ damage.*

3. Define the following terms:

   ED_{50}—*is the dose level at which 50 percent of the test organisms have an observed effect from the chemical under consideration.*

   LD_{50}—*is the dose level at which 50 percent of the test organisms have a lethal effect.*

   TD_{50}—*is the dose level at which 50 percent of the organisms have toxic effect.*

   NOEL—*No Observable Effect Level is the highest dose or exposure level that produces no noticeable effect on test organisms.*

   TLV—*Threshold Limit Value is the concentration of the chemical that produces no adverse effect in workers exposed for 8 hours per day, 5 days per week.*

4. What is the difference between LC_{50} and LD_{50}?

   LC_{50} *is the* <u>*concentration*</u> *(mg/L) that causes mortality in half the test organisms.*

   The ***LD_{50} (the lethal dose for 50 percent of the animals tested)*** *of a poison is usually expressed in milligrams of chemical per kilogram of body weight (mg/kg). Both the LC_{50} and the LD_{50} are measures of acute (lethal) toxicity in a sensitive population of animals.*

5. What is the difference between mg/kg and mg/l in describing amounts of exposure?

   Mg/kg is a dose, mg/l is a concentration

6. What are the relative strengths and weaknesses of:

   Laboratory testing *is done in a controlled environment. One chemical can be studied at a time, and very high doses can be administered. Because of this, laboratory studies may be easier to interpret than* *epidemiological studies of human populations. However, it may be difficult to apply laboratory results directly to the dose exposures that humans may experience in the real world, because real-world exposures tend to be much lower and may be confounded by exposures to multiple chemicals simultaneously.*

Epidemiological studies *attempt to establish the relationship between environmental factors and health. These studies look at selected populations that may have a higher exposure to a particular chemical than the general population and compare the incidence of illnesses (particularly cancers) in the select population with that of the general population. Epidemiological studies are directly related to real world situations. However, even in well-documented cases, it is not possible to use epidemiology to establish the exact risk of exposure to specific concentrations of chemicals. Laboratory studies come closer to doing this.*

7. Are chemicals with small LD_{50}s always more dangerous than those with large LD_{50}s? Why or why not?

   No. A small LD_{50} *indicates high toxicity, only. Other factors, such as persistence and mobility in the environment, affect the danger of a chemical. For example, a chemical with a small* LD_{50} *but a short half-life and low mobility may actually be less dangerous than a mobile chemical with a large* LD_{50} *and a long half-life.*

Student Activity 11

1. List three groups of pesticides that can cause cholinesterase depression.

   Organophosphate, carbamates, and chlorinated derivatives of nicotine—imidacloprid can all cause cholinesterase depression.

Organophosphates-mode of action is cholinesterase inhibition/suppression.

Carbamates-mode of action is cholinesterase inhibition/ suppression.

Chlorinated Derivatives of Nicotine-mode of action is cholinesterase inhibition/suppression.

2. How and why is cholinesterase used to monitor exposure to pesticides?

   Cholinesterase is an enzyme that regulates nerve function. With reduced cholinesterase levels, the nervous system does not function properly. Some pesticides inhibit cholinesterase activity. In particular, organophosphates and carbamates inhibit this enzyme. Exposure to these pesticides therefore reduces the level of cholinesterase in the blood. Blood samples are drawn regularly from pesticide applicators to monitor their comparative levels of cholinesterase over time.

Student Activity 12

1. EPA has set standards for pesticide residue in drinking water. Define the following terms used by EPA:

   Health Advisories (HA)*—is the concentration of a chemical in drinking water that is not expected to cause any adverse, non-carcinogenic effects over a lifetime of exposure, with a margin of safety.*

   Maximum Contaminant Levels (MCL)*—is the maximum permissible level of a contaminant in water that is delivered to any user of a public water system.*

   Maximum Contaminant Level Goal (MCLG)*—is the non-enforceable concentration of a drinking water contaminant that is protective of adverse human health effects and allows an adequate margin of safety.*

Drinking Water Equivalent Level (DWEL)*—is a lifetime exposure concentration that is protective of adverse, non-cancer health effects. It assumes that all of the exposure to the chemical comes from the drinking water source.*

2. List the three most likely routes of exposure for a toxicant.

   - *oral/ingestion*
   - *dermal/skin penetration*
   - *respiratory/inhalation*

3. Define the following terms.

Worker Protection Standards*—are standards established by EPA to reduce farmworker exposure to pesticides. As part of these efforts EPA has developed.*

Restricted-Entry Intervals (REIs)*—REIs are periods of time that farmworkers must remain away from a site after a pesticide has been applied*

Restricted Entry Intervals*—are periods that farmworkers must remain away from a site after a pesticide has been applied.*

Group Activity 2—Optional

1. Discuss the implications of pesticide usage and cancer. Give your opinion on the role of pesticides in cancer development in humans.

All pesticides are tested for cancer before registration. Laboratory animals, usually rats or mice, are given high doses over a lifetime in an attempt to induce cancer and, using conservative assumptions, results are extrapolated to very low doses that represent likely human exposure. Some pesticides are classified as probable or possible *human carcinogens by EPA based on high dose animal studies, but are allowed to be registered because estimated human exposure is low. In addition, analyses of the time pattern of cancers in the USA do not indicate that the increased manufacture and use of pesticides during the last few decades have resulted in an epidemic increase in cancer in the general population. There is much stronger evidence that other risk factors, such as diet, lifestyle, smoking, radon, or asbestos, are responsible for cancer in the general population. However, because all cancer risk factors are not known, exposure to pesticides that have been shown to cause cancer in laboratory animals should be minimized.*

Student Activity 13

1. Give three examples of how a pesticide could adversely impact an ecosystem.

   Loss of fish and aquatic biota in a stream caused by direct (pesticide impact on organism) and indirect (pesticide impact and organisms that are interrelated and dependent on each other).

   Loss of numbers of species (especially beneficial species) from an orchard that was sprayed with an insecticide. Other plants within the ecosystem may be deprived of important pollinators or other insects, which are natural predators, may be disrupted or eliminated.

   Decline and shift in age and survival of eagle and hawk populations due to the effects of DDT in their food supply on egg survival.

2. Give three examples of how a pesticide could adversely impact a community.

   Pesticide eliminating a species that was critical to preventing a weed infestation or a less desirable fish species from dominating the community.

   Pesticide disrupting the dynamics of the food webs in a community by destroying existing dietary linkages between species.

   Pesticide decreases the numbers and variety of species present in a community.

3. Give three examples of how a pesticide could adversely impact an individual within a species.

   An individual insect is sprayed directly with a pesticide resulting in death.

   A farm worker unintentionally inhales a large amount of a volatile pesticide resulting in sickness.

   A bird drinks from a puddle containing a large concentration of a pesticide resulting in sickness. (Some examples are given in Module 2, Part B, Section 4)

4. Define the following terms and give an example of each:

   Bioaccumulation—*is an increase in the concentration of a chemical in a biological organism over time compared to the chemical's concentration in the environment. Example: Lead accumulation in humans over time.*

   Bioconcentration—*is the specific bioaccumulation process by which the concentration of a chemical in an organism becomes higher than its concentration in the air or water around it. Example: The concentration of* *nitrates in the soil is 10 ppm but, the concentration of nitrate in rhubarb leaves is much higher. Bioaccumulation is occurring in the rhubarb.*

Biomagnification—*is the accumulation of a chemical in an organism at higher levels than are found in its food. It occurs when chemicals become more and more concentrated as they move through the food chain. Example: Higher concentrations of DDT in birds that eat worms than in worms that are directly exposed to DDT*

5. Define the following terms.

   Hydrophilic—*means water-loving. Hydrophilic chemicals are water-soluble.*

   Lipophilic—*means fat loving. Lipophilic chemicals are fat-soluble and usually water insoluble.*

   Elimination—*refers to the metabolic breakdown or excretion of a chemical from an organism. Lipophilic compounds tend to be more slowly eliminated from the body and thus have a greater potential to accumulate. However, metabolic reactions may change some lipophilic compounds into hydrophilic compounds that are readily excreted.*

6. Define Ecosystem, Population and Community.

   An ecosystem is the physical environment along with organisms (biota) inhabiting that space.

   Populations are simply a collection of individuals of the same species within an area or region.

   Communities are made up of different populations of interacting plants, animals, and micro-organisms also within some defined geographic area.

7. Describe the concept of Dynamic Equilibrium.

   In living organisms, an environmental chemical will at first move more rapidly than it is stored, degraded, and excreted. With constant exposure, the concentration inside the organism gradually increases. Eventually, the concentration of the chemical inside the organism will reach equilibrium with the concentration of the chemical outside the organism, and the amount of the chemical entering the organism will be the same as the amount leaving.

8. Describe the differences among microcosm, mesocosm, and field trials.

   A microcosm is a laboratory model ecosystem.

   A mesocosm is an intermediate sized system that may be an engineered field system, open-top plant chamber or field pen.

   A field trial gathers information about the effects of chemicals on processes and species in complex situations that reflect the real world.

Module 3—The Science of Nutrient and Pest Management

Overall Learning Objective

Once completing this module, participants will be able to describe the important chemical, biological, and physical processes underlying the science of nutrient and pest management.

Introduction: Systems, Ecosystems and Agro-Ecosystems

Engineers define "system" as any set of interacting objects that operate within some arbitrarily defined boundary. As an example, the interacting set of electrical components that convert electromagnetic waves into visual images with accompanying sound is the system we know as television. Systems can be mechanical, they can be biological, they even can be conceptual or virtual, but all systems always have emergent properties. This means systems have characteristics that cannot be determined simply by examining their individual components in isolation from each other. No one could examine the individual components that comprise a television and predict its emergent properties—mind—numbing shows that pass for entertainment! Systems always are more than the simple sum of their individual pieces.

Biologists too view the world as interconnected systems. An especially useful distinction is the ecosystem concept. An ecosystem formally is defined as a biological community—a grouping of living plants, animals, and microbes—which together interact with their physical environment. A pond, a forest, and a prairie—all are ecosystems. As a system, ecosystems have emergent properties that cannot be predicted from their individual components. Chief among these are that natural ecosystems are self-organizing: they tend to be continuous in space and time because the living and non-living components interact in complex ways that maintain and recycle nutrients and energy within the system boundaries or that internally regulate populations levels of the living organisms between certain upper and lower limits.

This ecosystem concept is particularly critical to practitioners of nutrient and pest management in agricultural field and row crops. Whereas natural ecosystems reinvest productivity into self-organization, agricultural ecosystems, or agroecosystems, deliberately are manipulated to concentrate nutrients and energy into food and fiber harvested for human use (and to make the producer an economic profit). Perhaps better stated, agriculture exploits ecological processes and so we humans must assume responsibility for any natural population regulation or nutrient recycling processes that have been sacrificed. The results can be unexpected and undesirable—insect pest outbreaks that develop when predators or parasites that serve as population brakes on herbivorous insects in natural systems inadvertently are eliminated or leaching of mobile nutrients because fertilizers are inappropriately applied. This is the basic lesson—nutrient and pest management decisions in agroecosystems cannot be made in isolation from each other. The questions cannot be which is the best pesticide or how much fertilizer should be applied. Rather, the better perspective is to ask questions like these: How do organisms interact with each other in my system? Have processes that normally contribute to long-term sustainability in natural ecosystems been designed out of my system? What do I know about the interconnectedness of the living and non-living components of my system?

Nutrients and pesticides are two important environmental pollutants often associated with agricultural operations. Understanding their function within agricultural ecosystems and their mechanisms of movement into and through the environment is essential to conservation planning (see Module 5). This module covers some of the basic scientific principals behind nutrient and pest management considerations in conservation planning. It *is not* a comprehensive study, however. For more detailed information you may want to consult some of the references listed at the end of the module.

This module is separated into eight major parts. *Parts A–F relate specifically to Nutrient Management*, and *Parts G & H relate specifically to Pest Management*. Although they are presented separately, many of the concepts are the same. As you read through each part consider the similarities between pest and nutrient.

Module 3, Part A, Section 1— General Principles of Plant Growth

Supporting Objective

- Define Liebig's Law of the Minimum.
- List and describe the five stages of plant growth

Introduction: Essential Components for Plant Growth

What are plants and how do they grow? The vast majority of plants are chlorophyll bearing organisms. They differ from animals in that they lack locomotive movement or obvious nervous or sensory organs, but they contain cell walls. Plants have the ability to convert solar energy into chemical energy through a process called photosynthesis. Most plants of agronomic importance are terrestrial plants. To grow they need sunlight, water, carbon dioxide (CO_2), oxygen (O_2), mineral nutrients and physical support. Plants anchor themselves to the soil with their roots. These roots absorb water and mineral nutrients from the soil. Oxygen in the soil is necessary for this absorption to occur. Plants absorb CO_2, and light energy through the leaves and stems.

If the components for plant growth are available in ample amounts, a plant will grow to its maximum genetic potential. However, this is seldom if ever the case. The Principle of Limiting Factors states that the level of crop production can be no greater than that allowed by the most limiting of the essential plant growth factors.

The requirement for mineral nutrients from the soil to sustain plant growth was established by a German chemist named Julius von Liebig in the 1840s. Liebig later proposed the Law of the Minimum, which states that, "by the deficiency or absence of one necessary constituent, all others being present, the soil is rendered barren for all those crops to the life of which that one constituent is indespensible." In other words, even though nitrogen is the nutrient most often needed by agronomic crops, *all of the essential mineral nutrients are essential. If even one of them is missing from a soil, the plant cannot grow*. By the Principle of Limiting Factors, if one of the essential mineral nutrients is limiting from a plant's growth medium, the plant cannot grow to its genetic capacity. The concept of limiting nutrients is often illustrated with a leaking barrel of water. The level of water in the barrel represents the level of crop production. The limiting factor is represented by the shortest stave in the barrel. If any factor is limiting, such as a plant nutrient, then the level of crop production is reduced to that level of nutrients. If this factor is increased to adequate levels, another factor may become limiting.

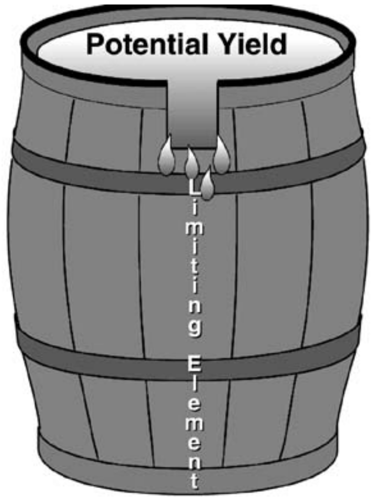


Figure 3.1 Liebig's Law of Minimum.

Stress factors impacting plant growth may include:

- mechanical harvesting or grazing
- a surplus or lack of soil moisture
- nutrient deficiency
- temperature extremes
- chemical and physical conditions in the soil.

Stress can also be present when multiple species in a plant community compete for the such finite resources as light, moisture, space or nutrients. These competing species are often considered to be "pest". When temperature, nutrients or moisture are not adequate for plant development, the plant is stressed and the rates of photosynthesis and biomass production are decreased.

Plants, browsing, or grazing animals, insects, fungi, bacteria, and other groups of organisms that have evolved together have found ways to live together. Different plant species grow in different microenvironments, so they each find a complimentary niche to exploit in the system. Insects and other organisms compete with one another, preventing any one species from taking over an area.

In agricultural ecosystems these mechanisms are artificially altered. Instead of a mixture of organisms occupying different niches in an area, the crops are generally grown in monocultures. If a pest becomes established, it may not face the normal competition from other organisms, because their niches are not present. In monocultures, a pest may be able to move more easily from one host plant to another and ultimately cause severe damage to the crop.

Healthy, growing plants are able to compete with pests for limited space, nutrients, air, and water. Even though some pests may be present in a field (a scattering of weeds, a few chewing insects, some disease), the healthy plant is able to compete and not be seriously damaged. Good plant nutrition is a complement of good pest management.

Plant Growth Stages

Plants go through 5 major stages of growth during their life cycle. These stages are:

- Germination
- Seedling development
- Vegetative growth
- Flowering/fruiting
- Senescence

During different growth stages plants have different requirements, and they absorb water, nutrients, and sometimes pesticides at different rates.

Germination

Seeds imbibe water from the soil environment surrounding the seed, swelling from 10 to 20 percent moisture content to 40 to 70 percent moisture content as germination begins. The germinating seedling initially derives its energy from carbohydrates and proteins stored in the seed. Once this energy has been used up, the seedling must begin to produce its own food through photosynthesis. The young seedling develops a root radical and some leaf chlorophyll to trap light energy from the sun. Sufficient water must be present for seeds to imbibe, but water and nutrient absorption during germination are negligible. Some herbicides are designed to be absorbed by germinating weed seedlings.

Seedling development

As seedlings develop, leaf tissue increases and roots expand. Carbohydrates are produced as the seedling begins the process of photosynthesis. Water and mineral nutrient usage begins to increase as roots develop and explore more soil volume, but the total nutrient and water requirements are still relatively low.

Vegetative development

The most rapid rate of plant nutrient and water uptake occur during the vegetative development stage. Roots, shoots, and leaves expand to their maximum, and water and nutrients must be continuously supplied to meet the needs of the rapidly growing plant. Certain herbicides and systemic pesticides are most effective during this stage of growth, because they are absorbed in greater amounts.

Flowering/Fruiting

For most plants flowering begins during vegetative growth, but it continues after vegetative growth has begun to slow. During flowering and fruiting, water and nutrient uptake rates do not increase, but continue at a high level. Nutrients and carbohydrates are being redistributed within the plant from other plant parts to the fruiting organs.

Senescence

During senescence plant height and canopy decrease. Both nutrient and water uptake decrease. Some plant parts die and begin to decompose, releasing nutrients back into the soil. These nutrients can then become available for new plants to use, and the nutrient cycle continues.

Crops take up nutrients at different rates during different stages of growth. During early stages of crop growth, when root systems are small, plants are unable to capture large quantities of nutrients. During later stages of crop growth, nutrient uptake slows as nutrients are recycled within the plant. In general, nutrient applications during early and late stages of plant growth should be minimal. During vegetative and flowering/fruiting plant nutrient requirements are greatest and whatever the soil reserve is unable to supply must be compensated by sufficient nutrient applications. When considering nutrient applications relative to plant growth stage, it is important to also time nutrient applications to meet critical plant growth stage requirements. This allows optimum plant uptake and use. It also reduces the amount of nutrients that are available for leaching or runoff losses.

Plant Nutrient Uptake

Nutrients in the soil become available to plants in two ways: by the movement of soluble nutrients through the soil to plant roots, and by plant roots as they grow and extend, coming into direct contact with nutrients in the soil.

Two mechanisms are largely responsible for the movement of soluble nutrients through the soil to plant roots. They are *mass flow* and *diffusion*. Mass flow is the movement of nutrients with soil water. When water flow is caused by root absorptive forces and in the direction of the roots the nutrients follow along. If the water is moving vertically, as it does in capillary flow and leaching, the uptake by the plant depends on the root intercepting the nutrient as it travels the vertical path. Mobile nutrients such as nitrogen in the nitrate form, move to the root predominantly by mass flow.

Diffusion takes place in the direction of a decreasing concentration gradient. Such gradients are generated when roots absorb nutrients and transport the ion up the plant. The concentration near the root is diminished compared to the concentration in the soil solution so nutrient ions move in the direction of the root. Non-mobile nutrients such as phosphorus rely mostly on diffusion to bring the nutrient to the root surface. New root growth is especially important for P uptake because it continuously exposes roots to a fresh supply of soil P.

Mass flow may carry nutrients to the outside of the root where they can be readily absorbed. This process decreases the nutrient concentration at the root surface. Diffusion then carries the nutrients to the root in an attempt to equalize the concentration.

There are also two mechanisms involved in the direct contact process. The first is *contact exchange* of ions moving from the root with ions on the soil particle. The principal of contact exchange is effective when the root and soil are in direct contact.

The other mechanism is *root growth and interception*. As roots grow and move through the soil they intercept plant nutrients that have been adsorbed to soil particles and organic matter. Providing a soil condition conducive to root growth is important for plant nutrient uptake.

Student Activity 1

1. Describe the difference between a natural ecosystem and an agro-ecosystem?

2. Define Liebig's Law of the Minimum.

3. List six stress factors impacting plant growth.

4. How do these stress factors influence plant growth?

5. List and describe the five growth stages as they relate to essential growth requirements of water and nutrients.

____

____

____

____

____

____

6. The two crop stages when nutrient uptake is at its peak are

_________________ and _________________ .

Module 3, Part B—Role of Soils in Nutrient and Pest Management

Supporting Objective

- Describe soil properties that have a role in nutrient and pest management.

Introduction

In Module 2, soil properties that affect movement of nutrients and pesticides in the environment were discussed. This part of Module 3 will review several of these same soil properties and their role in nutrient and pest management.

Soil Texture

Texture describes how coarse or fine a soil is. The coarsest soil particles are sand. Clay particles are the finest, and silt is intermediate in size (figure 3.2). Soil that contains a large amount of sand feels gritty, while silty soil feels smooth. Clay soil feels hard when dry, and sticky and plastic (moldable) when moist. Sand particles resemble small rocks, and silt particles are like even smaller rocks. Silt and sand particles are not very active chemically, and they contribute little to the ability of the soil to adsorb (bind) nutrients or contaminants. Most clay particles are structurally and chemically quite different from sand and silt. Clay is responsible for much of the chemical activity and water-holding capacity in soil. A soil typically contains materials of all three particle sizes. A soil scientist classifies the soil horizons into soil texture, based on the proportion of all three soil particle sizes (sand, silt and clay). The soil textural triangle (figure 3.3) illustrates soil types based on the proportion of the three soil particle sizes in a given example.

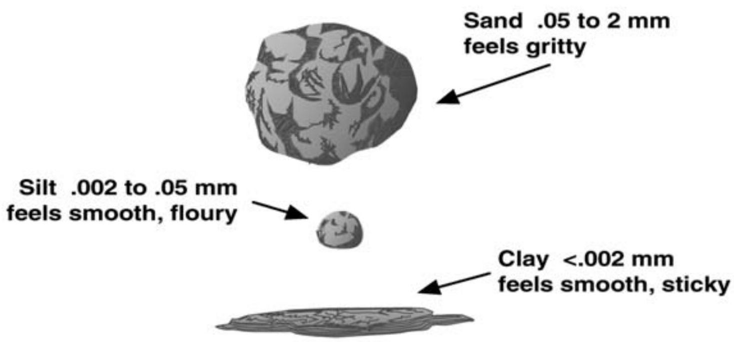


Figure 3.2 Sand, silt, and clay particles (magnification not proportional).

Texture influences the porosity as well as the chemical activity of a soil. Sandy soils contain mostly large pores. They hold little water, and excess water drains through them easily. The combination of low chemical activity and rapid water movement through sandy soils makes them more vulnerable to leaching of contaminants than finer textured soils. Soils which are mostly silt or clay have predominantly small pores that do not drain readily. These are referred to as fine-textured soils. The risk of ground water contamination is much less in these soils. They must be managed carefully, however, to prevent runoff from carrying sediment and other materials to surface water. Some soils have macropores formed by roots and soil organisms. These larger pores can provide preferential flow pathways allowing rapid movement of water and chemicals through the soil profile.

A *loam* is a soil that contains a roughly balanced mixture of sand, silt, and clay. Loamy soils have more chemical activity than sandy soils, and hold more water. They offer more protection to ground water. Also, water tends to infiltrate through them more readily than through fine-textured soils, so the risk of runoff is less.

Soil Structure

Individual particles of sand, silt, and clay tend to become clustered together in soil. This clustering of particles into aggregates gives structure to the soil. The granules of soil that we see hanging to grass roots when we dig into sod are a type of soil structure.

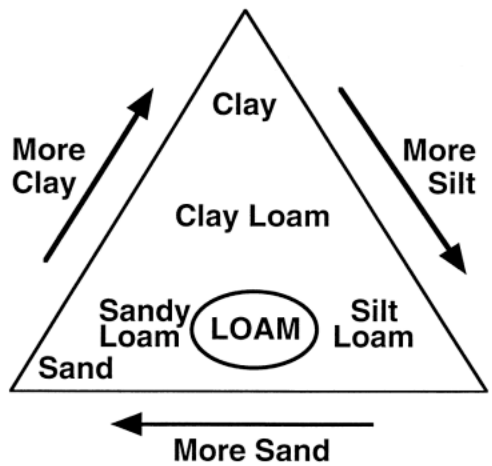


Figure 3.3 Simplified version of the soil textural classes triangle.

Structure is important because it determines the number and size of pores in a soil. In fine-textured soil, structure is essential to movement of water and air into and through the soil (infiltration and percolation). Good structure may lead to the deeper leaching of some contaminants, resulting in an increased risk to ground water. In general, however, good soil structure is desirable because it increases soil aeration, improves productivity, and reduces runoff.

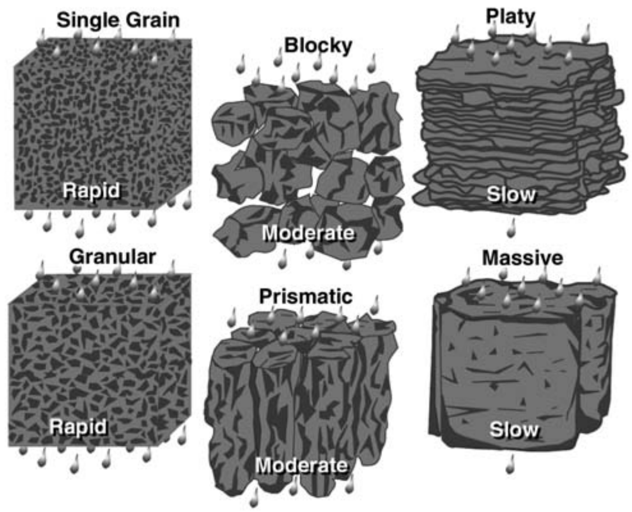


Figure 3.4 Soil structure and water movement.

Organic Matter

Organic matter is the soil fraction formed from the decomposed remains of plants, animals, and micro-organisms. Well-decomposed organic matter is called humus. Humus gives topsoil its dark color. Organic matter plays an important role in forming structure in soils by helping to bind soil particles into aggregates. Organic matter also resembles clay in that it is chemically active. On a weight basis organic matter has more negative charges than clay. (See discussion later on "Soil Exchange Capacity"). Organic matter is especially effective at binding many pesticides, and plays a key role in keeping pesticides out of ground water. Increasing the amount of organic matter in a soil can reduce the risk of pesticide leaching.

Subsurface Color and High Water Tables

Soil that has a high water table often has gray or mottled colors in the subsoil, while well-drained soil is more uniform in color. In a well-drained soil, enough oxygen is present in the soil pores to keep most biological and chemical processes aerobic. Under aerobic soil conditions, nitrification (nitrogen transformation from the ammonium to the nitrate form) continues. The process of denitrification is most likely to occur in poorly drained and water saturated soil. When a high water table exists, oxygen is limited. Under these conditions, certain soil microbes can substitute the nitrate ion for oxygen as an electron acceptor during respiration facilitating denitrification ($NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O\uparrow \rightarrow N_2\uparrow$). Soil phosphorus is also affected by the water status in the soil pores. When soil pores are filled with water, a reduced condition which favors the desorption of phosphorus from iron-bound compounds is created. High water tables and subsoil mottling are indications that at some time during the year there is a direct connection of the subsoil layer with the ground water. Therefore, contaminants can move from this soil layer toward the ground water or be a part of return flow to surface water.

Soil Reaction

When we talk about soil reaction we are talking about the soil pH. Soil *pH* is a measure of hydrogen ion concentration and thus acidity. A pH of 7 is neutral. As pH goes down acidity goes up. A pH below 7 is called acidic and a pH above 7 is called alkaline or basic. The pH of the soil is one of the most important soil properties because pH has a direct effect on nutrient availability (figure 3.5). The pH in most soil is generally in the range of 4 to 9. Soil pH is related to the percentage of bases adsorbed to the cation exchange capacity sites. The availability or solubility of some plant nutrients decreases with an increase of soil pH. Iron and manganese are two examples. Iron and manganese are commonly deficient in calcareous (high pH) soils. Molybdenum is the exception, with its availability greater at pH above 7.0. Other essential plant nutrients are most readily available in soil that has a pH between 5.5 and 7.5.

The soil pH also affects the activity of microorganisms. Soil microbe responsible for converting ammonium nitrogen to nitrate nitrogen is most active in the pH range of 5.5 to 7.5. Decomposing bacteria and fungi also work best in this range. High soil acidity inhibits earthworms in the soil. Soil pH also affects the activity of pesticides. In general pesticide activity decreases with lower pH.

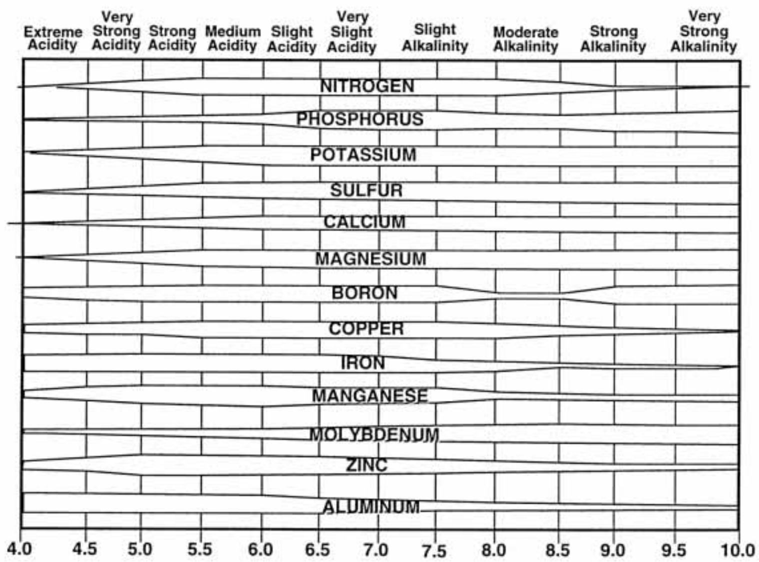


Figure 3.5 How soil pH affects availability of plant nutrients and aluminum.

Cation Exchange Capacity

Most soil particles are negatively charged. The amount of negative charge on the soil is called the *cation exchange capacity (CEC).* The CEC of a soil is a relatively stable soil property and is closely related to the percent clay and organic matter in the soil. This negative charge is balanced by positively charged ions, called cations (figure 3.6). Many of these cations are important plant nutrients such as: calcium, magnesium, potassium, and ammonium. Some ag chemicals are also cations and can be held by the negative charge on the soil particles. Cations on the CEC are held tightly enough so that they will not leach but yet they easily become available to plants by exchange with other cations in the soil solution. The relative proportions of the different cations on the CEC can be adjusted by liming and fertilization.

Soil Depth

To protect ground water, we need to know the depth of soil that provides contaminant removal. Once a contaminant leaches below the root zone, the soil microbial activity is much lower. Below the root zone, the contaminant tends to persist much longer, increasing the threat to ground water. Sometimes a high water table limits soil rooting depth. In other soils, we encounter a clayey or compacted layer at a shallow depth. Often, little water can move through this layer, which helps protect the underlying ground water. But, surface water may be at risk if contaminated water moves across this layer to a spring, stream, or lake. This is called *return flow* because ground water returns to the earth's surface. When shallow soils are underlain by loose sand or gravel, very little binding or microbial breakdown of contaminants occurs in the sand or gravel. In addition, leaching is rapid, making ground water vulnerable to pollution.

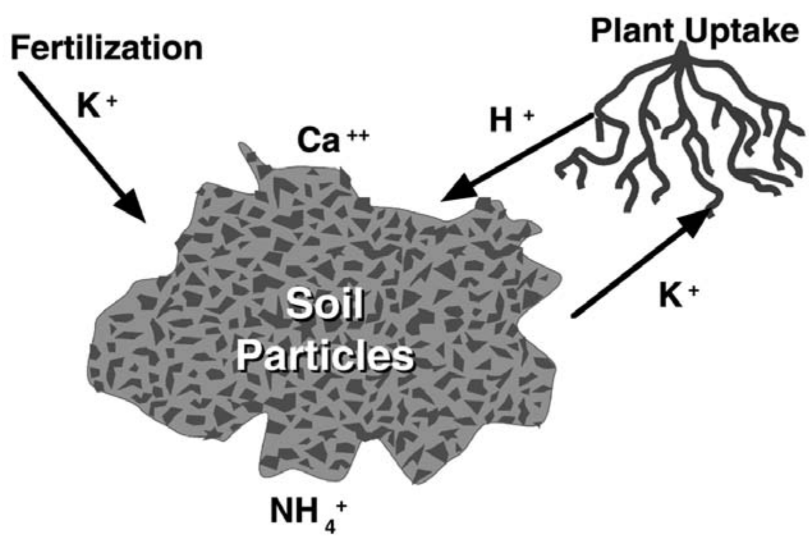


Figure 3.6 Soil exchange relationships.

Soil Variability

Sometimes soil properties vary considerably over short distances. Soil at the base of a hill is usually much wetter than soil near the crest, because water runs down slope and collects at the bottom. Soil near the crest of the hill also tends to be shallower than that at the base because of erosion. Some variability is due to changes in subsurface features that are not visible from the soil surface. Soil texture and depth can vary considerably over a field that looks uniform at the surface. A key to ground and surface water protection is identifying areas that have more vulnerable soils, and managing them properly. Soil surveys are a good source of information about soil variability.

Student Activity 2

Based on material covered in Module 2 and this module, rank the following soil textures in order of magnitude of the following soil properties (1 being highest). The clay content characteristic has been completed for you.

	Runoff	Leaching	Clay Content	CEC	Organic Matter
Sand			**3**		
Loam			**2**		
clay			**1**		

Module 3, Part C—Essential Plant Nutrients

Supporting Objectives

- List the three criteria needed to define a nutrient as "essential."
- List the 16 essential plant nutrients.
- For three of the essential plant nutrients, describe their role in plant metabolism and identify distinctive deficiency symptoms.
- List two examples of toxic effects of excess nutrients on plants or animals.

Introduction

The essential nutrients required by higher plants are exclusively inorganic chemicals. For an element to be considered an essential nutrient it must meet these three criteria:

- A deficiency of the element makes it impossible for the plant to complete its life cycle;
- The deficiency is specific for the element; and
- The element is directly involved in the nutrition of the plant as a cell component, in the metabolism, or enzyme system.

The plant nutrients that crops take up during the growing season may come from many sources, including soil reserves, nutrients added to the soil through fertilizer or manure, and crop residue. Some nutrients such as nitrogen, phosphorus, and potassium, are required in large quantities (*macronutrients*), while others are required in very small quantities (*micronutrients*). Nutrients such as sulfur, calcium, and magnesium (secondary nutrients) are required in intermediate quantities. Examples of each nutrient are given in Table 3.1, along with their abbreviations and the nutrient form taken up by plants. They are also highlighted in the Periodic Table (Figure 3.7). In addition to essential nutrients, carbon, hydrogen, and oxygen are also essential to plant growth. These are obtained primarily from the air and water. Manure can also represent a significant source of carbon and essential plant nutrients.

Table 3.1 Essential plant nutrients, their chemical symbols (in parentheses) and form taken up by plants [in brackets]

Macronutrients	Secondary Nutrients	Micronutrients
Nitrogen (N) [NH_4^+, NO_3^-] Phosphorus (P) [$H_2PO_4^-$, HPO_4^{-2}] Potassium (K) [K^+]	Sulfur (S) [SO_4^{-2}] Magnesium (Mg) [Mg^{+2}] Calcium (Ca) [Ca^{+2}]	Iron (Fe) [Fe_{+2}, Fe_{+3}} Manganese (Mn) [Mn_{+2}] Boron (B) [BO_3^{-3}, $B_4O_7^{-2}$] Chlorine (Cl) [Cl^-] Zinc (Zn) [Zn^{+2}] Copper (Cu) [Cu^{+2}, Cu^+] Molybdenum (Mo) [MoO_4^{-2}]

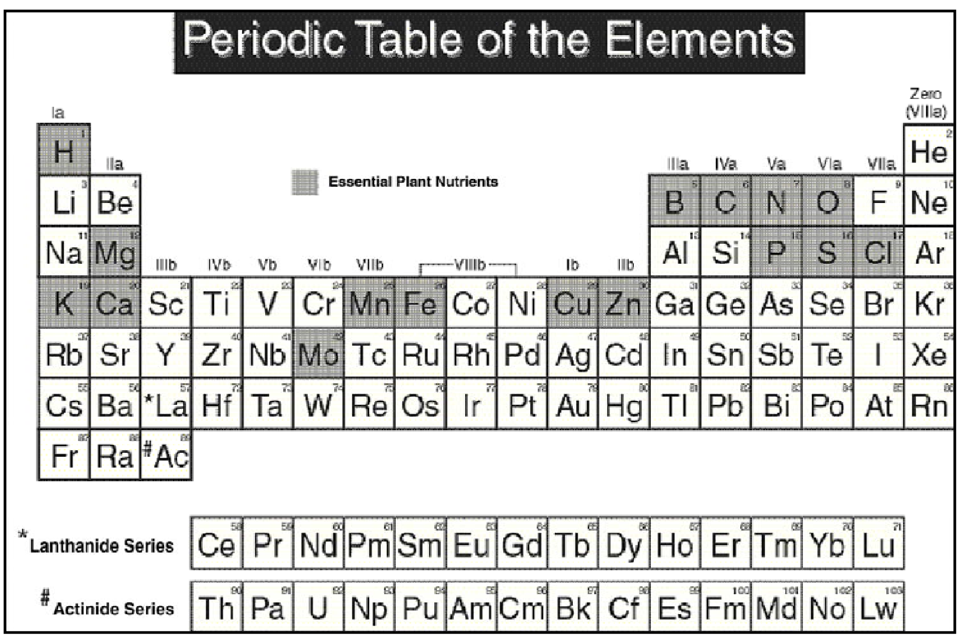


Figure 3.7 Periodic Table

A phrase used to remember the 16 essential plant nutrients goes like this:

C. HOPKIN'S CaFe, **Mig**hty fine **CuZ**i**n**e, **Mo**tley **M**a**n**ager, **B**urley **Cl**erk

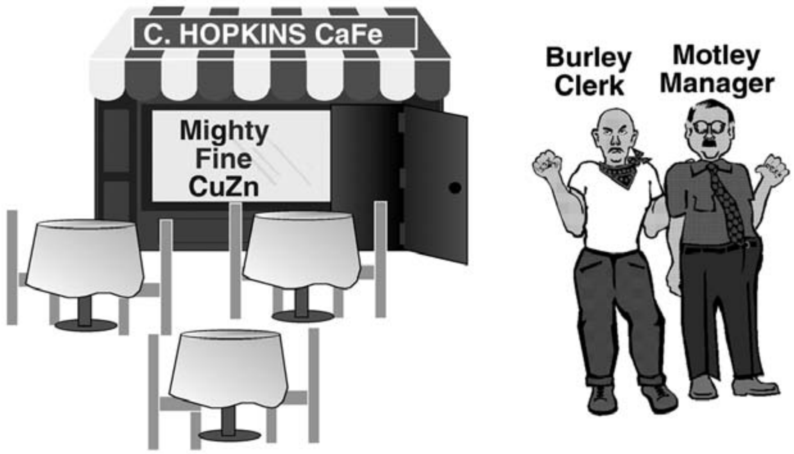


Figure 3.8 Essential plant nutrients.

The role and deficiency symptoms of the essential nutrients are to be discussed. The symptoms are rarely clear cut, so it is important to use both soil and plant analyses in trying to diagnose a suspected nutritional problem.

Macronutrients

The macronutrients, nitrogen, phosphorus and potassium, are needed in the greatest quantity by plants and are most often limiting to plant growth. Adding macronutrients to the soil is the most common means of alleviating crop nutrient deficiency.

Nitrogen (N) is a critical component of proteins, which control the metabolic processes required for plant growth. It is also an integral part of the chlorophyll molecule and thus plays a key role in photosynthesis. An adequate supply of nitrogen is associated with vigorous vegetative growth and a plant's dark green color.

Nitrogen deficiency is characterized by reduced plant growth and a pale green or yellow color. This yellowing generally begins at the tip of the leaf and goes down the middle of the leaf. If the deficiency is severe, the affected area eventually turns brown and dies. Because nitrogen is mobile in the plant, older leaves show the first symptoms of nitrogen deficiency.

Phosphorus (P) is a critical component of nucleic acids, so it plays a vital role in plant reproduction, of which grain production is an important result. Considered essential to seed formation, this mineral is often found in large quantities in seed and fruit. Phosphorus is essential to the biological energy transfer processes, which are so vital to life and growth. Adequate phosphorus is characterized by improved crop quality, greater straw strength, increased root growth, and earlier crop maturity. Phosphorus deficiency is indicated by reduced plant growth, delayed maturity, and small fruit set. These symptoms may be accompanied by a purple coloring, particularly in young plants. This purpling is often seen in relationship to cold wet soils. If soil phosphorus levels are adequate this is usually temporary and does not affect yields. Like nitrogen, phosphorus is mobile in the plant; therefore, any deficiency symptoms show up on the older leaves first.

Potassium (K) is not an integral part of any major plant component, but it does play a key role in a vast array of physiological processes vital to plant growth, from protein synthesis to maintenance of plant water balance. Potassium deficiency is characterized by reduced plant growth and a yellowing and/or burning of leaf edges. Since potassium is mobile in the plant, the symptoms appear on the older leaves first. Another indication of potassium deficiency is reduced straw or stalk strength, which results in lodging problems, reduced disease resistance, and reduced winter hardiness of perennial or winter annual crops.

Secondary Nutrients

The secondary nutrients, calcium, magnesium, and sulfur perform a variety of roles in plants.

Calcium (Ca) is an integral part of plant cell walls. Calcium deficiency is rare among agronomic crops. However, deficiencies can occur in crops such as potatoes, tree fruits, tomatoes, and peanuts. Calcium is non-mobile in plants, young tissue is affected first by deficiency. Deficiency symptoms can include death of the growing points, weakened stems, and fruit breakdown at the blossom end. When a soil is properly limed to maintain an optimum pH level, the calcium is usually adequate for agronomic crops.

Magnesium (Mg), a key component of chlorophyll, plays a critical role in photosynthesis. Magnesium deficiency is characterized by yellowish to white stripes between the leaf veins. Magnesium deficiency occurs on older or all leaves. Magnesium may be supplied by limestone (dolomite) that contains this nutrient.

Sulfur (S) is a common component of proteins and vitamins. Sulfur-deficient plants have a general yellowing and are spindly. Symptoms of sulfur deficiency are similar to those of mild nitrogen deficiency, except that they appear sooner in new growth than in old growth, because sulfur is not mobile in the plant. In some regions sulfur deficiency is not common because rainfall supplies significant amounts of sulfur. Cropland receiving manure applications seldom have sulfur deficiencies because sulfur is efficiently recycled in manure. Sulfur additions may be needed where soil deficiencies occur and to maintain nitrogen to sulfur ratios in some crops.

Micronutrients

Micronutrients are important in facilitating many of the processes important for plant growth. Micronutrient deficiencies are not as common as macronutrient deficiencies in the following situations: (1) heavier, loamy textured soils help to maintain adequate levels of micronutrients (sandy textured soils, by contrast, often show micronutrient deficiencies); (2) slightly acid soil helps maintain micronutrient solubility; and (3) cropland which gets periodic applications of manure, a good source of micronutrients.

Iron (Fe) is required for the formation of chlorophyll in plant cells. Deficiency shows up as a light pale leaf color with veins remaining green, first appearing on younger leaves; but severe deficiency may result in the entire plant showing such symptoms. Iron deficiency can easily be mistaken for a deficiency of manganese (Mn) and also occurs on high pH soils. The interveinal chlorosis caused by Fe deficiency is often whiter than Mn deficiency symptoms. Symptoms of Fe deficiency on wheat and other small grains appear as chlorosis on older leaves.

Manganese (Mn) serves as an activator for enzymes in growth processes. It assists iron in chlorophyll formation. Symptoms first appear in younger leaves, with yellowing between the veins, and sometimes brownish-black specks. The deficiency is sometimes confused with Mg; however, it usually appears first on the newer (upper) leaves while Mg occurs on older or all leaves. Best way to distinguish is to check soil properties. Manganese deficiency is more likely if the soil pH is higher and in soils high in organic matter during cool spring months when soils are waterlogged. Liming history is important because it helps determine the effect on soil pH.

Boron (B) functions in plant cell division and early growth. Boron deficiency generally stunts plant growth. The growing point and leaves are affected first. In crops, the symptoms of boron deficiency are well defined and quite specific, such as crooked and cracked stem in celery, corky core in apples, black heart in beets, hollow heart in peanuts and ringed or banded leaf petioles in cotton. Alfalfa is especially susceptible to boron deficiency, which is shown by rosetting, yellow top, and death of the terminal bud. Boron deficiency is often associated with drought conditions. Boron deficiency can be confused with K deficiency or leafhopper damage.

Chlorine (Cl) is taken up by the plant as the chloride ion. Chloride is required in the photosynthetic reaction in the plant. Deficiency symptoms on row crops and small grains are not common, but are frequently observed on oil palm and coconut. Deficient palms show high incidence of leaf diseases, droopy leaves and signs of moisture stress during mid-day, frond breakage, cracking of stems and stem-bleeding, and greatly reduced numbers of fruits or nuts. Chloride deficient small grains show higher incidence of moisture stress, greater incidence of root, stem, and leaf diseases and reduced yields. Soil tests can help diagnose chloride deficiency and predict needs for supplemental application. Tissue analyses can also help determine adequacy of chloride in the soil.

Zinc (Zn) is an essential constituent of several important enzyme systems in plants. Deficiency symptoms appear first on the younger leaves and other plant parts. In corn, the deficiency is sometimes called "white bud" because the new growth may turn white or light yellow while the leaves show bleached bands, or a striping parallel to the mid-rib. Other symptoms include bronzing of rice, rosette of pecans, "little leaf" of fruit trees, brown spots with yellowing leaf tissues in legumes, and small, pointed, yellow mottled leaves in citrus. Dry beans are very susceptible to Zn deficiency being severely stunted with chlorosis of new leaves.

Copper (Cu) is an activator of several enzymes in plants. Organic soils are most likely to be copper deficient, because copper is adsorbed in unavailable forms in these soils. Common symptoms of copper deficiency include dieback in citrus and blasting of onions and vegetable crops. When vegetable crops show copper deficiency, the younger leaves lose turgor and develop a bluish-green shade before becoming chlorotic and curling. The plants may fail to flower, and there is often excessive leaf shedding. Small grains fail to develop heads when copper is deficient.

Molybdenum (Mo) is required by plants to transform nitrate nitrogen into amino acids. Molybdenum deficiency symptoms show up as general yellowing of the plant with new growth areas stunted and starting to die back. In fact, this deficiency can cause N deficiency in legumes. Soil bacteria in legume root nodules must have molybdenum to help fix N from the atmosphere. A soil test helps diagnose the problem because molybdenum becomes more available as the soil pH increases. So liming may often correct the deficiency. This is not an easy deficiency to identify just from visual symptoms without a soil test or plant analysis and a history of treatment.

Nutrient Toxicities

Module 2 covered the impacts of excess nutrients on both target and non-target organisms. Excess nutrients can be toxic to both plants that absorb them and animals that consume the plants. Excess nutrients also have the potential to leave the site to which they were added, and cause offsite environmental problems. Figure 3.5 illustrates how pH affects nutrient availability. The availability for plant uptake of heavy metals and micronutrients increases as the soil pH decreases. The one exception is molybdenum. For most agricultural crops a soil reaction pH of 6.0–7.0 is optimum. As the pH decreases below 6.0, macronutrient (N, P, K, Ca, Mg, and S) deficiencies can occur, while at the same time micronutrient and heavy metal uptake increases. Animals, including humans, can also develop serious health problems if they ingest sufficient quantities of plants contaminated with one or more trace elements. The issue of trace element availability is a major concern when organic waste materials or biosolids, such as municipal sludges, are applied to agricultural land.

Plant growth is affected by excess amounts of copper and zinc in the soil. Both are toxic to plants at high soil concentrations and are both mutually competitive as well as competitive with other micronutrients at the root uptake sites. Excessive concentrations of either element in the available form in the soil induces a plant deficiency for other micronutrient elements.

Grass tetany (hypomagnesimia) is a serious disorder in lactating ruminants caused by low magnesium content in forage, especially grasses. Early season application of organic material with a high concentration of nitrogen and potassium to low magnesium soil can cause early growth of the grasses to increase uptake of nitrogen and potassium. This may then cause an imbalance of potassium to magnesium in the forage. The unbalanced plant nutrients cause impacts to the animals that graze on them. Legume crops are better balanced and have a greater concentration of magnesium. Organic material or fertilizer with a high concentration of nitrogen and potassium should not be applied to forages early in the season. These applications should be avoided until the slower growing legumes have an opportunity to flourish or grazing should be delayed until such time.

Although small amounts of boron are necessary for plant growth an excess of boron at levels only above the sufficiency range can be toxic for certain crops. This toxicity is generally expressed as poor seedling germination, leaf tip yellowing, and early leaf drop. Table 3.2 shows the relative tolerance of different crops to boron.

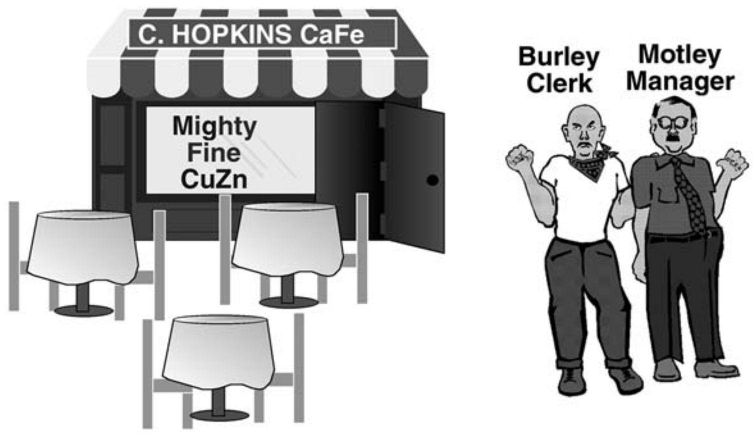
Table 3.2 Relative tolerance of plants to boron.

Relative Tolerance of Plants to Boron

Sensitive	Semi-Tolerant	Tolerant
(0.5 ppm)	*(1 ppm)*	*(2 ppm)*
Lemon	Lima Bean	Carrot
Grapefruit	Sweet Potato	Lettuce
Avocado	Bell Pepper	Cabbage
Orange	Tomato	Turnip
Thornless Blackberry	Pumpkin	Onion
Apricot	Zinnia	Broad Bean
Peach	Oat	
Cherry	Milo	Gladiolus
Persimmon	Corn	Alfalfa
Kadota Fig	Wheat	Garden Beet
Grape (Sultanina and Malaga)	Barley	Mangel
Apple	Olive	Sugar Beet
Pear	Ragged Robin Rose	Palm
Plum	Field Pea	(Phoenix Canariensis)
American Elm	Radish	Date Palm
Navy Bean	Sweet Pea	(Phoenix Dactylifera)
Jerusalem Artichoke	Pima Cotton	Asparagus
Persian (English) Walnut	Acala Cotton	Athel (Tamarix Aphylla)
Black Walnut	Potato	
Pecan	Sunflower (Native)	
(1 ppm)	*(2 ppm)*	*(4 ppm)*

Student Activity 3

1. Find the 16 essential plant nutrients in this figure.



List your answers below:

1. ______________	9. ______________
2. ______________	10. ______________
3. ______________	11. ______________
4. ______________	12. ______________
5. ______________	13. ______________
6. ______________	14. ______________
7. ______________	15. ______________
8. ______________	16. ______________

2. Of these essential nutrients, which are considered the primary or macronutrients?

____

____

____

____

3. For three of the essential plant nutrients, describe their role in plant metabolism and identify distinctive deficiency symptoms.

____

____

____

____

4. As the soil pH decreases, availability of most micronutrients ____________________ (increases or decreases). The exception to this relationship is molybdenum.

5. Define grass tetany and describe the condition that can cause it to occur.

____

____

____

____

Module 3, Part D—Nutrient Cycles

Supporting Objectives

- Identify major sources and sinks of nitrogen (N), phosphorus (P), potassium (K), sulfur (S), describe similarities and differences between each nutrient cycle, and describe possible pathways of loss as a potential pollutant in the environment.
- Describe the role of nutrient cycles in ecosystem health and environmental quality.

Introduction

Photosynthesis uses solar energy, water, and nutrients derived from the soil, to capture CO_2 from the atmosphere and converts it into the organic compounds such as lignin, cellulose, and proteins that make up higher plants. This carbon and other nutrients in plants may be directly returned to the soil as crop residue or indirectly as animal wastes. During decomposition of plant and animal residues by micro-organisms in soil, some of the nutrients are released to the atmosphere and the remainder become part of the soil organic matter. During this process nitrogen (N) and other elements (phosphorus, sulfur, and various micronutrients) that were part of the organic matter are released in inorganic forms. This process is called *mineralization*. These mineral forms are available to higher plants and are also susceptible to loss to the environment. Part of the native soil organic matter is also mineralized. Nutrients may remain in the soil organic matter for times ranging from weeks to centuries. In the process of forming soil organic matter, part of the nutrients are assimilated by micro-organisms and incorporated into the microbial biomass. This process is called *immobilization*. Thus nutrients are continuously cycled through the soil, plant, atmosphere continuum.

In the following material the N, P, K, S and C cycles will be examined separately. It should be noted, however, that these cycles do not operate independently but are linked by biological processes common to each, notably mineralization and immobilization.

Nitrogen

Of the macronutrients, nitrogen has the most complex cycle. Nitrogen makes up almost 80 percent of air, but this nitrogen may be used by the plant only after it is fixed (transformed from N_2 gas to a biologically accessible form), industrially or by certain soil bacteria in association with legumes. The total amount of N in soil is large, typically greater than 4000 pounds per acre in the plow layer. Most of this (approximately 98 percent) is found in organic form. Soil organic N, because of its chemical composition, is resistant to change and also unavailable for uptake by plants. The mineral forms of N, ammonium (NH_4^+) and nitrate (NO_3^-), make up the remainder of the N in the soil and are available to the plant. A nitrogen cycle illustrating nitrogen transformations is shown in figure 3.9.

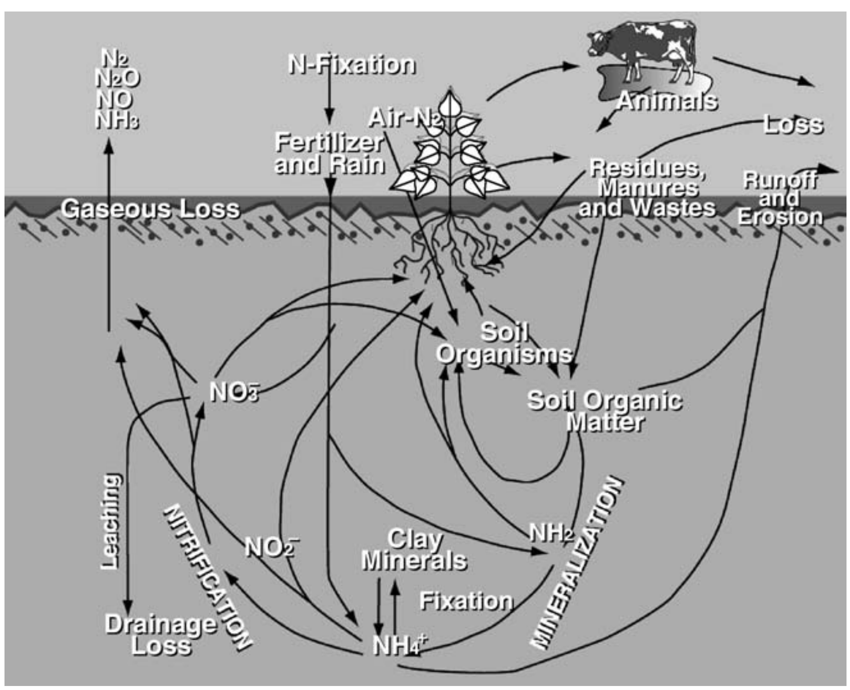


Figure 3.9 Nitrogen cycle.

Because most of the reactions of nitrogen in the soil are microbial they are very sensitive to environmental conditions, such as moisture and temperature. With a few exceptions, saturated or air dry conditions limit most microbial activity. Likewise at temperatures below 50°F or above 100°F limit activity. Our inability to predict the weather is a major factor in our difficulties in predicting N behavior in the soil and thus making specific N management recommendations and determinations about the fate of nitrogen. In soil, organic nitrogen from soil organic matter, crop residue and manure is broken down, or mineralized, into ammonium nitrogen (NH_4^+). Ammonium nitrogen is also the form of nitrogen added to the cycle in ammonium fertilizers and manures.

$$\text{Organic N} \longrightarrow NH_4^+$$

Ammonium nitrogen, being positively charged, is held by the soil on the cation exchange capacity (CEC) sites. In this form the nitrogen is relatively immobile, but still potentially available to plants.

Ammonium nitrogen can be converted to ammonia gas (NH_3), which can result in volatilization losses. This reaction requires a high pH. The urea form of N, found in urea-containing fertilizers and in animal manure, reacts to raise the pH and thus converts the ammonium to gaseous ammonia, NH_3. This ammonia is lost if exposed to the atmosphere by remaining on the soil surface. If the urea is incorporated by tillage or water (either rainfall or irrigation), this loss is eliminated because the ammonia is converted to ammonium N and adsorbed to the soil particles before it can escape.

$$NH_4^+ \xrightarrow[\text{high pH}]{\qquad\qquad} NH_3\uparrow$$

Ammonium nitrogen may be converted by soil bacteria to nitrate nitrogen (NO_3^-). This process is called *nitrification*.

$$NH_4^+ + \text{Oxygen} \xrightarrow[\text{bacteria}]{\qquad\qquad} NO_3^- + \text{Acidity } (H^+)$$

Nitrification requires naturally occurring bacteria and a warm, moist, aerobic environment. Under these conditions the process is rapid and most of the ammonium nitrogen will be converted to nitrate within a few weeks. Little nitrification occurs when the soil temperature is below 50°F. Some commercially available compounds may be added to nitrogen material to inhibit the activity of nitrifying bacteria. These compounds are known as nitrification inhibitors. Notice that one of the products of this reaction is acidity. The acidity created by the nitrification of ammonium nitrogen is often the largest source of acidity in agricultural soils.

The approximate pounds of calcium carbonate ($CaCO_3$) needed to *neutralize* the acidifying effects of 1 pound of nitrogen are as follows:

> 3 pounds of $CaCo_3$ for ammonium nitrate (NH_4NO_3), urea (NH_2^- CO^- NH_2), nitrogen solutions/UAN (urea + NH_4NO_3 + water), and anhydrous ammonium (NH_3).
>
> 5.3 pounds of $CaCO_3$ for diammonium phosphate (DAP), [$(NH_4)_2$ HPO_4]
>
> 7 pounds of $CaCO_3$ for ammonium sulfate [$(NH_4)_2$ SO_4], monoammonium phosphate(MAP), [$NH_4H_2PO_4$], and ammonium polyphosphate (APP)

Although most fertilizer nitrogen is in the ammonium form, some fertilizer sources, such as ammonium nitrate and calcium nitrate, contain nitrate nitrogen. Acid rain and some high-nitrate irrigation water also contribute nitrate nitrogen to the soil.

Nitrates can then be changed to nitrogen gases (N_2 and N_2O) through a process called *denitrification*. In a water saturated soil (because of poor drainage, excessive rainfall, or a field depression where water tends to stand) there is a lack of air and therefore little free oxygen. Under these conditions certain soil bacteria can use the oxygen from nitrate (NO_3^-) in place of the oxygen from air. In this process, the nitrate nitrogen is converted to nitrogen gases (N_2 and N_2O), forms unavailable to plants and easily lost to the atmosphere. An organic source of energy for the microbes is necessary for denitrification. Manure provides an excellent energy source for the microbes, and denitrification occurs rapidly soon after soil is saturated with water and soil oxygen is no longer available to the microbes. Extent of N loss by denitrification is difficult to estimate, but significant losses can occur in less than a week of saturated conditions.

$$\text{Organic C} + NO_3^- + \text{anaerobic conditions} \xrightarrow[\text{bacteria}]{} N_2\uparrow + N_2O\uparrow$$

Water, in excess of what can be held by a well-drained soil, moves down through the soil profile. This water will carry nitrate with it in a process called leaching. This occurs because *nitrate is a negatively charged ion* and is not held by the negatively charged soil particles. Ammonium has a positive charge and thus is held to soil particles, securing it from being leached. The amount of ammonium held is affected by the soil texture and thus the cation exchange capacity. The higher the cation exchange capacity, the greater the capacity of the soil to hold ammonium. The potential loss of N by leaching is greatest in coarse textured soils, during periods of high moisture accompanying limited plant growth and low evapotranspiration.

Like plants, microbes require nitrogen for growth. They compete with plants for the supply of mineral nitrogen in the soil. In this process nitrogen is assimilated into soil organic material by the microbes (*immobilization*). The amount of immobilization that occurs depends on the relative amount of energy, in the form of carbon compounds, and the nitrogen available to soil microbes. The relative amount of carbon to nitrogen in an organic material is referred to as the carbon to nitrogen (C:N) ratio. The C:N ratio will determine whether the net amount of nitrogen in the soil will increase or decrease. If the added organic material has a relatively low amount of carbon relative to its nitrogen content (a low carbon to nitrogen ratio) the microbes will have a sufficient balance of carbon to nitrogen for energy and nutrition to decompose or break down the organic material, there will be a net release of mineral nitrogen. However, if the added material has a high amount of carbon relative to its nitrogen content (a high carbon to nitrogen ratio), there will not be enough nitrogen from the material to support the microbial growth and thus there will be a net tie up of mineral nitrogen because microbes must scavenge mineral nitrogen from the soil to balance their needs. Generally materials with *carbon to nitrogen ratio (C:N) less than 20 will result in a net release (mineralization*) of nitrogen. Materials with a *C:N ratio greater than 30 will usually result in net immobilization of nitrogen*. Between 20 and 30 there will be little net change in mineral nitrogen in the soil.

Nitrogen tie up by immobilization is a temporary process because when the carbon source is depleted the microbes will die and the nitrogen they have assimilated in their bodies will eventually be released back to the mineral form. This process is illustrated in figure 3.10.

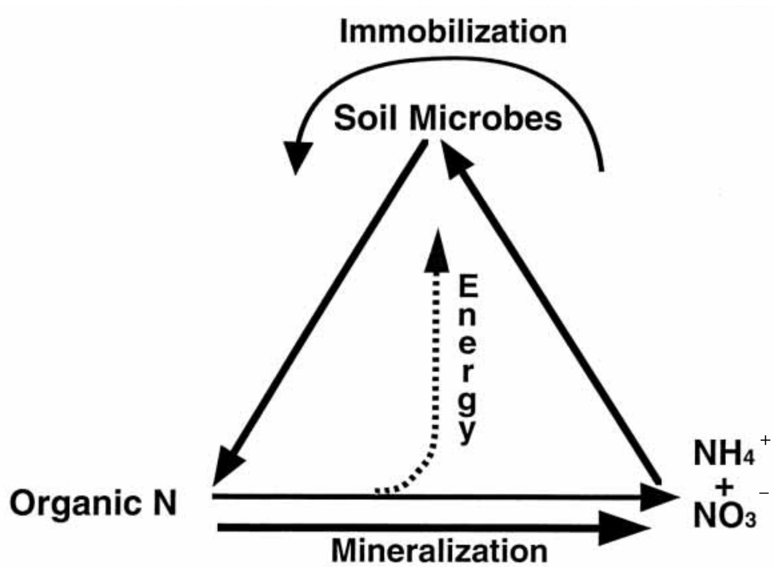


Figure 3.10 Mineralization and immobilization.

Organic material with their carbon to nitrogen ratios are given in table 3.3. The material will either release plant available nitrogen or immobilize available nitrogen from the soil.

Table 3.3 Carbon:Nitrogen ratios of common materials.

Organic material	**Carbon to Nitrogen ratio**	**Release or immobilize**
Soil humus	10	release
Clover forage	12	release
Barnyard manure	20	release
Clover hay	23	release
Green rye	32	immobilize
Sugar cane	50	immobilize
Corn stover	60	immobilize
Wheat straw	80	immobilize
Newspaper	200	immobilize
Pine needles	225	immobilize
Sawdust	400	immobilize

To determine whether or not nitrogen will be released or mobilized, relative amounts of carbon and nitrogen must be determined. Consider this example:

A farmer adds 1 ton of sawdust bedding to each ton of barnyard manure. What is the resultant Carbon:Nitrogen ratio of the mixture? Will the material be mineralizing or immobilizing nitrogen when incorporated into the soil?

From table 3.3, 1 ton of manure has a C:N ratio of 20:1

1 ton of sawdust has a C:N ratio of 400:1

1 ton manure contains 1,905 lbs. C and 95 lbs. N (20:1 ratio)

$\frac{2{,}000 \text{ lbs.}}{21} \times 20 = 1{,}905$ lbs. C, $\frac{2{,}000 \text{ lbs.}}{21} \times 1 = 95$ lb. N

1 ton sawdust contains 1,995 lbs C and 5 lbs N (400:1 ratio)

$\frac{2{,}000 \text{ lbs}}{401} \times 400 = 1{,}995$ lbs C, $\frac{2{,}000 \text{ lbs}}{401} \times 1 = 5$ lb N

A mixture of the two materials will produce a C:N ratio of:

(1,905 lbs + 1,995 lbs)C/(95 lb + 5 lb)N = 3,900:100 = 39

A C:N ratio of 39 is greater than the pivotal C:N ratio of 30. Therefore, the mixture of sawdust and manure will immobilize (take in) nitrogen from the soil.

Organic nitrogen and ammonium nitrogen are both relatively immobile compounds, but, like all nutrients, they can be displaced with the soil when it is eroded. Nitrogen loss from a field because of erosion and runoff can be substantial, particularly if the runoff occurs shortly after nutrient application and remains unchecked year after year. Some nitrate nitrogen can also be moved in the runoff water.

Only nitrate and ammonium nitrogen ions are taken up by plants. However, most nitrogen is taken up as nitrate because it is the predominant form of inorganic nitrogen in agricultural soil. The exception is rice soils where the predominant nitrogen ion is ammonium. Because of the complexity of the nitrogen cycle, such as transformations to unavailable forms and losses of nitrogen from the soil root zone, accounting for plant uptake from added nitrogen sources is less than perfect. In most environments it is difficult to predict the actual nitrogen behavior. Under typical field conditions less than 50 percent of the added nitrogen can be accounted for by plant uptake.

Legumes and some other plant species have the ability to fix atmospheric nitrogen through a symbiotic relationship with bacteria in root nodules. The bacteria in these nodules fix N_2 from the atmosphere and make nitrogen available to the legume plant. In most cases more nitrogen is fixed than is used by the legume resulting in residual organic nitrogen in the soil. This residual organic nitrogen can become available to subsequent crops through the processes in the nitrogen cycle. Symbiotic nitrogen fixation will be limited when inorganic nitrogen is available in the soil for the legume uptake.

In soils, mineral and organic nitrogen are vulnerable to a complex variety of processes brought about by the interactive effects of climate, soil organisms, and human activity. Some of these processes may cause the loss of plant or animal available nitrogen. Other processes may transform the nitrogen into unavailable forms. Therefore the quantity of nitrogen in the soil and the transformations that take place are generally unpredictable.

Phosphorus

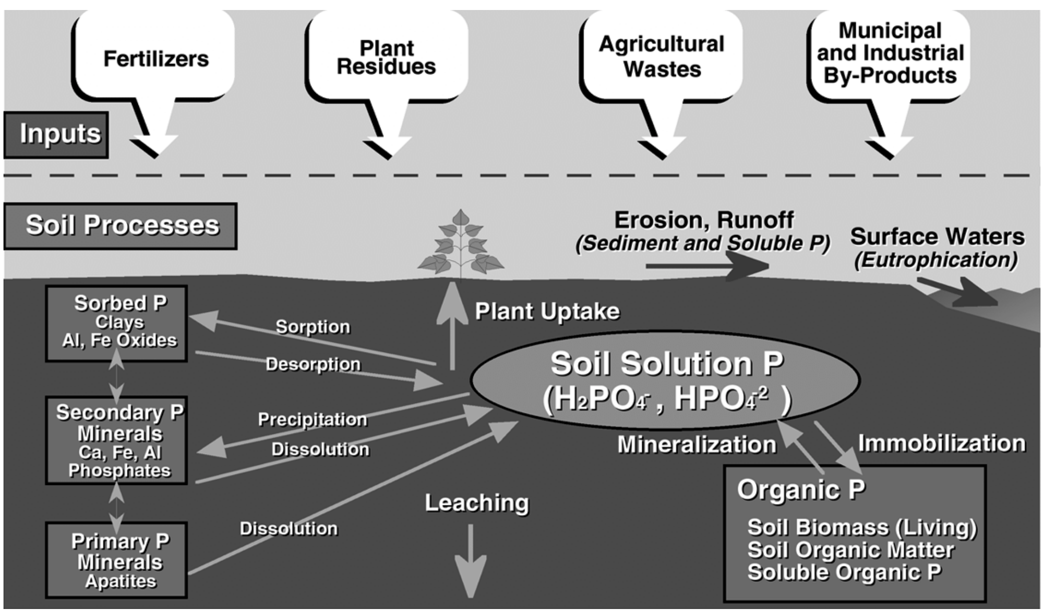


Figure 3.11 The phosphorus cycle.

The general behavior of phosphorus is illustrated in figure 3.10. In the soil, phosphorus is the least mobile of the macronutrients. Under very acidic or very alkaline conditions, phosphorus may become fixed in insoluble compounds with iron, aluminum or calcium. Thus soil pH is an important management factor for phosphorus availability to crops. Maintaining soil pH between 6 and 7 will usually result in optimum phosphorus availability. This fixation reduces the amount of phosphorus available to plants and also allows phosphorus to build up in the soil. This buildup could have detrimental effects on plant growth such as phosphorus induced zinc deficiency. Fortunately, this is rarely a problem in soil where the high levels of phosphorus come from manure because the manure also supplies zinc to maintain a proper balance. Where high levels of phosphorus come strictly from fertilizer, however, this can be a serious problem.

Historically, phosphorus has been added to soil to meet crop uptake. Phosphorus is applied to the soil in the form of commercial fertilizer or organic amendments like animal manure. The phosphate ion (PO_4^{-2}) contained in these materials is rapidly adsorbed to soil particles or combined to form a slightly soluble chemical compound. As we discussed in Module 2, phosphorus occurs in the soil as inorganic orthophosphate, clay complexes, and minerals and organic compounds such as organic matter. Plants take up phosphorus in the orthophosphate form. Although the total amount of phosphorus in the soil is large, the quantity of plant available phosphorus in the soil solution as orthophosphate is very small. There exists a dynamic equilibrium in the soil between the adsorbed phosphorus of mineral and organic components and the soil solution. Plants require approximately 0.5 to 1.0 pounds of phosphorus per acre per day. To achieve this amount of uptake the soil solution must be replenished continually by the equilibrium. Also, the roots must explore new soil volume.

Consider this example that clearly demonstrates the dynamic equilibrium of phosphorus in the soil and the need for continual replenishment of phosphorus in the soil solution:

> A wheat crop requires 50 lbs of P_2O_5. At any one time in the soil solution the concentration of phosphorus is 0.1 ppm P.
>
> The soil solution concentration of phosphorus is 0.1 ppm. This is equal to 0.2 pounds per acre in the soil plow layer. [A plow layer of soil weighs 2,000,000 lbs x 0.1 / 1,000,000 (parts per milliom) = 0.2 lbs].
>
> 50 lbs of P_2O_5 is the same as 21.8 lbs of elemental P (1 lb of elemental P = 2.29 lbs P_2O_5).
>
> Because the crop requires 21.8 lbs of P and the soil contains 0.2 lbs of P, it would take 21.8 / 0.2 = 109 replenishments of phosphorus from the soil to the soil solution during the growing season.

Because the soluble forms of phosphorus are rapidly converted to insoluble forms, phosphorus is not generally leached from the soil. It may leach from saturated soil or soil low in clay, especially when excess levels of P are present. However, phosphorus, especially in soils with high phosphorus levels or freshly fertilized or manured soils, particularly on steep slopes, may be lost because of erosion and runoff. The phosphorus carried into surface waters by erosion can eventually be converted to the orthophosphate form and become available for aquatic plant and algae uptake. Properly designed, installed, and maintained soil and water conservation practices are critical for minimizing phosphorus losses associated with runoff and erosion. The main characteristics of a site that must be evaluated to determine the potential for phosphorus loss include: soil erosion of the site, soil runoff class, distance from watercourse, soil test P level, P fertilizer rate and method of fertilizer application, organic P application rate, and method of application. All of these factors must be integrated to evaluate a site for phosphorus loss. A phosphorus index has been developed that uses these site characteristics to provide a relative potential phosphorus loss rating for a site. The phosphorus index will be covered in more detail in Module 5.

Potassium

The general behavior of potassium is illustrated in figure 3.12.

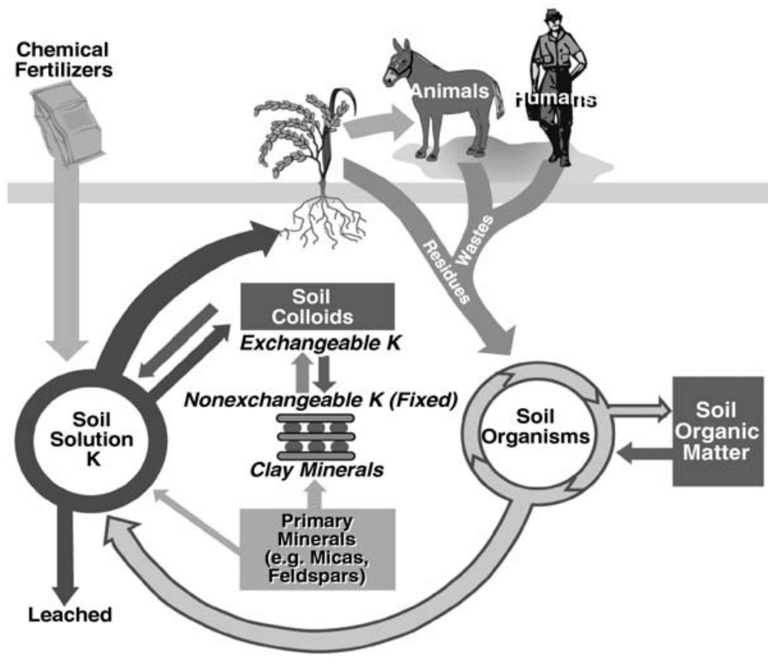


Figure 3.12 Potassium cycle.

Potassium is intermediate in mobility among the macronutrients. Primary and secondary minerals are the major pool of this element. Organic matter holds and releases potassium, but the relationship between organic matter and potassium is not as important as with nitrogen, phosphorus, or sulfur. The major additions of potassium to the soil are fertilizers and animal manures. Being a cation, soil potassium is held on the soil by the cation exchange capacity (CEC) sites. In this form, as an exchangeable cation (K^+), the potassium is available to plants when released to the soil solution. Over time certain clay minerals can strongly adsorb potassium in non-exchangeable sites. This potassium is unavailable for plant uptake because it is trapped within the clay structure. Potassium can accumulate to excessive levels and have a detrimental effect on plant growth mainly through salt effects. Small amounts of potassium may be leached from the soil, especially sandy soils, but potassium is generally not considered a pollution problem. *The main loss mechanism for potassium is through soil erosion.*

Sulfur

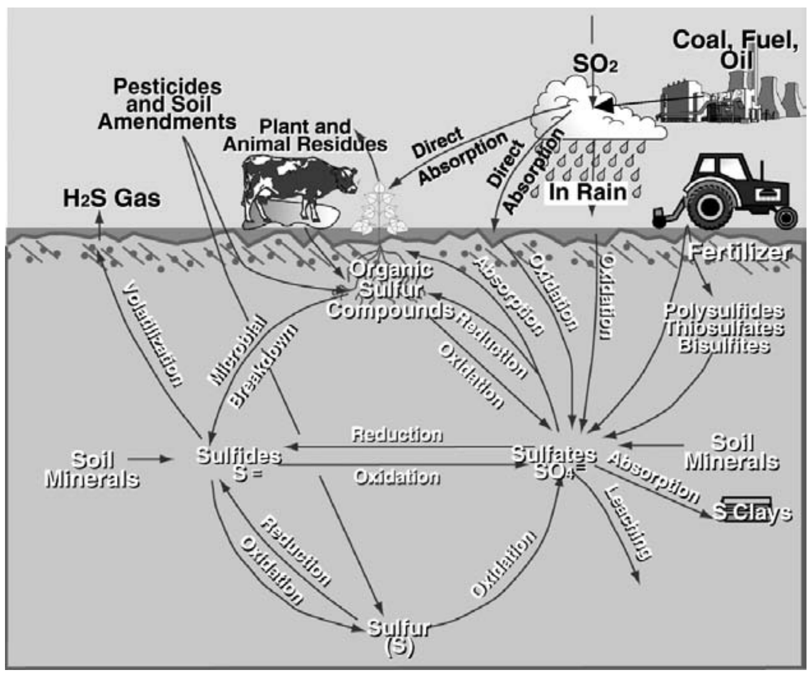


Figure 3.13 The sulphur cycle.

Because organic matter is the major source of sulfur in soil, much of the sulfur cycle is similar to the nitrogen cycle. Mineralization of the soil organic matter results in the release of mineral sulfur compounds, such as sulfate (SO_4^{-2}), that is the plant-available form of sulfur. Plant available sulfates can be immobilized back into organic sulfur forms by microbes. Because it is an anion, sulfate can also be leached from the soil. However, sulfate leaching is less than nitrate leaching.

Sulfur also undergoes several important chemical transformations which not only affect the availability of sulfur, but also affect other soil properties, especially pH. Elemental sulfur is oxidized by soil bacteria to the sulfate form (SO_4^{-2}). In the process a large amount of acid is formed. Elemental sulfur is not commonly found in soils; however, it is added to soils as an amendment to supply sulfur to plants and to lower soil pH.

Elemental sulfur (S) + water + oxygen ———> Sulfuric acid (H_2SO_4)
bacteria

In mining operations pyrite minerals (iron, copper, and zinc sulfides) are often exposed to the air atmosphere. These sulfides react with oxygen to form sulfuric acid. This reaction can create a major problem in the form of acid mine drainage.

Pyrite (FeS_2) + oxygen ————> Sulfuric acid (H_2SO_4)

Sulfur is added to the soil in fertilizers, irrigation water, and through atmospheric deposition. In some areas of the country where acid rain is common, enough sulfur is deposited to meet the needs of most crops.

Carbon

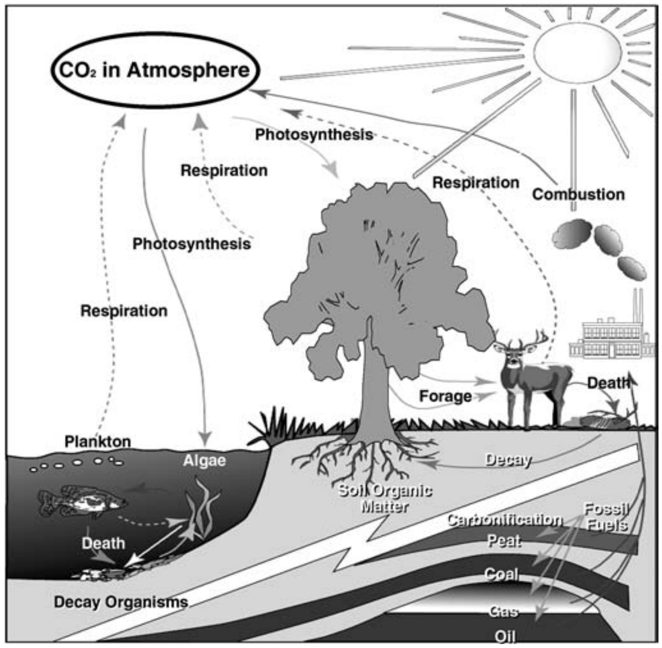


Figure 3.14 The carbon cycle.

Carbon is present in the atmosphere as carbon dioxide (CO_2), at an average concentration of 0.03 percent. Atmospheric CO_2 is in equilibrium with CO_2 dissolved in the water. The total amount of CO_2 dissolved in the oceans is about 50 times higher than that contained in the atmosphere. Carbon is also present in some soils in the form of calcium and magnesium carbonates (calcite and dolomite). These materials are generally outside of the organic carbon cycle, although they constitute a significant concentration of carbon in the earth's crust.

Carbon dioxide from the atmosphere is assimilated by photosynthetic organisms, primarily algae and higher plants. Photosynthetic materials form a reservoir of carbon-containing compounds that are the constituents of living plants. Part of this reservoir is recycled into the atmosphere CO_2 directly through respiration by living organisms. Other parts of the reservoir are also recycled as CO_2 via respiration of organisms that consume green plants.

Not all of the carbon in plant residues and micro-organisms is recycled at the same rate. Some organic compounds, including some manmade agrichemicals and by-products of microbial degradation are resistant to decomposition. Over time these compounds accumulate in the soil and become soil organic matter. Photosynthetic products of earlier geologic ages have become fossilized and their carbon temporarily removed from the cycle. Since the industrial revolution, these fossil fuels have been burned at a rapid rate, releasing the stored carbon to the atmosphere as CO_2 and returning it to the carbon cycle.

Student Activity 4

1. Define the following terms:

   a. Mineralization ____________________________________

   ____

   b. Immobilization ____________________________________

   ____

   c. Nitrification ____________________________________

   ____

   d. Denitrification ____________________________________

   ____

   e. Carbon:Nitrogen ratio ____________________________

   ____

2. List the forms of nitrogen that can be taken up by plants.

   ____

   ____

   ____

3. A farmer adds one ton of wheat straw to a ton of manure. Calculate the resulting C:N ratio if the wheat straw has a C:N ratio of 80:1 and the manure has a C:N ratio of 20:1.

   ____

   ____

   ____

   ____

4. Will this mixture result in net mineralization or net immobilization of soil nitrogen?

____

____

____

5. List six characteristics of a site that should be evaluated to determine the potential for phosphorus loss. The Phosphorus Index has been developed using these site characteristics.

____

____

____

6. List the plant-available forms of the following elements:

Phosphorus ______________________________________

____

Potassium ______________________________________

____

Sulfur ______________________________________

____

7. Which of the following elements is typically the most limiting in the environment for plant growth, nitrogen, phosphorus, potassium or sulfur?

____

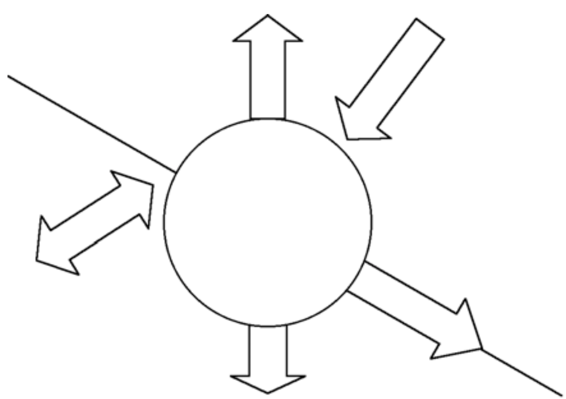
____

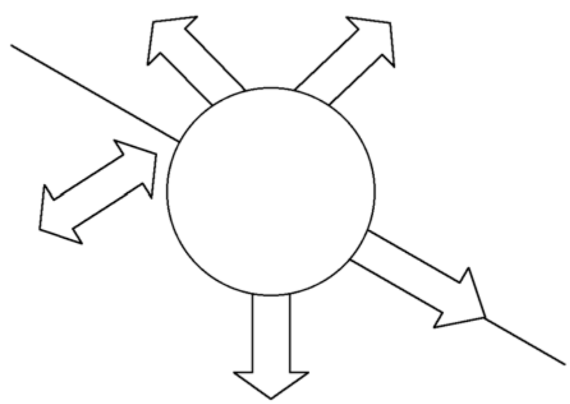
____

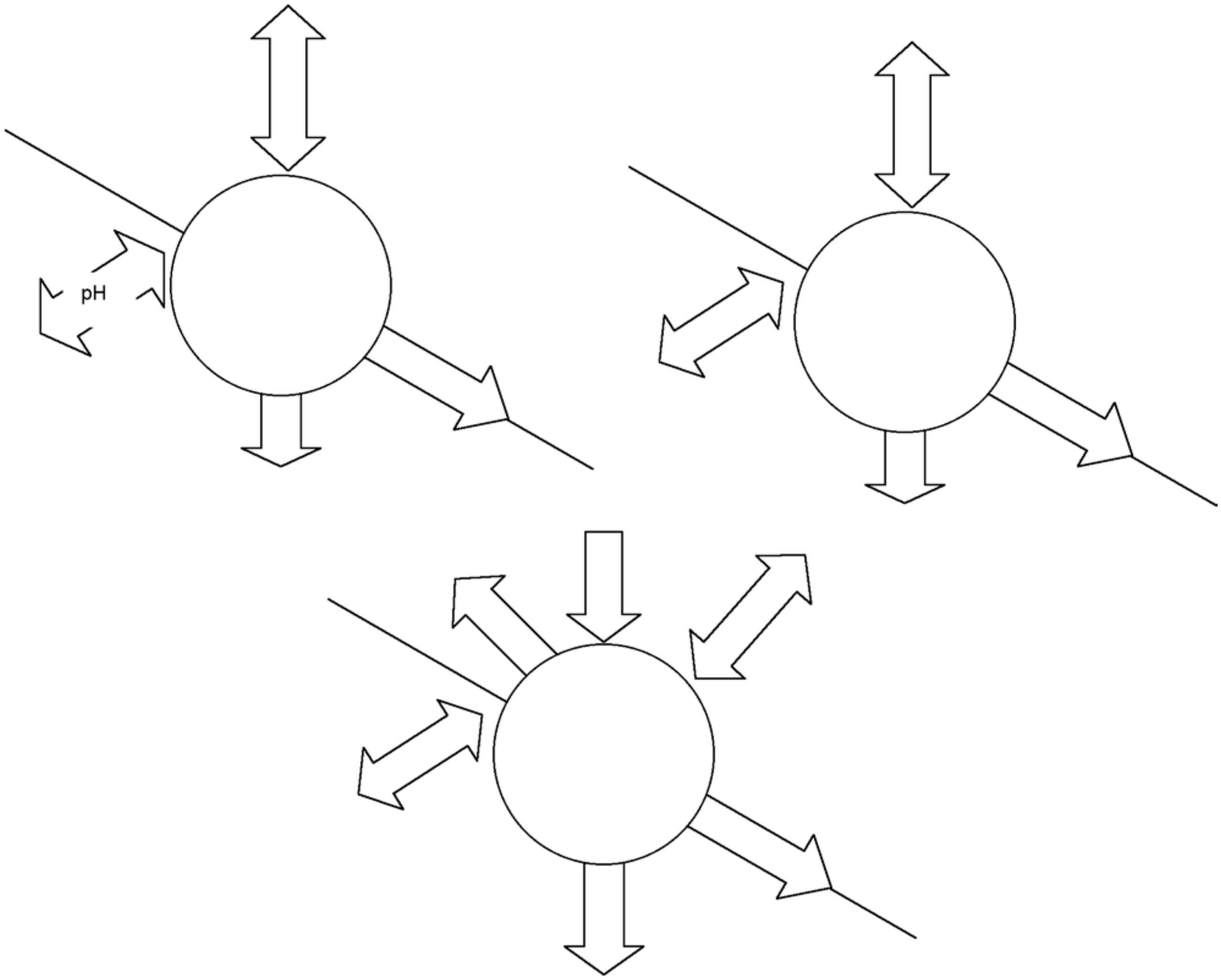
8. For each of the nutrient elements given, determine a source of that nutrient, a sink of that nutrient, and a possible path for loss of that nutrient as a potential pollutant in the environment.

Nutrient	Carbon	Nitrogen	Phosphorus	Potassium	Sulfur
Source					
Sink					
Pathways to become a pollutant					

9. Using the blank nutrient cycles provided, label each cycle with the appropriate nutrient (K, N, P, S and C) and major pathways of movement.






pH

Module 3, Part E—
Nutrient Management

Supporting Objectives

- Describe the role of nutrient management in cash crop agricultural systems, crop and livestock agricultural systems and intensive livestock agricultural systems.
- Describe four methods of monitoring for nutrients in agriculture. Outline an example of a situation in which each type of monitoring might be used.
- Discuss critical and optimum soil test levels as they relate to crop yield response and potential environmental impacts.
- List four factors in addition to testing results that should be considered and integrated into any fertilizer recommendation.

Introduction

Social and economic considerations can have a significant impact on the way landusers choose to adopt and apply conservation practices. *Decisionmaker goals must be considered*. Without this consideration conservation planning will likely never be complete and needed conservation practices will not be implemented. Resource inventories are critical to good management decisions. Inventories should include such things as: Locating land area boundaries; determining land use(s); determining field boundaries; determining vegetation types or crop rotations; reviewing management history; determining where and when soil analyses should be taken; determining producer objectives and yield goals; identifying sensitive areas and offsite effects; determining the nutrient value of any waste products (i.e. manure, litter, wastewater); and identifying pathways and forms in which nutrients can leave the farm.

Nutrient Cycling and Farming Systems

Modern land production enterprises are complex operations that convert resources (nutrients, water, air, sunlight, chemical and metabolic energies) to marketable products such as grain, meat, milk, fiber, or even recreation. Conversion of resources varies in efficiency. Effective management of these resource streams or cycles is necessary to sustain the environmental and economic viability of the enterprise as well as the health of the surrounding community or ecosystem. The management of nutrient streams can be facilitated by the fundamental planning elements: inventory, analysis and determining objectives. A diagramatic inventory of nutrient flow is shown in figure 3.15a. A more specific diagram can be constructed for any particular enterprise. To better understand nutrient management it is helpful to consider some representative farm enterprises and the management consequences of the nutrient cycles on each.

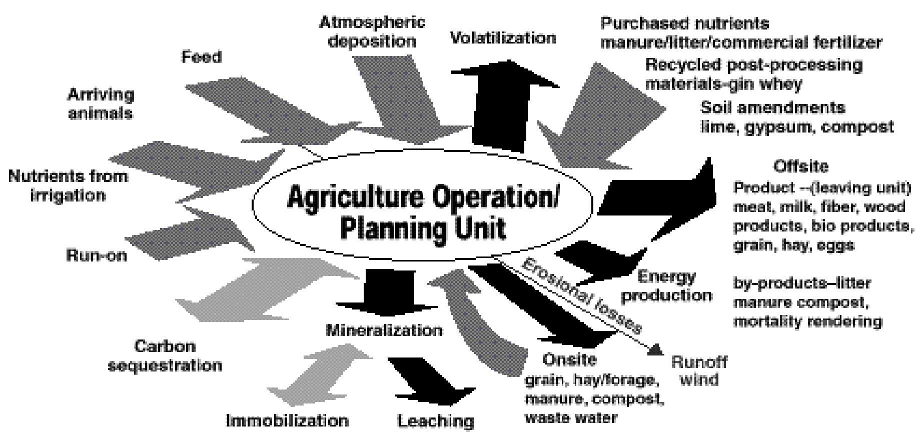


Figure 3.15a Generalized nutrient flow for a farm.

Cash Grain Enterprise

Nutrients come on to a modern cash-crop farm in fertilizers and other materials that are applied directly to the fields (figure 3.15b).

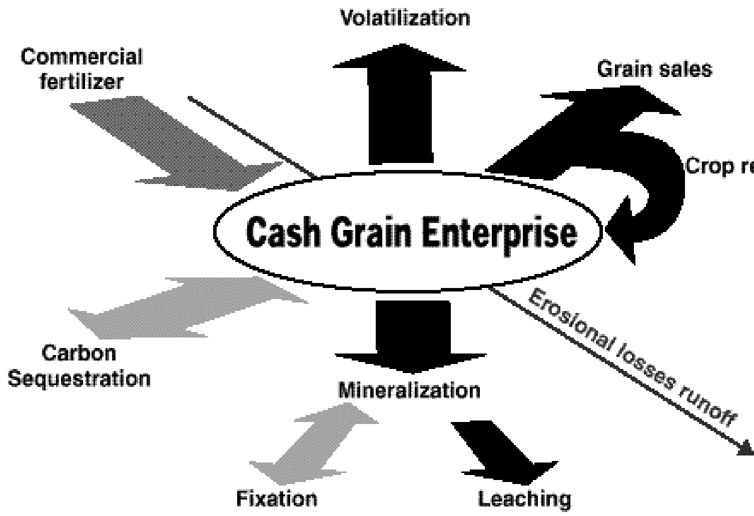


Figure 3.15b Nutrient flow in a cash grain enterprise.

Crops harvested from the fields take a fraction of the applied nutrients with them. When the crops are sold, the nutrients the crops contain leave the farm. There is a direct connection between the flow of nutrients and the agronomic or economic performance of the farm with this pattern of organization.

Traditional economic and agronomic incentives can then be effective in guiding nutrient use on these farms both for crop production and for environmental protection. Of course, the managed nutrient paths discussed are not the only ones nutrients can take. If nutrients are over-applied or allowed to be lost from the fields with erosion, runoff, volatilization, or leaching water, significant losses can occur. On these farms such nutrient losses usually have direct negative economic and environmental consequences. Therefore, the cost of practices that reduce nutrient losses on a cash-crop farm can be at least partially offset by decreased costs in purchased fertilizer. Thus, on this type of farm there are incentives to manage nutrients to minimize loss and environmental impact. However, there are other factors such as minimizing risk on high value crops that may override some of these direct economic incentives.

Crop and Livestock Enterprise

On farms with livestock, a large proportion of the plant nutrients that were in the crops produced as feed for the animals are returned to the farm fields in manure from the animals (figure 3.15c). Thus, with this recycling, the pattern of organization is significantly different from a modern cash-crop farm. Traditionally crop and livestock farms have been viewed as producing outputs that result from the almost exclusive use of on-farm resources. However, the feasibility of supplementing on-farm crop production with fertilizer, off-farm feeds, or other animal inputs is more likely on a modern crop and livestock farm with ruminant animals, than on traditional self sufficient crop and livestock farms.

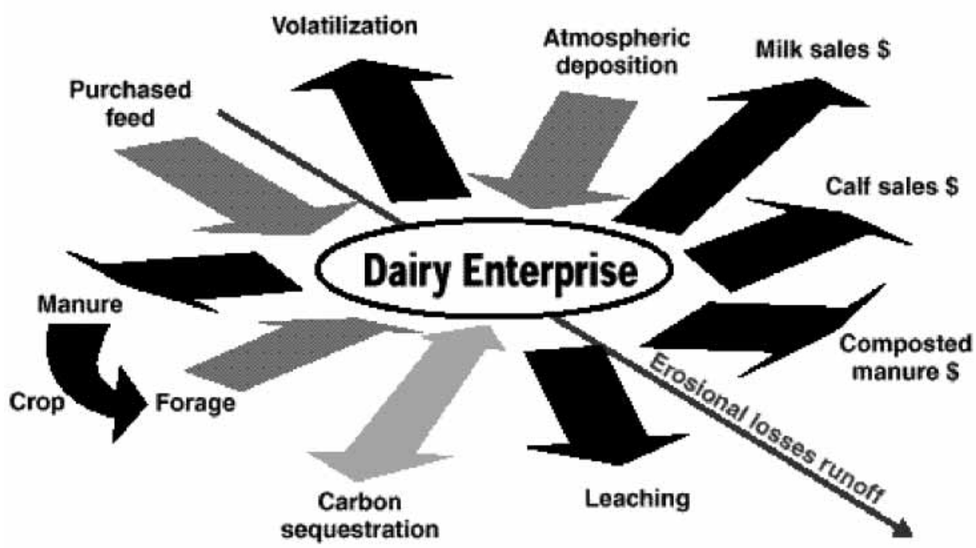


Figure 3.15c Nutrient flow in a dairy enterprise.

Also, off-farm feeds can either be produced on another nearby farm and transported by the farmer to the farm where the animals are housed or they can be purchased commercially from a distant farm through a feed company and delivered to the farm. The key factor on these farms is that the manure produced by the animals is no longer spread on the fields where the crops were produced. The plant nutrients in the feed inputs can offset the losses of nutrients from the farm in the animal products or the manure handling losses as fertilizer did on the cash crop farm. Also, these inputs enable farms to have more animals on fewer acres. Consequently, in some cases these off-farm feed nutrients can exceed what is needed for the crops resulting in excess manure nutrients that can be lost to the environment. Thus, accounting for all sources of plant nutrients being applied to fields becomes an important management activity to protect the environment from negative impacts associated with the over-application of nutrients to crop fields.

Because ruminant animals often spend part of their time outside of buildings, the number of animals in barnyards and holding areas can be greater on these more intensive livestock farms. The result is that the areas immediately around farmyard facilities can be degraded and become sources of nutrient losses from the farm directly to the environment.

Finally, because farms with this pattern of organization sell primarily animal products, neither crop production or fertilizer use are directly connected to the output of such farms. Farm performance depends on the animal husbandry skills of the farmer, not just success in crop production. On a farm organized this way the decisions about plant nutrient use in the fields are not as sensitive to the economic or agronomic criteria in crop production as on the modern cash-crop farm. Typically these type of operations are more sensitive to environmental criteria.

Concentrated Animal Enterprises

Trends in animal housing and the success of crop production on cash-crop farms in specialized geographic regions have made it possible to concentrate large numbers of animals, especially non-ruminants, on small land areas. Most, if not all, of the feed necessary for these animals can be economically transported to the farm where the animals are housed (figure 3.15d).

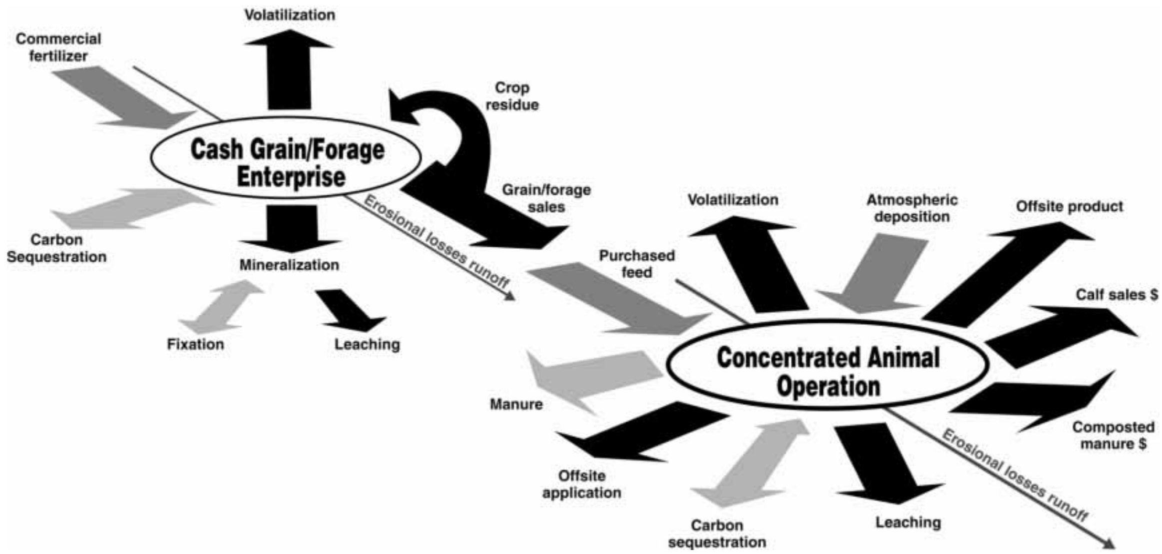


Figure 3.15d Nutrient flow for a concentrated animal operation.

Even though these farms may produce crops for off-farm sale, the land areas involved can be quite limited because the focus of the management activity is on animal production. In reality, the cash-crop farm and the intensive, modern livestock farm are connected by the flow of feed. However, nutrients in this flow often do not cycle back to their original locations. The application of nutrients to the fields on these farms is not closely related to the major production activity of the farm, selling animals or animal products. This usually will result in an excess of nutrients on the farm and a high potential for environmental problems.

The field-based economic and agronomic incentives that can be effective incentives to manage nutrients on a cash-crop farm, and that will also minimize negative environmental impacts, are not as significant on the intensive livestock production-oriented farm. Further, field-based agronomic practices may be of limited effectiveness in treating the total quantity of nutrients on the farm because of the small land area on the farm. It is not likely that plant nutrient management to protect environmental quality can be accomplished solely on the farm where the animals are housed. Successful management of nutrients to protect the environment will depend on support from off-farm people and organizations. Neighbors with land for manure application could cooperate by providing land for manure distribution. Off-farm organizations may deal with manure hauling to locations where the manure can be used directly or transformed into another product such as compost.

Initial approaches to dealing with nutrient problems were based on the assumption that mismanagement was the root of the problem and focused on “correcting” on-farm management. There was a heavy emphasis on broad implementation of such traditional best management practices (BMPs) as developing improved manure allocation plans and building manure storage. This tightening of management did lead to improvements in the situation but through this experience it has also became apparent that this approach, by itself would not solve the entire problem.

Recreational Enterprises

Modern land production enterprises also include recreational systems like golf courses. As shown in figure 3.15e, nutrient flow in these systems is similar to that of some farming systems. As you would expect there is a direct connection between the flow of nutrients and the economic performance of the operation. If nutrients are mismanaged, there can be severe economic consequences. Because of the nature of this enterprise, nutrients can be easily over-applied or allowed to be lost from the field through runoff or leaching. Managing nutrients on these type of enterprises, is equally important, especially from an environmental viewpoint.

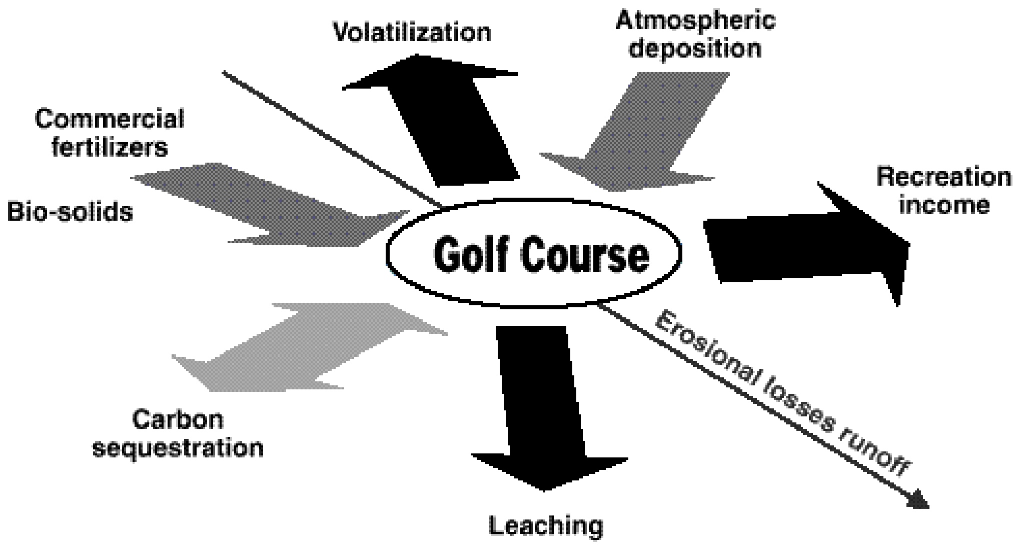


Figure 3.15e Nutrient flow for a recreational enterprise.

Crop Rotations and Systems

Manure nutrients can be used effectively by most crops. Most crops need all the nutrients in manure. However, legumes do not need nitrogen. Thus manure is more effectively used on non-legume crops such as corn and cereal grains. In general, if manure is applied to meet the nitrogen needs of a continuous grain crop, phosphorus and potassium will likely be applied in excess of crop needs and eventually build up to excessive levels in the soil. Forage crops planted in rotation with grain crops will help remove the excess phosphorus and potassium and keep the three nutrients in balance over the rotation. This is illustrated in figure 3.16. In both examples manure was applied to totally meet the nitrogen needs of the corn crop. With continuous corn (A), note the large excess of phosphorus and potassium that are applied. In the rotation example (B. Corn/alfalfa rotation), when manure is applied to meet the nitrogen needs of the corn, but not applied to the alfalfa, the alfalfa in the rotation uses the excess phosphorus and potassium and some fertilizer phosphorus and potassium will probably be required to meet the needs of the alfalfa. This effect will vary with different rotations but the concept will be the same.

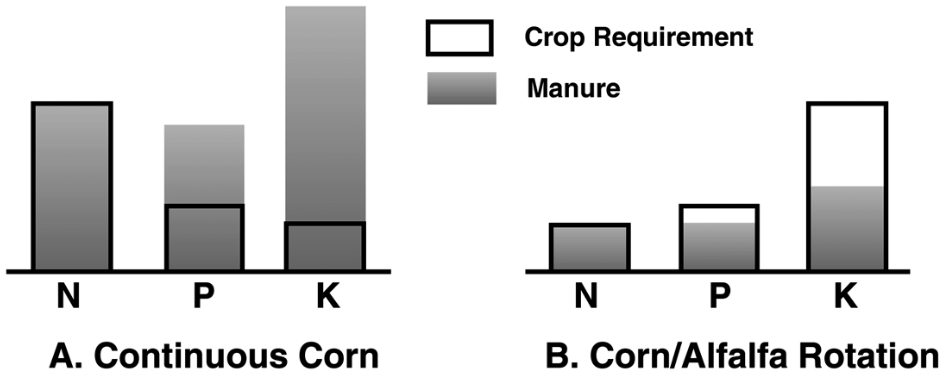


Figure 3.16 Crop requirement vs. manure nutrients for continuous corn and for a corn/unmanured alfalfa rotation.

Student Activity 5

1. Using the following diagram for an agricultural operation, label possible inputs and outputs (fertilizer, hay, milk, runoff, volatilization, etc.). Using a crop/dairy operation for an example, specifically identify materials that are brought on to and carried off of the operation.

2. Describe how the inputs and outputs would change if it were a poultry farm with no cropland?

____

____

Refer to figure 3.16, Part A. Continuous Corn

3. What occurs to the nitrogen, phosphorus, and potassium when manure is applied to meet the nitrogen requirements of the continuous corn crop?

____

____

4. If the manure is applied to meet the phosphorus needs of the crop, how does that affect the nitrogen requirement?

____

____

____

Refer to figure 3.16, Part B. Corn/Alfalfa Rotation

5. Why is the crop requirement for nitrogen reduced in the corn/alfalfa rotation?

____

____

____

6. How would this figure change if the corn were harvested for silage?

____

____

____

Balancing Crop/Rotation Nutrient Applications with Nutrient Requirements

Regular soil testing is necessary to monitor the balance of phosphorus and potassium over the crop rotation. The ideal pattern of soil test levels for phosphorus or potassium is illustrated in figure 3.17. Note the buildup of nutrients in the corn part of the rotation and then the subsequent draw-down in these levels in the forage part of the rotation. The bottom line is that over the rotation the trend in soil test levels is level in the optimum to high range.

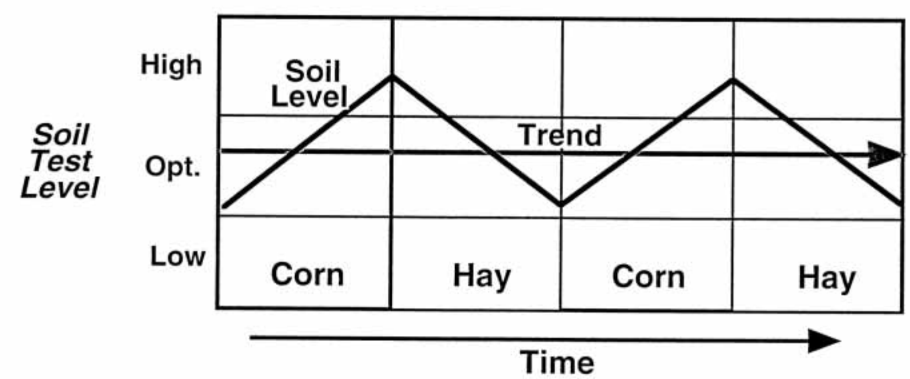


Figure 3.17 Trend in soil P or K levels over a crop rotation with only the corn crop manured.

If manure is also applied to the alfalfa in this rotation, for example, to utilize excess nutrients present on the farm, this rotational balance will be disturbed. Large excesses of phosphorus and potassium will now be applied (figure 3.18). Figure 3.19 shows the same rotation as in figure 3.17, except that in addition to the manure applied to the corn, manure is also applied to the alfalfa at a rate to equal the nitrogen removed by the alfalfa. When this management program is followed, the nitrogen remains in balance but the soil test levels for phosphorus and potassium increase over time. This raises serious environmental concerns because excess phosphorus in the soil increases the risk of offsite impacts.

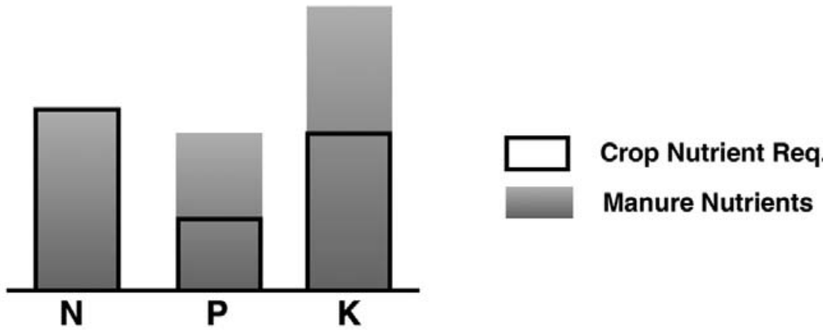


Figure 3.18 Crop requirement vs. manure nutrients for a corn/manured forage crop roation with manure applied to meet the nitrogen needs of both the corn and the legume.

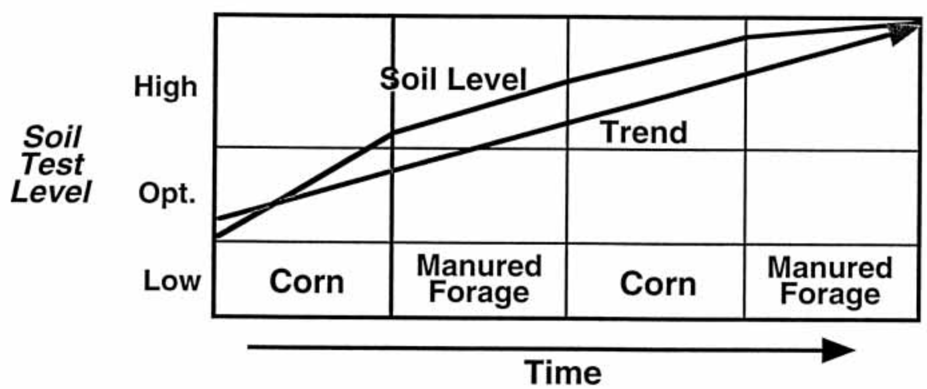


Figure 3.19 Trend in soil test P or K levels over a crop rotation with corn and a manured forage crop. Soil test P and K levels in a corn/alfalfa rotation with manure applied to meet the nitrogen needs of both the corn and the alfalfa.

Nutrient Monitoring in Agriculture

Nutrient monitoring is used to quantify nutrient contents. The four types of nutrient monitoring in agriculture are water testing, plant tissue testing, soil testing, and organic waste testing.

Water Testing

The chemical properties of irrigation water supplies can significantly impact their effectiveness in irrigated agriculture. All irrigation waters should be analyzed to determine nutrient loading and chemical characteristics.

Surface water supplies should be sampled during the irrigation season once a consistent supply of water is being received. Irrigation wells should be sampled after they have been pumped long enough for a draw-down pattern to be established. Contact your local testing laboratory to obtain procedures and sample bottles.

Irrigation water should be analyzed for pH, electrical conductivity, dissolved salts, calcium, magnesium, sodium, sulfur, nitrate nitrogen, boron, chloride, carbonate and bicarbonate. These properties can effect the suitability of water for irrigation practices.

Of particular concern is the total salt content (EC_w) of irrigation water, reported as deciseimens per meter (dS/m) or millimhos per centimeter (mmhos/cm). Long-term use of irrigation water high in salts can contribute to crop production problems. The most common are:

- Reduced plant available water—Because the salts in the soil have a strong chemical attraction to water molecules, less water is available for crop uptake.
- Crop toxicity—High levels of certain salts can adversely affect crop germination and growth.
- Reduced infiltration—Sodium in irrigation water adsorbs to the clay particles in the soil. This causes the clays to disperse, or run together, reducing soil pore space and thus reducing the infiltration rate. The sodium adsorption ration (SAR) is a measure of this effect.

Table 3.4 gives information on the effect different levels of EC_w and SAR have on crop growth and development.

Nitrate can also be a major consideration. In some areas ground water can contain enough nitrate to effect nitrogen fertilization rates.

Table 3.4 Guidelines for interpretation of irrigation water quality.

Potential Irrigation Problem	Units	None	Slight to Mod.	Severe
Salinity (affects crop water availability)				
EC_w (or)	dS/M	<0.7	0.7-3.0	>3.0
TDS	mg/L	<450	450-2000	>2000
Infiltration (affects infiltration rate of water into the soil; evaluate using EC_w and SAR tother)			EC_w	
SAR=0-3	dS/M	>0.7	0.7-0.2	<0.2
=3-6	dS/M	>1.2	1.2-0.3	<0.3
=6-12	dS/M	>1.9	1.9-0.5	<0.5
=12-20[1/]	dS/M	>2.9	2.9-1.3	<1.3
=20-40	dS/M	>5.0	5.0-2.9	<2.9
Specific Ion Toxicity (affects sensitive crops)				
Sodium (Na)				
surface irrigation	SAR	<3	3-9	>9
sprinkler irrigation	me/L	<3	>3	
Chloride (Cl)				
surface irrigation	me/L	<4	4-10	>10
sprinkler irrigation	me/L	<3	>3	
Boron (B)	mg/L	<0.7	0.7-3.0	>3.0
Miscellaneous Effects (affects susceptible crops)				
Nitrogen (NO_3-N)	mg/L	<5	5-30	>30
Bicarbonate (HCO_3) (overhead sprinkling only)	me/L	<1.5	1.5-8.5	>8.5
pH		Normal Range 6.5-8.4		

[1/] In soils with high SAR (>12), increasing dissolved salts (EC_w) in the irrigation water may act to increase infiltration rates. Gypsum (CaSO4) will increase dissolved salts in the irrigation water.

Plant Tissue Testing

Analysis of plant tissue can indicate the success of a soil fertility program and uncover potential problems. Plant tissue analysis complements soil testing by measuring the nutrients actually taken up by the plant. In addition, secondary nutrients and micronutrients that currently are not routinely measured in soil can be reliably measured in plants. However, plant nutrient content represents the effects not only of soil nutrient status but of all the factors controlling plant growth such as moisture status, climate, and crop variety. Therefore, a single year's information may not be useful for planning a soil fertility management program. As results are accumulated over time, the information will become more valuable.

Sample collection protocol is very important. The nutrient concentration in a plant varies with the age of the plant and the part of the plant sampled. Tables of reference values to interpret plant analysis are based on research using specific plant parts collected at a specific stage of growth. Therefore, if plant analyses are to be meaningful:

> *The appropriate plant part must be collected for the age of the plant; and a specific number of plants must be included to obtain a representative sample.*

Specific directions on plant sampling are generally available with sampling kit instructions from the plant analysis laboratory. As an example, sampling instructions and sufficiency levels for corn, alfalfa, small grains, and soybeans are given in table 3.5.

Table 3.5 Plant part to be sampled, sampling time, and sufficiency levels for plant tissue analysis. The sufficiency range is valid only for the crop, plant part, and sampling time indicated. At least 10 subsamples of the indicated plant part(s) should be taken to make a complete sample for submission to the lab.

Crop:	**Corn**	**Alfalfa**	**Small grains**	**Soybeans**
Plant part:	Ear leaf	Leaves, top 33% plant	Uppermost leaves	Uppermost full leaves
Time:	Silking	Bud to 10% bloom	Before heading	Prior to or early flowering
Element Sufficiency range ---------- % ----------				
Nitrogen	2.75-3.50	3.75-5.50	2.50-3.50	4.25-5.50
Phosphorus	0.25-0.50	0.25-0.70	0.20-0.40	0.25-0.50
Potassium	1.70-2.50	2.00-3.50	1.50-3.00	1.70-2.50
Calcium	0.20-1.00	1.75-3.00	0.20-1.00	0.35-2.00
Magnesium	0.20-0.60	0.30-1.00	0.15-0.60	0.25-1.00
Sulfur	0.20-0.50	0.25-0.50	0.15-0.50	0.20-0.40
Element Sufficiency range ---------- ppm ----------				
Manganese	20-150	30-100	25-150	21-150
Iron	20-250	30-250	20-250	50-350
Boron	4-25	30-250	6-25	20-50
Copper	6-20	10-30	6-25	10-30
Zinc	20-70	20-70	20-70	20-50
Aluminum	10-300	10-300	10-200	10-200

Plant tissue analyses may be a useful tool in diagnosing crop nutritional problems. Take samples from the problem area and a nearby normal area for comparison. Use all available information to interpret the plant analysis for diagnosing a nutrient deficiency. Look carefully at the symptoms on the plants, note any patterns in the field, and consider the timing of the appearance of the problem. Keep in mind that not all nutrient deficiencies in plants are the result of nutrient deficiencies in the soil. Soil tests and plant analysis are often complementary. They can confirm each other, but they can also indicate when the cause of the problem is something other than a soil deficiency of the nutrient. If the soil test level is adequate but the plants are deficient this indicates that some other factor is limiting the plants ability to take up the available nutrients. Some areas to consider include: possible interactions with other cultural practices such as tillage or pesticides; pest injury such as root worm feeding; differences in varieties or hybrids; or soil physical conditions such as compaction.

Yield and plant analysis at harvest can be used to estimate nutrient removal by the crop. This may be important in determining nutrient balance as part of nutrient management planning. Yields can be used to assist in the evaluation of plant nutrient management.

Student Activity 6

Farmer Pea had a soil test on his corn field that indicated that all nutrients were adequate for the crop being grown. The farmer wants to do a plant tissue test to see if the crop nitrogen uptake is sufficient.

1. Using table 3.5 (page 74) give a recommendation for his sampling procedure and the desired results.

____

____

____

____

____

____

____

2. A plant tissue test from the same field indicated that a nutrient was deficient. Suggest possible reasons for this result.

____

____

____

____

____

____

____

Soil Testing

Four major components makeup a soil testing program:

- Sampling
- Interpretation
- Analysis
- Recommendation

To maximize the effectiveness of soil testing it is important to understand each of these components.

Sampling

Generally the largest source of errors in soil testing is in obtaining a representative sample. Many of these errors are due to the variability of soils. This can be natural variability or human-induced variability caused by farming practices. Natural variability in soil nutrient levels is due to on-going soil forming processes and is characterized by soil properties such as soil texture, mineralogy, depth, drainage, slope, aspect, erosion and deposition, and landscape location. For example, sandy-textured soils have a lower cation exchange capacity (CEC) and thus will hold lower levels of cations like calcium (Ca), magnesium (Mg), and potassium (K).

Farming practices such as fertilizer and manure application, land leveling, can also cause variability in soil nutrient levels. Sources of human-induced variation in soil nutrients are the uneven application of nutrients as fertilizers or manures; irrigation; and tillage. Uneven application may be intentional such as when fertilizer is banded or manure is injected, or it may also be caused by improper adjustment or operation of application equipment

Tillage methods will affect nutrient variation in the soil. Over time the repeated mixing of the surface layer of soil by conventional tillage tends to minimize the effects of human-induced variation because of nutrient application in this "plow layer". In no-till or reduced tillage systems, there is no mechanical mixing of the soil. Therefore, any natural or human-induced variation in soil nutrient levels tends to remain and over time usually becomes greater. In no-tillage systems all nutrient applications are made to the soil surface and that is where their effects remain the greatest. Application of immobile nutrients like phosphorus in fertilizer or manure will result in higher soil test levels near the surface and a decline in soil test level with depth down through the soil profile. In no-tillage systems, where the N fertilizer or manure is surface applied and not incorporated, this acid residue remains at the soil surface resulting in much lower soil pH at the surface of no-till fields. The most common impact of this *acid layer*, which is often called an acid roof, is the effect it has on the effectiveness of some herbicides and thus on weed control.

Several general guidelines should always be followed when soil sampling. First, think *representative sample*. Composite samples should be taken within major management or soil groups in a field. Samples should be taken within field and away from border areas. Non-uniform areas such as low spots or inclusions should be avoided.

Traditionally, soil sampling recommendations for P, K, Ca, Mg, micronutrients, pH and lime requirement in routine agronomic soil testing programs have been to sample the surface soil usually at a depth of 0–6 inches or 0–12 inches. The exact depth to sample should be based on the recommendation from Extension or the laboratory conducting the analysis. Sampling to "plow depth" has the advantage that it is usually easy to determine the correct sampling depth on each field by looking at a soil core. Because the plow layer is relatively uniform vertically in conventional tillage systems, taking a shallower sample within the plow layer has a minimal effect on the soil test result.

In reduced and no-tillage systems the depth sampled has a much greater impact on the soil test result than in conventional tillage systems. As noted above, nutrients tend to concentrate near the surface in these tillage systems. Some soil testing labs now recommend that minimum and no-till fields be sampled to a depth of 0 to 2–4 inches. However, other labs recommend that these fields continue to be sampled to "plow depth", but that in addition a shallow sample 0 to 1–2 inches deep be taken primarily for measurement of soil pH. In permanent sod crops it is usually recommended that the soil be sampled to a depth of 0 to 2–4 inches for routine soil tests.

Sampling instructions for nitrogen are usually different than for the routine soil tests. In general, because of the greater mobility of nitrogen a deeper sampling depth is recommended. In the drier areas of the country soil samples for nitrate analysis are often taken to a 2 to 4 foot depth. In the more humid areas of the east the most common soil test for nitrogen is the pre-sidedress soil nitrate test (PSNT) for corn. For this soil test the recommended sampling depth is 1 foot.

For a uniform field the best approach would be to randomly select locations in the field to take soil cores, and then after these are thoroughly mixed a composite sub-sample is sent to the lab for analysis. The result is an average soil test level for the field. Take 20 to 30 cores at random locations to make up the composite sample. Usually the locations for taking cores are not totally random but are selected by walking a zig-zag pattern that covers the whole field and randomly stopping to collect a core. This method is generally adequate for a field that is expected to be relatively uniform.

In a non-uniform field, where there is wide variation across the field, sample separately within the field according to subunits that share common characteristics such as soil map unit, soil drainage, past manure, or fertilizer application patterns. Ideally in a non-uniform field, the variability across the field should be determined and mapped. Then the different areas of the field should be managed differently according to these differences. The usefulness of characterizing the variability in a field will depend on the ability to change management based on this variability. A grid sampling approach is useful for large regularly shaped fields such as in the Midwest. Many fields in the northeast and in other parts of the U.S. are smaller and irregularly shaped, making grid sampling a less practical alternative. A common compromise is to systematically sample on the basis of known or suspected gross variability in the field. In this case rather than dividing the field on a regular grid pattern, the field is divided on the basis of the known or suspected variability. A good soil sampling plan must account for the variability discussed above for the results to be valid. Always check with the soil testing lab to determine the recommended sampling procedures for their tests.

Student Activity 7

Figure 3.20 shows a 40-acre area divided into four 10-acre fields each with a different cropping sequence. The 40-acre field has three soil types (A-C) as shown in the field map.

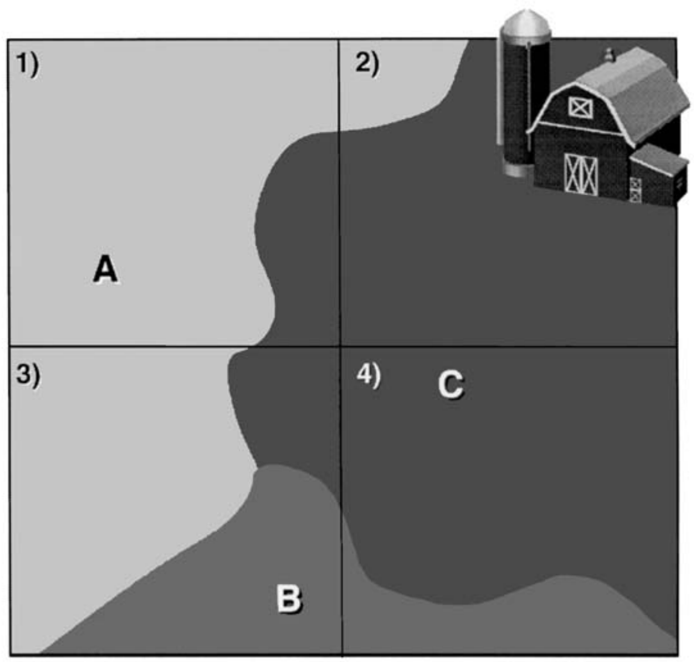


Figure 3.20 Soil sampling exercise map.

Field 1 & 3 are cropland, continuous corn silage with manure applied on the whole unit for the past 3 years.

Field 2 is pastureland, perennial grass with manure applied on the whole unit for the past 5 years.

Field 4 is hayland, perennial grass, which has never had manure applied, but a balanced fertilizer has been used for the past 8 years.

1. How many samples would be necessary to characterize the 40 acres?

____

2. How many sub-samples would be necessary to make up each composite sample?

____

3. How would you handle the barnyard area in your sampling scheme?

____

Analysis

After a proper soil sample has been collected, it is usually submitted to a lab for analysis. There are soil test methods that have been determined by extensive research to be the most appropriate for use under the soil, crop, and climatic conditions found in each region of the country. The recommended methods are published for the different regions of the country. With a few exceptions, such as the measurement of nitrate-nitrogen in low rainfall areas, most soil test extractants do not directly measure the available amount of a nutrient in the soil. There is no one absolute measurement of nutrient availability in soils. Thus, most soil tests are based on extracting a fraction of the nutrient from the soil that is related to the availability of that nutrient to crops. In most cases soil test correlation research will indicate that the amount extracted by a particular method or similar methods are more closely related to nutrient availability under local conditions than are other methods. This extractant or extractants then becomes the recommended method for that area.

Generally the soil test user does not need to be concerned with the details of the soil analysis methods being used. The most important thing to make sure is that the lab doing the testing is using procedures that are recommended for the region where the samples came from. It is easy to send a soil sample to a lab anywhere in the country, and that lab may do an excellent job in its area. However, the results and interpretations may be misleading because other areas of the country have different soils, and growing conditions. It is also important to know what methods are used when comparing results from different labs. Actual soil test results can only be compared when the exact same methods are used.

One final area that sometimes causes confusion related to the soil analysis concerns the units that the results are presented in. Some soil tests results are presented on a volume basis. The most common system is based on an actual or assumed weight for the soil. Results in this system are presented in various units. Parts per million (ppm) or pounds per acre are used. To further complicate this issue, some results are presented as the pure element (N, P, K) while other results are presented as the fertilizer oxide (P_2O_5, K_2O). These different units used by different labs can all be easily converted back and forth depending on the preferences of the user. Some common conversion factors are given in table 3.6.

Table 3.6 Common conversions for soil test units.

ppm x 2 = lb/ acre furrow slice (6-2/3 in.)	lb/acre furrow slice / 2 = ppm
P x 2.3 = P_2O_5	P_2O_5 x .43 = P
K x 1.2 = K_2O	K_2O x .83 = K
NO_3^- x .23 = N	N x 4.43 = NO_3^-

For example, if a phosphorus recommendation was 40 lb/acre phosphorus and a fertilizer oxide P_2O_5 was to be applied, the conversion would be:

40 lb/acre phosphorus x 2.3 = 92 lb/acre P_2O_5

Interpretation

Soil test levels are calibrated against crop response to the nutrient to correctly interpret the soil test results. This is accomplished by conducting fertilizer response experiments at different soil test levels covering the nutrient range of interest. These experiments must be conducted for all crops and under all of the conditions which the test will be used. These soil nutrient levels are then interpreted in terms of the soil's ability to supply nutrients to crops. The graph in figure 3.21 illustrates this calibration.

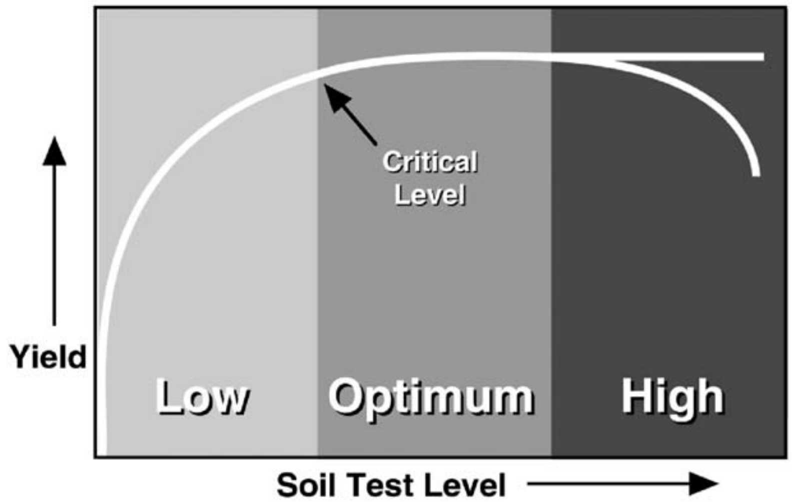


Figure 3.21 Soil test yield response curve.

As soil test level increases, the yield increases up to a point where the soil nutrient level is no longer limits the crop yield. This point is called the soil test *critical level*. As soil test levels increase above this critical point there is no further increase in yield. Theoretically this critical level is the optimum soil test level for the given crop and the conditions. Because of the variation in natural systems an optimum range rather than just a point is used for practical interpretation of a soil test. This optimum range is the soil test levels that lie just above the critical level. As soil test levels increase above the optimum range into the high range, there is no further increase in yield and under some conditions there may be a decrease in yield and/or quality at high soil test levels. The risk of offsite environmental impacts also increases with soil test levels above the optimum range. Table 3.7 summarizes general definitions for the soil test interpretation categories for crop response.

Table 3.7 General soil test category definitions and recommendations.

Category name	Category definition	Recommendations
Low	The nutrient is probably deficient and will likely limit crop yield. There is a high probability of an economic yield response to adding the nutrient.	Recommendations based on crop response. These recommendations will generally build the soil into the optimum range.
Optimum	The nutrient is probably adequate and will not likely limit crop growth. There is a low probability of a economic yield response to adding the nutrient.	For annual soil testing no nutrients may be recommended. For periodic soil testing, recommendations are generally for maintenance applications to maintain the soil in the optimum range .
High	The nutrient is probably more than adequate and will not limit crop yield. No response is expected and there is the possibility of a negative impact on the crop or the environment if additional nutrients are added.	No nutrient additions are recommended.

The shape of this response curve is determined from the results of the calibration experiments and then the soil test levels corresponding to definitions in table 3.7 for the test method being used are determined as shown in figure 3.22. The soil test levels that correspond to these categories are published by the laboratory so that they can be used to interpret soil tests from that lab. Some laboratories will subdivide these main categories in to subcategories such as *Very Low* or *Very High*. However the basic definitions given in the table still hold. These adjectives simply indicate the degree of low or high for example.

Understanding how a soil test result is interpreted is important; usually the user does not need to worry about actually making the interpretation. Most laboratories give the interpretation with the test results on the soil test report. This may be presented in words such as *Low*, *Optimum* or *High*. Finally some labs present interpretation in the form of a chart. An example adapted from a soil test report is in figure 3.22.

Soil nutrient levels		***Low***	***Optimum***	***High***
Soil pH	6.3	XXXXXXXXXXX		
Phosphate (P_2O_5)	300 lb/A	XXXXXXXXXXX	XXXXXXXXXXXX	XXXXX
Potash (K_2O)	170 lb/A	XXXXXXXXX		
Magnesium (MgO)	250 lb/A	XXXXXXXXXXX	XXXXXX	

Figure 3.22 Chart for displaying the soil test interpretation on a soil test report.

Some labs report their results in the form of an index number. A common index system would assign an index of 100 to the optimum level. With this system index numbers less than 100 would indicate the degree of sufficiency and numbers above 100 would indicate an excess of nutrient over the optimum for the crop. Regardless of the system used to indicate the interpretation on a soil test report, if an equally valid but different soil test method were used for a given soil, the numbers might be different but the interpretations should be identical.

The Land Grand University Extension Service has developed soil test recommendations based on soil test results using field research. Though these recommendations vary from state to state, they are all calculated using locally derived algorithms for specific crops and soils. Calculated nutrient recommendations are given to the producer as part of the soil test, analysis, interpretation, and recommendation report. The nutrient planner is not required to derive the crop nutrient recommendation, as this is part of the soil test report. USDA, NRCS policy states that recommended nutrient application rates are based on Land Grant University guidance or standard industry practice, if recognized by the Land Grant University [190-General Manual, 402.06(b)].

Consider this example for determining nutrient recommendations based on soil sample analysis and Extension Service formulae:

The Extension Service ranges for phosphorus levels in the soil are shown below:

0 – 40 ppm = LOW, 40 – 60ppm = OPTIMUM, > 60 ppm = HIGH

An Extension Service formula for phosphorus recommendation for a sorghum crop with a yield expectation of 5,000 lb/acre is:

$$\frac{80 - (\text{Soil sample P (ppm)} + 30)}{0.44} = \text{recommended lbs } P_2O_5 \text{ per acre}$$

Example 1

The soil sample analysis has been returned from the laboratory indicating that the soil sample contained 100 ppm phosphorus.

Based on a soil test of 100 ppm the phosphorus level in the soil is HIGH (>60 ppm), and using the Extension Service formula the recommendation would be:

$$\frac{80 - (100 + 30)}{0.44} = -114 \text{ lbs } P_2O_5 \text{ per acre}$$

The negative result (-114) indicates that phosphorus is probably more than adequate and will not limit crop yield. No response is expected and there is the possibility of a negative impact on the crop and/or the environment if additional nutrients are added. The soil can supply adequate P for the crop, therefore no phosphorus would be recommended.

Example 2

The soil sample analysis has been returned from the laboratory indicating that the soil sample contained 40 ppm phosphorus.

Based on a soil test of 40 ppm the phosphorus level in the soil is OPTIMUM (40–60 ppm), and using the Extension Service formula the recommendation would be:

$$\frac{80 - (40 + 30)}{0.44} = 23 \text{ lb } P_2O_5 \text{ per acre}$$

Although the soil test indicates the phosphorus level is OPTIMUM, it is on the lowest end of the scale. When using the Extension Service formula the positive result (23) indicates that the soil phosphorus is slightly low and 23 pounds of P_2O_5 should be added.

Student Activity 8

1. If a phosphorus recommendation was 20 lb/acre phosphorus, how much P_2O_5 fertilizer would need to be applied?

2. The Extension Service ranges for phosphorus levels in the soil are shown below:

   0 – 40 ppm = LOW, 40 – 60ppm = OPTIMUM, > 60 ppm = HIGH

   The formula for phosphorus recommendation by Extension Service for a sorghum crop with a yield expectation of 5,000 lb/acre is:

   $$\frac{80 - (\text{Soil sample P (ppm)} + 30)}{0.44} = \text{recommended lb } P_2O_5 \text{ per acre}$$

   The soil sample analysis has been returned from the laboratory indicating that the soil sample contained 70 ppm phosphorus.

   a. Would you recommend phosphorus for the crop? If so how much?

   b. If the soil test result was 20 ppm, would phosphorus fertilizer be recommended? If so how much?

3. Define soil test critical level and optimum range.

Interpreting Soil Tests for Environmental Concerns

The preceding discussion focused on interpreting soil tests in terms of crop response. Increasingly there is concern about the potential impact of nutrients on the environment. In this regard, questions are being asked about interpreting soil tests in terms of predicting potential environmental impact from nutrients. For example, one can make the assumption that phosphorus soil test levels in the High range show that phosphorus is available in amounts greater than a plant can use, and thus may be more available for runoff to surface water. However, a soil that is rated low for phosphorus could also pose an environmental threat if site conditions and management are favorable for movement offsite. These site condition include site specific factors such as proximity to a stream, sensitivity of a receiving waterbody, steep slopes, or soil conditions like erodability and runoff class; and management related factors such as tillage, irrigation, nutrient application timing and placement, and crop rotation. *Remember that the interpretations discussed above (Low, Optimum, and High) are based on the probability of an economic response by the crop to additional nutrients. Thus, it is not possible to directly use a soil test interpretation for crop response to make an environmental interpretation.*

The soil test level will need to be interpreted in the context of site specific characteristics and management. As briefly discussed earlier in this module, an example of this approach is the Phosphorus Index (See Module 5). The Phosphorus Index provides a site vulnerability index for potential P loss based on the soil test level in addition soil erosion, irrigation induced erosion, runoff class, distance from watercourse, P fertilizer application rate, method of P fertilizer application, organic P (manure, sludge, compost) application rate, and organic P application method.

Recommendations

The final step in the soil testing process is making a recommendation. This is usually the most difficult part of soil testing because there are many factors in addition to the soil test result which must be integrated to make a recommendation. These include obvious factors such as the crop, expected crop yield and quality, other soil characteristics, climate, cultural practices, nutrient sources, and economics. There are less obvious factors such as management skill of the farmer, availability of nutrient sources, aversion to risk, and philosophy. This last factor, philosophy, is a common source of controversy in soil testing. An example of a common philosophical difference in soil test recommendation is fertilizing the crop for optimum economic response by the immediate crop vs. fertilizing the soil to obtain a soil test level sufficient to meet the needs of future crops. Arguments can be made to support both approaches. Although it is not possible to discuss all the possible approaches and philosophies for making soil test recommendations, the farmer and the farm advisor must understand the approach that is used to make the recommendations given to them. As computers are used more and more to make soil test recommendation, it is likely that farmers will be able to choose from several different recommendations based on their situation and preferences.

Having pointed out the considerable differences in approaches to making soil test recommendations, there are some common underlying principles that should be understood. Table 3.7 summarizes the general approach to making recommendations based on the soil test level. At low soil test levels recommendations are usually based on the expected response of the crop to adding the nutrient. Some of these recommendations are based on recommending the minimum amount needed to get the optimum immediate economic crop response. Other recommendations may also include an amount to either rapidly or gradually build the soil out of the low range and into the optimum range. This is an example of the philosophical differences discussed in the previous paragraph.

In the optimum range there are generally two common approaches to making recommendations. Remember that the definition of an optimum soil test level is that the nutrient is adequate and there is a low probability of an economic yield response to adding more of that nutrient. Thus, a logical and valid recommendation would be that no additional nutrients are needed. However, the crop will remove nutrients from the soil resulting in a drop in the soil test level by the end of the growing season. Therefore, a new test must be run for the following year so that this crop removal is accounted for in the next recommendation. Thus annual soil testing or using some estimate of the change in the soil test level caused by crop removal must be used. Unfortunately, few farmers are willing to soil test every year. An alternative approach to recommendations when the soil is in the optimum range is to include an amount of nutrient equal to the expected crop removal. The objective of this type of recommendation is to offset the crop removal and thus maintain the soil in the optimum range over time. Because nitrogen is so mobile in the soil, it is difficult to optimize nitrogen applications without some sort of annual soil test for nitrogen. It is important to account for nitrogen availability early in the growing season and to balance application amounts with crop requirements. By optimizing the nitrogen balance during the growing season, little residual nitrogen will be left in the soil available for loss after the growing season.

In the high range there is generally good agreement that little or no nutrients are usually recommended because by definition the nutrients are already more than adequate. A low probability exists for getting an economic response by adding more nutrients.

Finally recommendations are determined and presented in different forms. The two most common methods are lookup tables and equations. In the lookup table method, tables of soil test levels and often other factors such as soil type and expected yield are developed for each nutrient and crop with their corresponding recommendations. With the increased use of computers, more labs are using an equation relating the soil test level and the other factors to a recommendation. The recommendations are also presented in different ways. Examples include a single recommendation for a given year and crop, multiple recommendations covering a several year period, or a single recommendation to be applied for several years to a given crop. It is important to recognize how the recommendations are being presented, especially with the last approach. Some soil test laboratories will give suggestions as to the timing of nitrogen applications.

Student Activity 9

1. Draw a graph of yield versus soil test level. On this graph sketch a soil test crop response curve including the critical level and general soil test interpretation categories. Discuss the significance of this curve to crop production.

2. Does a high soil test result indicate a high environmental threat?

3. For the three soil test categories (LOW, OPTIMUM and HIGH), describe what the general recommendations would be.

   LOW

   OPTIMUM

   HIGH

Organic Waste Testing

Manure Nutrient Analysis

The amount of manure available for field application and the nutrients in that manure varies with: the type and management of the animal; the animal's age, ration, and feed consumption; and the way the manure is handled before and during field application. Various handbooks list the average daily manure production for various livestock and the average amounts of nutrients in their manure. The extent of nitrogen losses as a result of various manure handling and storage systems before field application are often accounted for in the nutrient values.

Actual manure characteristics can easily vary almost 100 percent above or below average values, and the volume that a handling system must accommodate may be much larger because of the addition of water and bedding. Because the figures listed in tables are approximate, each livestock farm should have its manure analyzed, at least once for each type of manure and manure group, and following any change in feed or ration. In a storage structure where the manure cannot be completely homogenized separate samples should be taken as differences in the manure are observed. Ideally a storage structure, especially a new one, should be subject to at least one intensive sampling program to characterized the variation in analysis within that storage and handling system. An example of the variation in percent solids and N analysis is in figure 3.23.

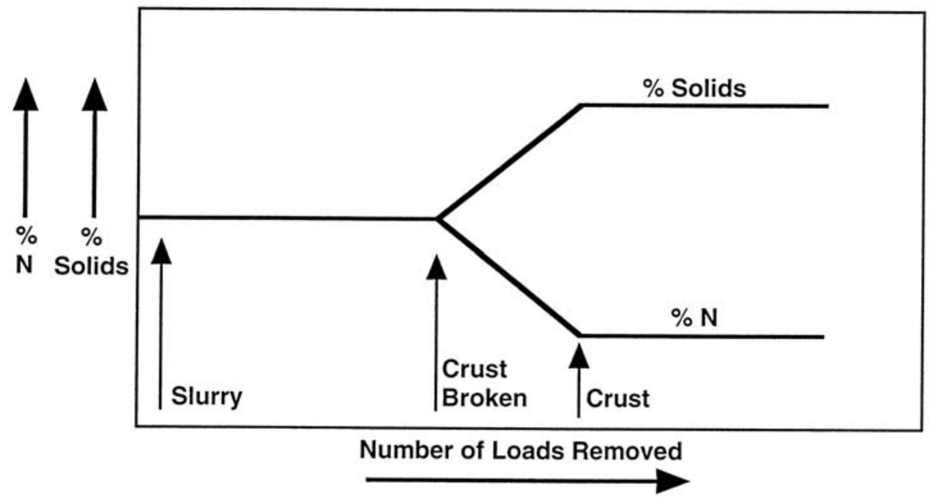


Figure 3.23 Variation in dairy manure analysis as a manure storage is unloaded.

Knowing the composition of the manure at the time it is spread on the fields is important. Although animals can be studied and their manure production linked to the production of similar animals on a particular farm, manure as it is spread on fields is subject to many management actions that influence its composition. Therefore, good sampling procedures at the time of spreading are necessary to accurately manage the nutrients in each situation.

Collecting Manure Samples for Nutrient Management

Manure sampling procedures will depend on the level of management of other components of the manure management process. If the rest of the process is closely managed, including manure spreader calibration, good yield measurements, and accurate records of manure applications to the fields, then more sophisticated sampling procedures will be justified. If approximations are used in other aspects of manure management, then simple manure sampling procedures will be adequate. Manure sampling procedures can be changed as the overall level of nutrient management sophistication increases. Contact your local cooperative extension agent, conservation district or NRCS office for assistance in determining the proper sampling procedure.

Nutrient assessment procedures use three general methods to determine the nutrient content of agricultural waste. The methods are:

- *Laboratory analysis of waste samples.*
- *Use of published tables* (data). Tables presenting the nutrient (N, P, and K) content of various agricultural waste can be found in chapter 4 of the Agricultural Waste Management Field Handbook, and in your State conservation practice standard for waste utilization (633).
- *Use of data on the feed intake of the animals producing the waste*. In general, this method is used to estimate the nutrient content of animal waste from the feed intake records and knowledge of the amount of nutrients used by the animal during its growth. This method is not widely used.

The most accurate nutrient content values are obtained through laboratory analysis of waste samples by a qualified laboratory. The accuracy of the lab results depends upon the proper collection and handling of waste samples. Two basic methods used for obtaining waste samples are:

- Field sampling requires the collecting of samples in the field during the spreading or land application of the waste. This method provides the most accurate assessment of the amount of each nutrient actually being applied to the field. However, this method is considered to be somewhat impractical because of the time delay between analysis of the sample and the application. Source sampling is considered to be more practical.
- Waste source sampling involves taking the samples directly from the waste source (waste storage pond, lagoon, composting facility—figure 3.24). The samples (manure, lagoon or waste storage pond effluent, or irrigation water) that are to be analyzed should be representative samples. A good representative sample is obtained by using correct

sampling procedures. Sampling guidelines recommend that several random samples be taken from the source (composter, manure pile, lagoon, or waste storage pond) at different locations. The random samples obtained from a waste source should be mixed to form a composite sample that is representative of that particular waste source. If a lagoon or waste storage pond is to be agitated before pumpout, the representative sample should be taken at the pumping site after the contents have been mixed. Detailed information on sampling procedures is generally available at the local Cooperative Extension Service Office.

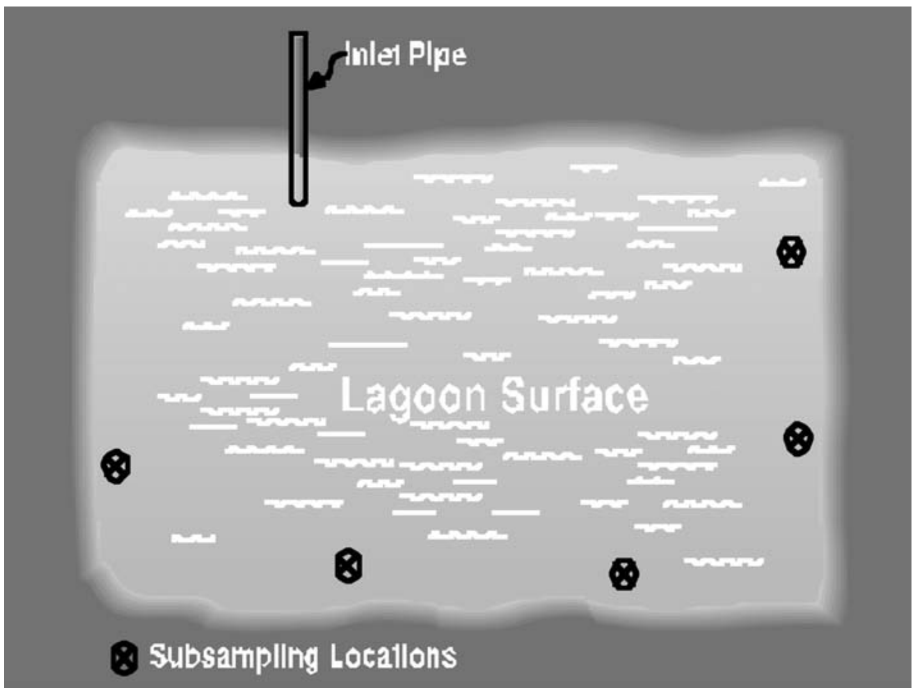


Figure 3.24 Several small subsamples (approx. equal volume) should be taken at different locations within the lagoon. These subsamples are mixed and a representative sample is obtained. Samples should not be taken at the waste inlet location.

Student Activity 10

1. List three situations when a manure nutrient analysis should be done.

   a. ____

   ____

   b. ____

   ____

   c. ____

   ____

2. Describe how to assess available nutrients in agricultural waste.

   ____

   ____

   ____

   ____

   ____

   ____

Group Activity 1—Optional

Note to Student: Group activities will be handled in a facilitated session.

1. Describe four methods of monitoring for nutrients in agriculture. Outline an example of a situation in which each type of monitoring might be used and discuss its relationship to any associated agricultural and environmental concerns.

2. List four factors in addition to testing results that should be considered and integrated into any fertilizer recommendation.

3. Describe general approaches to making a nutrient recommendation based on soil test results and general soil test interpretation categories.

Module 3, Part F—Nutrient Application Management

Supporting Objective

- List and describe the four major components of nutrient application management.

Introduction

The four major components of nutrient application management are:

- Application rate
- Application timing
- Nutrient form
- Method of application

Application Rate

The nutrient needs of a crop are determined by the expected yield. The expected yield is a factor in many nutrient recommendations. A crucial factor in setting realistic yield expectations is the yield potential of the soil, which is a function of soil properties independent of manure or fertilizer application. Thus, expected yields should be estimated based on the soil productivity. Expected yields should be adjusted to account for factors other than soil productivity, such as weather, management, and economics. Records of yields produced in the past are a good starting point for determining realistic yield expectations for the future.

The amount of nitrogen, phosphate, and potash (N, P_2O_5, and K_2O) per unit of yield taken up by various crops can be found in various references. The USDA, NRCS, Agricultural Waste Management Field Handbook, table 6-6 is a good reference. These values can be used with the expected yield to estimate crop nutrient removal in the harvested portion of the crop. Perhaps the best references for determining nutrient application rates are university fertilizer guides, which are typically based on expected yields and some sort of budgeting approach.

Nutrient Form

Inorganic fertilizers

Nitrogen fertilizers

Many different chemical and physical forms of nitrogen (N) fertilizers are available. Some of the more common fertilizer nitrogen sources are given in table 3.8. The nitrogen in most farm-grade fertilizers is readily available. Such fertilizers as *turf-grade* fertilizers release nitrogen slowly. Plants can use nitrogen in one of two forms: ammonium nitrogen (NH_4^+) or nitrate nitrogen (NO_3^-).

Table 3.8 Common nitrogen fertilizers.

Description of Fertilizer Materials

Fertilizer	Total N, %	Available Phosphoric acid, %	Soluble Potash %	Equiv-alent Acidity	Salt Indx	Comments
Anhydrous Ammonia (NH_3)	82	0	0	148	47	A high-pressure liquid that turns into a gas when released. Must be injected 6-8 inches deep on friable, moist soil. N loss by volitilization can occur if not properly injected or if soil is too wet or too dry at application.
Urea (NH_2-CO-NH_2)	46	0	0	84	75	A dry material in dry or prilled form, urea-N rapidly hydrolyzes to NH_4^+. Used for direct application, in mixed fertilizers, and in liquid nitrogen. N at application is present as urea-N. Within 1 day after application, about 66% of urea-N is hydrolyzed to ammonia-N, all within 1 week. When not incorporated, significant N loss by volitalization can occur until approximately 0.5 inch of rain has fallen. Not recommended for starter use. Broadcast (incorporated) or sidedress.
Ammonium Nitrate NO_3NH_4	33-34	0	0	63	105	A dry material in dry or prilled form, in which half of the N is as nitrate and half is as ammonium. Used for direct application and in the production of nitrogen solutions (see below). Broadcast or sidedress. Can be left on surface or incorporated into soil.
Nitrogen Solutions (UAN) (Urea+NH_4NO_3+Water)	28-32	0	0	54	74	A mixture of ammonium nitrate urea and water. Urea supplies about half of the N that may be subject to volatilization loss–read comments above for urea. The other half of N is supplied by ammonium nitrate–read comments above for ammonium nitrate. Once applied, nitrogen solution behaves exactly like dry urea and ammonium nitrate. To minimize N loss, incorporate into soil as soon as possible after application. Use caution when spraying, as leaf burn can occur. To minimize injury, do not spray on vegetation. For postemergence application, use a directed spray or dribble between the rows.
Ammonium Sulfate $(NH_4)_2SO_4$	21	0	0	112	69	A dry crystalline material in which the nitrogen is all in the ammonium form. Produced by two methods–by-product and synthetic. Used for direct application and blended complete fertilizers. Broadcast or sidedress. Can be left on surface or incorporated into soil. Contains 24% sulfur.

Ammonium nitrogen (NH_4^+) carries a positive charge and is adsorbed onto soil particles. In this chemical form, leaching of nitrogen will not occur. However, NH_4^+ is changed to the NO_3^- form by bacteria. This process occurs rapidly (beginning within 2 to 3 days) as the soil temperature climbs above 50°F. Complete conversion from NH_4^+ to NO_3^- occurs rapidly under ideal conditions. Nitrate nitrogen (NO_3^-) carries a negative charge and is not adsorbed onto soil particles; it is free to be leached from the soil. Nitrate nitrogen can also be lost to the atmosphere through denitrification when the soil becomes water-saturated. The nitrogen fertilizers listed in table 3.8 contain nitrogen in either or both of these forms. A long-range effect of all nitrogen fertilizers is to lower soil pH. Anhydrous ammonia, urea, diammonium phosphate, and nitrogen solutions, when first applied, greatly but temporarily increase soil pH in the zone of application. Ammonia is released and can "burn" germinating seeds or seedling roots in the area of fertilizer placement. However, in the eventual conversion of NH_4^+ to NO_3^-, an acid residue is formed.

Acidity is a particular problem under no-till and minimum-till conditions, as the nitrogen is concentrated on the soil surface. An *acid roof* is formed; the pH in the upper 1 to 2 inches may be 0.5 to 1.0 pH units lower than at lower depths. This greatly decreases the efficiency of triazine herbicides. Therefore, the upper 2 inches of soil should be tested for pH regularly. For details on taking this sample, see the discussion on sampling no-till fields (Part E—Nutrient Management, Soil Testing). If the normal soil sample does not indicate a need for limestone, the surface pH should be checked. If the surface pH is below a critical level, apply calcium carbonate (lime) every few years. This should be sufficient to take care of the acidity because of nitrogen fertilizer. As a rule of thumb, 6 pounds of calcium carbonate equivalent (CCE) are required for each pound of nitrogen applied as ammonium sulfate, and 2 pounds of CCE are required for each pound of nitrogen applied as anhydrous ammonia, urea, ammonium nitrate, nitrogen solution, or manure nitrogen.

The nitrogen in urea is completely water soluble. Upon application, urea nitrogen changes rapidly to NH_4^+. Therefore, urea nitrogen is readily available to plants upon application to the soil. Urea presents another problem in that when it is surface-applied, significant quantities of nitrogen may be lost as ammonia through volatilization. Losses are accelerated in warm moist soil, at high pH, and with surface residue. Losses are higher on low cation exchange capacity (CEC) or sandy soils than on soil that has a high CEC, a heavy clay content, or a high organic matter content. Thus, urea or nitrogen solutions (which are approximately 50% urea) should be incorporated into the soil by mechanical mixing or by water movement. Light tillage or one-half inch of rain or irrigation is usually adequate. Research also has shown that volatilization losses from nitrogen solution can be reduced significantly by dribbling in a band on the surface, rather than spraying it over the entire soil surface. This can be accomplished by using drop tubes on a conventional sprayer. Urea and urea-blended fertilizers are not recommended as starter fertilizers because of possible ammonia toxicity to germinating seeds, which results in reduced plant stand. When the different nitrogen fertilizer materials are applied properly, they will give the same results per unit of nitrogen applied.

Phosphorus fertilizers

Table 3.9 lists several common phosphorus fertilizers. The chemistry of phosphorus in fertilizer and in the soil is very complex. Plants absorb most of their phosphorus from the soil solution as orthophosphate ($H_2PO_4^-$ and HPO_4^{2-}), regardless of the original source of phosphorus. With a negative charge, orthophosphate is not held on the soil cation exchange sites. However, it reacts readily in the soil, primarily with iron, aluminum and calcium, to form products that become very insoluble and thus unavailable to plants. A major factor controlling this reaction is the soil pH. At low or high pH, the solubility of phosphorus is low. Maximum availability of phosphorus in the soil occurs in the 6.0 to 7.0 pH range.

Table 3.9 Common phosphorus and potassium fertilizers.

Description of Fertilizer Materials

Fertilizer	Total N, %	Available phosphoric acid, %	Soluble potash %	Equiv-alent Acidity	Salt Indx	Comments
Diammonium Phosphate (DAP)$(NH_4)_2HPO_4$	18-21	46-53	0	74	34	A dry granular or crystalline material. Common analysis 18-46-0. Used for direct application and in blended fertilizers. Starter fertilizers containing DAP should be used with caution; be sure to band at least 2 inches to the side and 2 inches below seed.
Monoammonium Phosphate (MAP) $NH_4H_2PO_4$	11-13	48-52	0	65	30	A dry granular material. Common analyses are 11-48-0 and 13-52-0. Used for direct application and in blended fertilizers. Makes an excellent starter fertilizer, either alone or with a small amount of potash.
Ammonium Polyphosphate	10	34	0	53	–	A liquid solution (10-34-0). The agronomic effectiveness of APP is similar to that of MAP. Sequesters some micronutrients and impurities in fluid fertilizers, keeping them in solution. Also produced as a solid material (11-55-0) similar to MAP.
Triple Superphosphate $Ca(H_2PO_4)_2$	0	46	0	0	10	Dry granular material. Used for direct application and in blended fertilizers.
Muriate of Potash KCl	0	0	60-62	0	116	Dry crystalline material. Used for direct application and in blended fertilizers.
Potassium Sulfate K_2SO_4	0	0	50	0	46	Dry crystalline material. A specialty fertilizer used for direct application and in blended fertilizers.
Potassium Nitrate KNO_3	13	0	45	-26	74	Dry crystalline material. A specialty fertilizer used for direct application and in blended fertilizers.
Potassium Hydroxide KOH	0	0	70	-89	–	Crystalline material usually used in liquid fertilizers. Basic nature of this material allows production of neutral liquid fertilizers. Primarily used in liquid starter fertilizers.
Sulfate of Potash Magnesia (Sul-Po-Mag or K-Mag)	0	0	22	--	–	Crystalline material made from langbeinite. Contains 22% sulfur and 11% magnesium.

The solubility of phosphorus in fertilizer varies. The legal definition of available phosphorus in fertilizer is the sum of the phosphorus that is soluble in water plus that which is soluble in a citrate solution. The analyses of phosphorus fertilizers are given as phosphate (P_2O_5). To convert from phosphorus (P) to phosphate (P_2O_5), multiply by 2.3. The water solubility of this phosphorus can vary from 0 to 100 percent. Generally, the higher the water solubility, the more effective the phosphorus source. This is especially important for short-season, fast-growing crops, for crops with restricted root systems, for starter fertilizers, and for areas where less than optimum rates of phosphorus are applied to soils testing low in phosphorus.

The most common phosphate fertilizers are triple superphosphate (0-46-0), monoammonium phosphate (11-48-0 or 11-52-0), diammonium phosphate (18-46-0), and ammonium polyphosphate (10-34-0 liquid or 11-55-0 solid). All of these materials are highly water-soluble. The ammonium phosphates are also excellent nitrogen sources. Monoammonium phosphate and ammonium polyphosphate, either alone or with some added potassium, make excellent starter fertilizers because of their high P to N ratios, high water-solubility, and low free ammonia. Diammonium phosphate (DAP) is not recommended as a starter material because it produces free ammonia, which can harm the seed. However, many starter fertilizers contain DAP; thus it is critical that the starter is accurately placed a safe distance from the seed (about 2 inches), and high rates are avoided.

Potassium fertilizers

Potassium occurs in the soil in three forms: as exchangeable (available) potassium (K^+) adsorbed onto the soil CEC; fixed by certain minerals from which it is released to available form very slowly; and in unavailable mineral forms (most of the potassium in soil). Plants take up potassium as the K^+ ion. The common source of the fertilizer potassium is muriate of potash (0-0-60), which chemically is potassium chloride (KCl). Potassium chloride is highly water-soluble. At excessive rates, muriate of potash can cause salt damage to plants. Other potassium materials used in specialty fertilizers are also listed in table 3.9.

Blended fertilizers

Blended fertilizers are made by physically mixing different fertilizer materials to give a desired analysis. The individual particles remain separate in the mixture and segregation may occur. This problem can be reduced by using materials with the same particle size. In granulated complete fertilizers, as contrasted to blended fertilizers, each particle contains all of the nutrients in the grade. For example, a 10-20-10 blend contains individual particles of the nitrogen, phosphorus, and potassium sources used. In a granulated 10-20-10 fertilizer, each particle theoretically contains 10 percent nitrogen, 20 percent phosphate, and 10 percent potash. If properly made so as to reduce segregation during transportation and application, blends are generally equal in agronomic effectiveness to granulated complete fertilizers. There is often confusion between granulated complete fertilizer and ammoniated fertilizer. Most granulated complete fertilizers are ammoniated, and any blended fertilizer that contains DAP, MAP, or ammonium polyphosphate is also ammoniated. Blends have the added advantage of allowing a wide range of fertilizer grades, thus making it possible to exactly match a fertilizer to a soil test recommendation. When using a blend as a starter fertilizer, urea and diammonium phosphate should be avoided as ingredients. Both materials produce free ammonia, which can inhibit seed germination and seedling growth.

Fluid fertilizers

Fluid fertilizers are becoming more and more common, with nitrogen solution (UAN) heading the list. Multi-nutrient fluid fertilizers are also becoming more popular. The fluid fertilizers may be categorized into two groups: clear solutions and suspensions. In clear solutions, the nutrients are completely dissolved in the water. The major advantage is in handling. The disadvantages are the generally higher price and low analyses possible, especially when the material contains potassium.

Suspension fertilizers are fluids in which the solubility of the components has been exceeded and in which very fine undissolved particles are kept from settling out by including a clay in the fertilizer. Again, the major advantage of these materials is in handling. Suspensions also can be formulated at much higher analyses than can the clear solutions. Analyses similar to dry materials are possible. The major disadvantage of suspensions is that they require constant agitation even in storage. Furthermore, suspension fertilizer cannot be used as a carrier for certain other chemicals, including paraquat. The bottom line in comparing fluid fertilizers with dry fertilizers is that, when used properly, they provide an equal amount of plant food on a nutrient unit basis. Remember when making calculations on fluid fertilizers that the analysis is given as a weight percentage, not on a volume or *per-gallon* basis.

Most fluid fertilizers weigh 10 to 11 pounds per gallon. The analysis of liquid fertilizers is based on a *weight*, not volume basis. One gallon of 10-34-0 ammonium polyphosphate weighs 10 pounds.

Since 1 gallon weighs 10 lb, and the analysis is 10-34-0, there would be 1 lb N, 3.4 lb P_2O_5, and 0 lb K_2O in 2 gallon of this fertilizer. Also since 1 ton is 2,000 lb, there would be 200 lb N, 680 lb P_2O_5, and 0 lb K_2O in a ton of this material.

Organic Nutrient Sources

Plant nutrients can be added in the form of many different organic amendments such as manure, composts, and biosolids such as sewage sludge. The availability of nutrients in these materials is controlled by the microbial processes described in the nutrient cycling section of this document. Therefore, their availability to plants can be dependent upon the organic source and climate conditions. Once these nutrients have been released to the soil solution they react the same as nutrients from commercial fertilizers. An example of how these organic amendments provide nutrients is given in the following discussion of animal manures.

Manure nitrogen

The availability of nitrogen in manure varies depending upon whether the nitrogen is contained in the urine or in the feces. In urine, the nitrogen is in the form of *urea*, the same compound that makes up urea fertilizers. Urea is unstable, and as the manure dries and the urea breaks down into ammonium nitrogen on a barn floor, in a manure pile, or in the soil, it creates the high pH alkaline conditions that favor ammonia production. If the urea is exposed to the air as it dries, the nitrogen in the ammonia gas will be lost to the air. When properly handled and incorporated into soil, however, the unstable nitrogen in manure is as effective as commercial nitrogen fertilizers for providing nitrogen to crops. Nitrogen availability factors must be used to estimate the available nitrogen in manure. These factors are necessary to account for management factors, such as time between application and incorporation or application at different times of the year.

The organic nitrogen in the solid fraction of the manure decomposes into ammonium nitrogen more slowly, so the nitrogen is more likely to be used by the crop before it is lost. In soil, the decomposition is greatest during the first year after manure is applied. Residual nitrogen and nitrogen released after the first year will be available for plants during succeeding years. Experimentally determined factors are used for estimating the availability of this residual nitrogen.

Often these availability factors are based on the total N content of the manure. However, for manure that has been handled atypically, has been treated or composted, or for less common types of manure or sludges a better estimate of available nitrogen is possible if the manure is also analyzed for ammonium nitrogen in addition to total nitrogen.

With this additional information the availability of the ammonium nitrogen is adjusted for volatilization losses based on the time to incorporation. The organic nitrogen, which is the difference between the total nitrogen and the ammonium nitrogen, is then used to estimate the release of organic nitrogen for the current crop. The amount of organic nitrogen also determines the amount of residual organic nitrogen that will be available in subsequent years. *Mineralization of this organic nitrogen varies with the type of manure and the soil and climate conditions*.

Each state may have its own procedure for calculating nitrogen availability from manure. Nitrogen release factors for your area can be obtained from your local cooperative extension, NRCS, or conservation district offices.

Consider the following example for determining manure nutrient amounts. Local information on manure nutrient availability:

Manure analysis:	N	=	12 lb/ton
	P_2O_5	=	4 lb/ton
	K_2O	=	8 lb/ton
Crop requirement:	N	=	180 lb/acre
	P_2O_5	=	40 lb/acre
	K_2O	=	80 lb/acre

Manure nutrient availability for the current crop:

Incorporation	N	P_2O_5	K_2O
--------------------Percent available to crop---------------------			
Immediate incorporation	50	100	100
No incorporation	20	100	100

If manure is applied and incorporated immediately, 6 lbs of N is available per ton.

12 lb N/ton x 50 percent = 6 lb

If the manure is applied and incorporated immediately, how much manure is needed to meet the N requirement of this crop?

180 lb N crop requirement / 6 lb available N /ton = 30 ton

Manure phosphorus

In manure, phosphorus is present chiefly in feces in insoluble inorganic and organic forms. It becomes soluble and available to plants when the organic matter is broken down. Over time, phosphorus from manure is as efficiently used by plants as phosphorus from broadcast fertilizer. Thus, for building soil phosphorus levels, manure phosphorus can be substituted on a one for one basis for broadcast fertilizer phosphorus in meeting crop requirements. However, because it breaks down slowly, the organic phosphorus in manure is not a substitute for starter fertilizer.

Manure potassium

Manure potassium, chiefly present in the urine fraction of manure, is readily available and is equivalent to fertilizer potassium and is thus considered 100 percent available for plant growth in the year that it is applied.

Student Activity 11

1. How much N, P_2O_5, and K_2O are in 1 gallon of 10-34-0 (ammonium polyphosphate) ?

2. How much N, P_2O_5, and K_2O are in 1 ton of liquid ammonium polyphosphate?

Use this information to answer the following questions:

Manure analysis: N = 10 lb/ton
P_2O_5 = 4 lb/ton
K_2O = 8 lb/ton

Incorporation	N	P_2O_5	K_2O
--------------------Percent available to crop---------------------			
Immediate incorporation	50	100	100
No incorporation	20	100	100

Manure nutrient availability for the current crop:

Crop requirement: N = 125 lb/acre
P_2O_5 = 40 lb/acre
K_2O = 80 lb/acre

3. If manure is applied and incorporated immediately, how much N is available per ton?

4. If the manure is applied and incorporated immediately, how much manure is needed to meet the N requirement of this crop?

5. Based on this rate of application, how much available P_2O_5 and K_2O would be applied?

6. How does this compare with the crop needs for P_2O_5 and K_2O?

Application Timing

Ideally nutrients should be applied as close as possible to the time that the crop needs them to assure maximum efficiency and to reduce potential environmental hazards. Proper timing will vary depending on the crop, the nutrient, the soil, and the climate. For practical reasons compromise will often be necessary in making timing decisions. Best management practices, such as use of soil and plant analysis, split applications, fertigation, and foliar feeding, improve our ability to meet crop demands and reduce environmental impact. Several examples follow to illustrate the importance of timing.

Nitrogen timing on corn is a major management concern. Leaching of nitrate out of the root zone and denitrification are processes that cannot be directly controlled. However, the potential for their occurrence can be reduced by waiting to apply N until the crop is ready to take it up, thereby reducing the time the N sits in the soil. Conditions for denitrification and leaching are greatest in the spring, but corn uptake of N is minimal until approximately 35 to 40 days after emergence, when a spurt of growth and N uptake occurs. Therefore, 50 to 90 percent of the required N should be applied as a sidedress when the corn is 10 to 20 inches tall (figure 3.25).

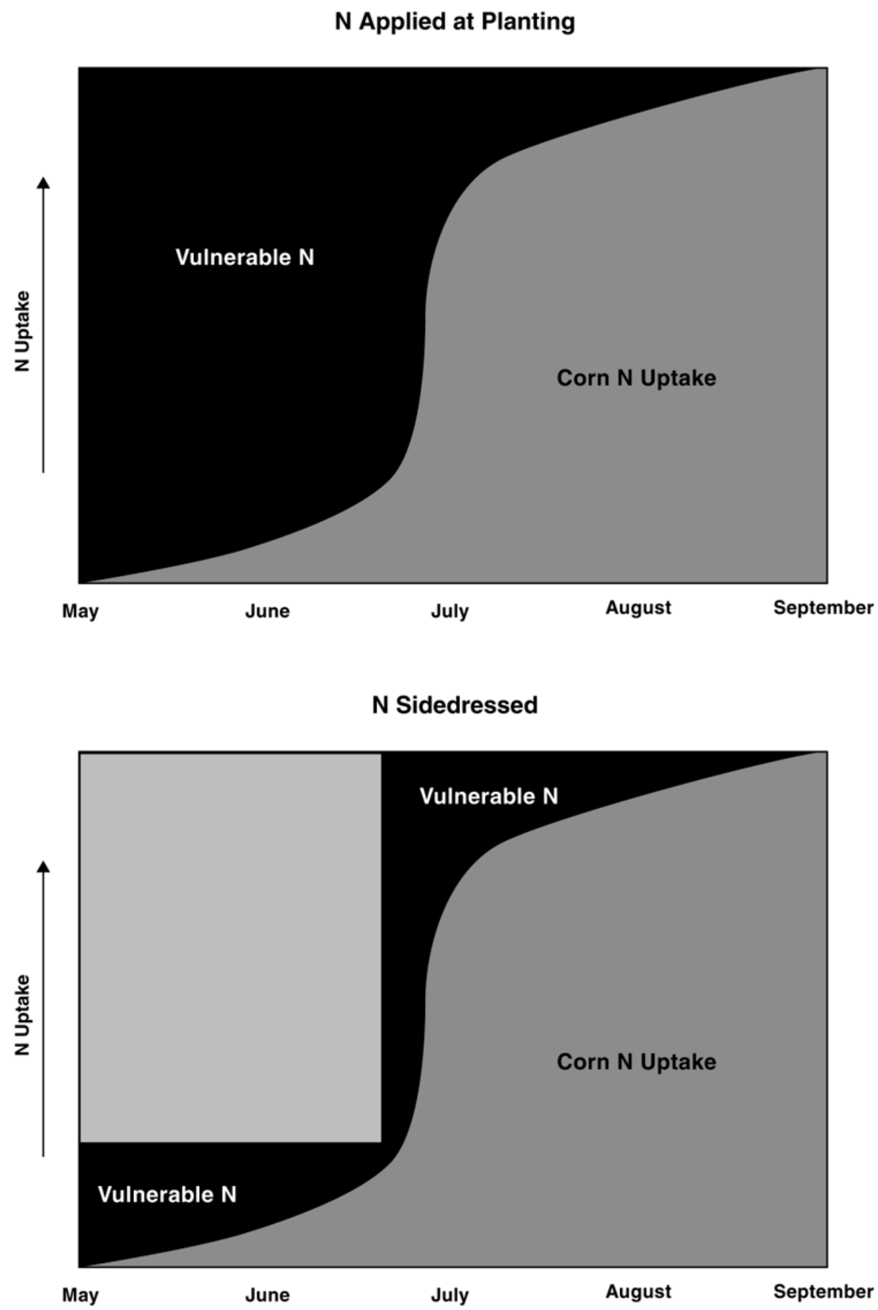
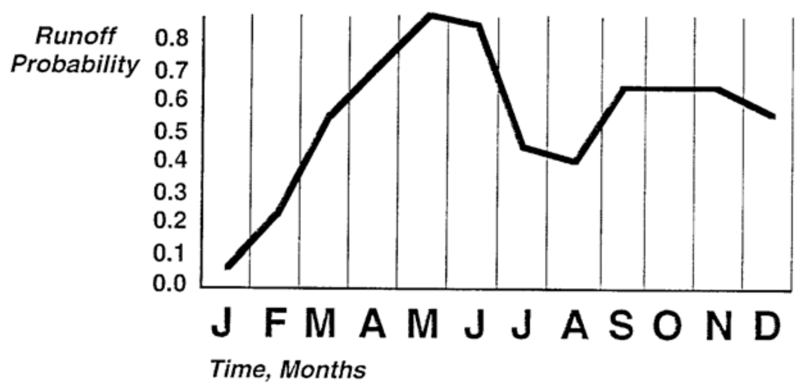


Figure 3.25 Relative vulnerability to loss of nitrogen applied at planting and sidedress.

Small grain crops use only small amounts of nitrogen early in their development. Most uptake of nitrogen occurs from jointing to boot. Nitrogen applications should be timed to coincide as closely as possible with these growth stages. For example, nitrogen is applied to winter wheat in humid areas usually in late winter or early spring, just before jointing. In dry areas where leaching potential is low, nitrogen may be applied earlier without significant loss.

Most of the poultry litter in the southeast U.S. is spread on fescue or bermudagrass pastures during the months of March, April, and May. Historic climate data indicates that these same months have the highest probability for storm intensities that create runoff and erosion (figure 3.26a). Consequently these large storms are responsible for the transport of the bulk of phosphorus to surface waters. Manure application timing strategies such as split application in early fall and early winter will avoid application of manure during periods of high runoff probability and thus environmental risk. Regardless of the time of year of application, weather forecast should be monitored to guide manure applications so that manure is not applied within 48 hours of anticipated rainfall that could produce a runoff event.



(Edwards, D.R., 1989)

Figure 3.26a Hydrograph showing runoff during the year in northwest Arkansas.

Method of Application

Method of fertilizer application and placement can significantly influence crop growth, fertilizer use efficiency, and environmental impact of applied nutrients. Application and placement methods selected will depend upon cropping system, form of nutrient source, and soil properties and anticipated climatic conditions (figure 3.26b).

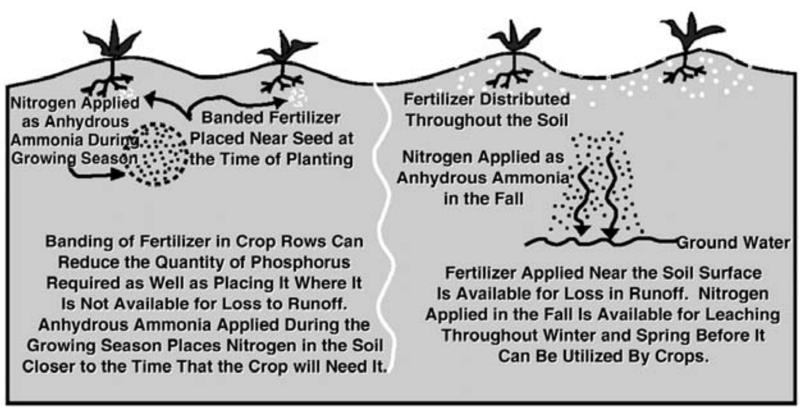


Figure 3.26b The pollutant delivery process.

Nitrogen incorporation

Use of urea fertilizer as an N source can result in N losses if the fertilizer is not incorporated. Loss of urea N because of volatilization may be eliminated by immediate mechanical or water (rainfall or irrigation) incorporation. Because of the volatilization problem, no-till corn production requires better fertilizer management. Non-urea N fertilizers are not usually subject to volatilization losses. However, on high pH soils (>7.5) ammonia can be volatilized from any ammonium source.

Nitrogen application methods

The same N materials available for preplant application are generally compatible with sidedress application. The materials and their associated methods of application each have certain limitations with regard to sidedressing.

Whether applied preplant or as a sidedress, anhydrous ammonia is an excellent source of N when proper soil conditions exist. However, if rocks or uneven terrain cause the injection knives to come out of the soil, NH_3 will immediately be lost to the atmosphere. Soil moisture is chemically and physically important for effective application of anhydrous ammonia. The NH_3 reacts with water to form NH_4^+ and is adsorbed to the soil particles. Soil moisture also affects the closure of the soil slit behind the knife and thus the escape of NH_3. Timing of sidedress NH_3 application, therefore, may be more critical than that of other materials. The presence of a crop does not prevent sidedress broadcasting of granular forms of N. Broadcasting is still probably the least time-consuming method of application, but leaf burn from the fertilizer granules is likely. However, plants recover within 2 weeks, apparently with no potential yield reduction. If urea is the N source used, surface application without incorporation by water (rainfall or irrigation) or cultivation can result in volatilization and loss of 30 percent or more of the applied N. If N is applied without incorporation, apply it to a dry soil surface, preferably just before a rain. In areas with low rainfall, surface sidedress applications may be less effective than subsurface banding because nitrogen will not move down into the active root zone available for plant uptake. Spinner spreader application inherently either covers field edges too lightly or wastes N beyond the field edges.

Solutions of urea and ammonium nitrate (UAN) are versatile, and their use, especially on no-till corn, has been increasing. Spray applications, either pre- or post emergence as a sidedress, are often combined with herbicides in a *weed and feed* operation. Such an operation saves a trip through the fields, but spray application increases the susceptibility of urea N to volatilization and loss. In addition, corn leaf burn is generally worse than when broadcasting granular forms. Again, however, recovery without yield reduction is usually the case.

More efficient use of fertilizer N, in terms of total N availability, can be obtained with sidedress banding. Banding conserves the N applied and provides more uniform distribution of N across the field. A practical method for banding N is to apply UAN solution dribbled between the corn rows from hoses attached to the nozzles of a boom sprayer. Hoses should drag the ground to prevent them from swinging freely. The nozzle spacing should be close to that of the corn row spacing. Applying the N solution between alternate rows is adequate, in most cases, if the band placement is approximately midway between the two rows.

When sprayed and dribbled applications of UAN were compared at several rates of N, maximum yield was obtained at a much lower rate with the dribbled application. Spraying, as compared to dribbling, exposes a larger proportion of the solution to the atmosphere and thus facilitates volatilization under certain conditions. Although the differences between the methods may not be large every year, the risk potential of dollars of yield lost favors dribbled application, even though it may be a slower operation.

Phosphorus Placement

Because of phosphorus immobility and soil fixation, placement of fertilizer phosphorus can affect its availability to plants. Fertilizer that is broadcast and plowed down is mixed uniformly with a large amount of soil. Thus, the probability of root contact with the fertilizer is maximized. So too, though, is fertilizer contact with absorbing surfaces in the soil. When the fertilizer is applied as a concentrated band, contact with the soil, and thus fixation, is minimized; however, lack of phosphorus movement from point of placement also means that the number of roots in contact with the fertilizer may also be minimized. The greater the ability of the soil to fix phosphorus, the greater too the importance in overriding that fixation capacity with a concentrated band. Crop response to fertilizer phosphorus placement is further complicated by crop root characteristics, soil phosphorus levels, and soil temperature.

Placement limitations imposed by sod crops and no-till culture often result in an accumulation of nutrients near the soil surface. Provided proper residue management is practiced, corn root distribution appears to respond to differences in soil moisture and nutrient location in no-till culture, producing greater root density within the surface 6 inches of soil. With proper residue management nutrient uptake of surface applied fertilizer equals or exceeds uptake under conventional-till management.

Is band or broadcast application the better method? The answer depends mostly on the soil phosphorus status. On soils with optimum to high levels of phosphorus, banding has less advantage and broadcast applications are generally adequate (sometimes superior to banding). Row crops in general, and corn in particular, appear to yield better when soils contain relatively high levels of phosphorus throughout the rooting profile. In tests with the recommended phosphorus application split between band and broadcast, versus all by one method, the maximum yields have been obtained with some combination. The advantage to building up the general soil level of phosphorus is probably because of the need of all roots to take up some phosphorus.

Crops with limited rooting systems have less capacity to explore soil. Therefore, phosphorus placement is more critical for shallow-rooted crops than for deep-rooted or perennial crops. Greater yield response to banded-P is common, especially on low phosphorus soils or soils that have a greater ability to fix phosphorus. Recommendations of incorporated-broadcast phosphorus for small grains have frequently been twice as high as if the phosphorus were banded because higher soil phosphorus levels compensate for reduced phosphorus uptake ability of the crop. Where soils are built up to optimum or high phosphorus levels, however, banded or broadcast-P can be equally effective.

Starter fertilizer is usually a specific band application at a specific time. Even if you are planning to broadcast the majority of the required nutrients, a banded starter application is important for spring-planted crops, particularly corn. However, on soils that have excessive nutrient levels or for late planting on soils that have optimum or high nutrient levels, a starter fertilizer may not be necessary.

Limited root growth combined with cold and wet soils early in the season, especially in no-till fields, reduces the availability of phosphorus and the plant's uptake ability. Early plant vigor, and often final yield, are improved by starter-P applied close to seedling roots, even when soil phosphorus levels are high or when manure has been applied. Phosphate applied in combination with ammonium-N results in greater phosphorus uptake.

Phosphorus itself has a low salt effect and may be placed close to the seed; however, if applied with N and K_2O, the rate should be limited so as to supply no more than 70 pounds total of N and K_2O if placed 2x2 inches from the seed. If starter fertilizer is placed in the row with the seed, the safe rate drops to 10 pounds total N plus K_2O per acre. In this case neither DAP nor urea are acceptable materials! Although most N sources are readily soluble, their suitability in a starter application varies greatly.

Ammonium sources of N, compared to other N sources, increase P uptake. Ammonium phosphate materials are thus used regularly in starter formulations, and monoammonium phosphate (MAP) is an excellent material for this purpose. However, reactions producing free ammonia (NH_3) occur with diammonium phosphate (DAP). Ammonia is toxic to seedling roots, and this material is safe for starter use only when the rate is kept low and the material is placed two inches away from the seed. For this same reason, urea, which produces more free ammonia, should never be used in a starter fertilizer application. Subtract nutrients applied in the starter from the total amount recommended.

The best time to think about starter fertilizer for alfalfa establishment is in the years before rotating a field to alfalfa. Yield response to starter fertilizer is most likely when the alfalfa seedlings will be stressed by low fertility level or by adverse soil or moisture conditions. High soil phosphorus level is required by the forage, so plan ahead by building phosphorus levels into the high range during the last year of corn, and soil test in the fall before alfalfa establishment. If fertility is optimum by planting time, starter fertilizer can usually be omitted.

Fertigation is the practice of applying plant nutrients through irrigation water. Fertigation is one type of chemigation that refers to the application of any chemical through irrigation water. Fertigation offers distinct advantages in comparison to conventional application methods:

- Soil compaction is avoided because heavy equipment never enters the field.
- The crop is not damaged by root pruning, breakage of leaves, or bending of the plants as occurs with conventional chemical field application techniques.
- Less equipment may be required to apply the chemical.
- Less energy is expended in applying the chemical.
- Usually less labor is needed to supervise the application.
- The supply of nutrients can be more carefully regulated and monitored.
- The nutrients can be distributed more evenly throughout the entire root zone or soil profile.
- The nutrients can be supplied incrementally throughout the season to meet the actual nutritional requirements of the crop.

- Nutrients can be applied to the soil when crop or soil conditions would otherwise prohibit entry into the field with conventional equipment.

Fertigation is applicable in some form to all types of irrigation. Remember, with fertigation the uniformity of nutrient application is only as good as the uniformity of the water application. Therefore, irrigation flood or furrow irrigation may not be an efficient way of applying a leachable nutrient such as nitrogen. Extra nitrogen will be applied in places where extra water is applied. This can lead to an increased potential for nitrogen leaching. Water leaving the field can also carry nutrients that have been added through fertigation to adjacent surface water.

Fertigation is used extensively with sprinkler irrigation. The major advantages of this management practice is the ability to put the nutrient where the water is and thus increase nutrient use efficiency. To apply nutrients, especially nitrogen, throughout the growing season as required by the plant significantly increases nitrogen uptake, improves use efficiency, and reduces the potential for leaching losses.

Drip irrigation and micro sprinkler irrigation techniques limit the volume of soil explored by the plant root system. Therefore, fertigation that puts the nutrients where the water has been applied is a physiological necessity.

Nitrogen is the primary nutrient added through fertigation. Other nutrients such as phosphorus and potassium are applied in some areas. The quality of the irrigation water plays an important role in fertigation. Poor quality of irrigation water may lead to the formation of chemical precipitates when crop nutrients are added to the water.

Fertigation applies nutrients to the soil, and these nutrients are intended to be absorbed by the plant roots. Foliar application of nutrients intends that the plant absorbs the nutrients though the leaf or stem.

Foliar fertilization

Fertilizer solutions in the proper nutrient concentrations can be applied directly to the leaf surface of the plant. A portion of the applied nutrient can be absorbed through the foliage. Urea, potassium, and zinc may be taken rapidly into the plant through the leaf tissue. The effectiveness of foliar application is dependent upon the crop, the form of the nutrient, and the climatic conditions.

Student Activity 12

1. How can nutrient application timing maximize application efficiency and reduce a potential environmental hazard?

3. List five advantages to fertigation over conventional fertilizer application methods on irrigated cropland.

   a.

   b.

   c.

   d.

   e.

4. List the four major components of nutrient application management.

a. ______________________________

____

____

b. ______________________________

____

____

c. ______________________________

____

____

d. ______________________________

____

____

Group Activity 2—Optional

Note to Student: Group activities will be handled in a facilitated session.

1. List and discuss the four major components of nutrient application management in a group setting.

   a. ______________________________

   ____

   ____

   b. ______________________________

   ____

   ____

   c. ______________________________

   ____

   ____

   d. ______________________________

   ____

   ____

2. List three major agronomic crops in your area and describe the timing and placement alternatives for optimum production and minimum environmental impact.

a. ____

____

____

b. ____

____

____

c. ____

____

____

References

Soil Fertility. (Second Edition) by Henry D. Forth and Boyd G. Ellis, Lewis Publishers, 1996. This is a general soil fertility text that covers the basics of soil fertility and is used in many college courses.

Western Fertilizer Handbook. Interstate Publishers, Inc., 510 North Vermillion Street, P.O. Box 50, Danville, IL 61834-0050. Although listed as a western handbook this general book would be of value in all locations. It contains good basic information as well as knowledge accumulated by the writers over a number of years of filed experience. The book contains many charts, nutrient contents, and practical conversions.

Module 3, Part G, Section 1— Introduction to Integrated Pest Management, Meet the Pests

Instructions to the Student

You should view the IPM video at this time. Upon completion of the video, continue your study in this Student Guide.

Supporting Objectives

- Define *pest*.
- Name five major groups of agricultural pests and give an example of each including the damage they may cause.

NRCS pest management policy defines *pest* as a weed, insect, disease, animal, and other organism (including invasive and non-invasive species) that directly or indirectly causes damage or annoyance by destroying food and fiber products, causes structural damage, or creates a poor environment for other organisms. A pest is any organism (plant or animal) judged by people as undesirable. The important idea is that the term pest is an entirely artificial and human-defined judgement. Ecologically speaking, no organism is born a pest; it all depends on human perspective. For example, a corn plant that sprouts from a seed that remains in the field after harvest and that grows the next year in a soybean field could be a pest if it reduces bean yield by competing for water and light or if it interferes with soybean harvest. Yet other people correctly could consider that same corn plant a desirable species if it harbors beneficial insects that attack an insect that threatens the soybean crop.

So why exactly is this distinction important? The answer is because pest problems do not arise as independent or isolated events. Crops are ecosystems. They are governed by the same biological processes in natural ecosystems. The implications are that attempts to control one pest species without regard for the entire ecosystem can disrupt checks and balances between crop plants, pests, beneficials and the physical environment. Failure to appreciate these ecological interactions may only increase the severity of pest infestations. Action taken against one pest may exacerbate problems with another or may be incompatible with another control tactic. IPM depends on a detailed understanding of pest growth and development; particularly the forces that explain outbreaks and that predict survival.

Major Pest Groups of Agricultural and Horticultural Crops

Major pests of agricultural and horticultural crops include insects and their relatives, nematodes, pathogens, vertebrates, and weeds.

- Insects and related arthropods: such invertebrate animals as caterpillars, bugs, beetles, and mites that cause injury by feeding on plants and animals and by serving as a vector for (transmitting) pathogens that cause diseases;
- Nematodes: microscopic, multicellular, unsegmented roundworms that parasitize animals and plants. Most nematodes that attack agricultural crops feed on the roots; a few feed aboveground on inside stems and leaves;
- Pathogens: disease-causing bacteria, fungi, viruses and related organisms. Note that a pathogen is the agent whose injury causes a disease whereas a disease is an injury or impairment that the pathogen causes. Most pathogens are too small to be seen with the naked eye, while the diseases they cause produce visual symptoms in the plant.

- Vertebrates: Any native or introduced, wild or feral, non-human species of vertebrate animal that is detrimental to one or more persons as a health hazard, general nuisance, or by destroying food, fiber, or natural resources. The majority of direct damage is caused by vertebrate feeding in agricultural crops, including such animals as mice, rats and birds. Vertebrates may also cause damage indirectly by transmitting human diseases.

- Weeds: undesirable plants that reduce crop yield and quality by competing for space, water, and nutrients; weeds also may harbor crop-attacking insects and pathogens. Weeds also include plants that interfere with other human activities, such as by prolifically growing in waterways, or those that cause discomfort, such as skin irritation or hay fever;

Student Activity 13

1. List the five major pest groups of agriculture and horticulture and give an example of each including the damage they may cause.

a. ____

____

____

b. ____

____

____

c. ____

____

____

d. ____

____

____

e. ____

____

____

Group Activity 3—Optional

Note to Student: Group activities will be handled in a facilitated session.

1. What are the major pests in your area?

2. What pests do you find are the greatest nuisances?

3. List some examples from your area of plant, insect or other organisms that are a pest in one situation and not in another.

Module 3, Part G, Section 2— Definition and Goals

Supporting Objectives

- Define integrated pest management (IPM).
- Describe the role for chemical pesticides in IPM.
- Describe the basic goal of IPM.
- Describe the "PAMS" approach to IPM and give examples for each PAMS category.

Integrated Pest Management

Integrated Pest Management (IPM) is a sustainable approach to pest control that combines the use of prevention, avoidance, monitoring, and suppression strategies to maintain pest populations below economically damaging levels and to minimize harmful effects of pest control on human health and environmental resources. IPM includes biological controls, cultural controls, and the judicious use of chemical controls.

Integrated means that a broad interdisciplinary approach is taken using scientific principles of plant protection to bring together a variety of management tactics into an overall strategy. IPM strives for maximum use of naturally occurring control forces of the pest's environment, including weather, pest diseases, predators, and parasites.

Rather than focusing on 'one-shot' chemicals to kill pests after problems occur, IPM looks first to non-chemical measures that help prevent problems from developing in the first place. With IPM, the role for chemical pesticides is one of a treatment of last resort if alternatives fail to correct the problem. Pesticides never are applied according to a preset schedule or spray calendar in an IPM program. Instead, they only are used if close inspection shows they really are needed to prevent severe damage.

The goal of IPM is to satisfy economic, environmental, and social objectives (which sometimes are in conflict with each other) to develop cost-effective pest control that minimizes adverse impacts on human health or the quality of environmental resources. Although the theory and practice of IPM first was put forth by entomologists during the 1950's and 60's in response to the problems associated with insecticide misuse, particularly the so-called *pesticide treadmill*, it quickly was embraced by all the plant protection disciplines and since has become the dominant philosophy of pest control in agriculture. The broad appeal of IPM is that it combines principles of ecology and economics in ways that provide farmers with effective pest suppression at the same time it minimizes adverse impacts to environmental resources and human health. The Federal Government has provided considerable funds for IPM research and demonstration during the past 25 years. University Cooperative Extension System IPM programs have been in place nationally for nearly 20 years. Virtually every economic evaluation of these programs has demonstrated increased profits to farmers through decreased production costs, primarily by eliminating unnecessary (preventative) pesticide use.

Conceptually, the various pest control tactics that make up an IPM system comprise a triad (figure 3.27) that fits together such complimentary non-chemical measures as biological and cultural methods with pesticides. The idea is that the weaknesses of any single control measure are outweighed by the strengths of the other tactics. But whereas figure 3.27 depicts an idealized textbook definition of pest management, IPM in the real world more often makes relatively minor use of biological or other non-chemical methods and instead primarily depends on pesticides applied prescriptively when field scouting shows that pest infestation levels exceed critical threshold densities (figure 3.28). Some critics argue for an alternative approach, christened *bio-intensive IPM* (figure 3.29). Here conventional pesticides are replaced by so-called bio-rational or least-toxic pesticides products that only kill the target pests and so pose reduced risks to human health or environmental quality. Under bio-intensive IPM, conventional pesticides only are used if all other alternatives fail. Although bio-intensive IPM is a worthy goal, relatively few bio-rational products presently are available to make it work in commercial agriculture.

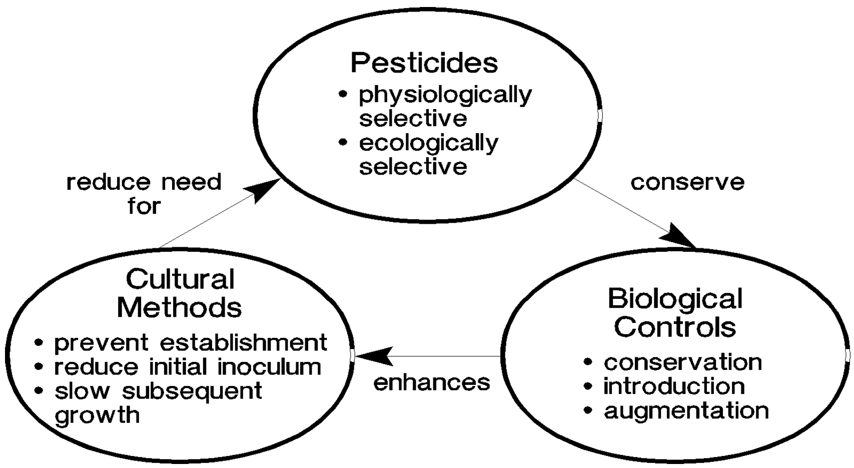


Figure 3.27 Conceptual model for Integrated Pest Management showing how control tactics are integrated into a complimentary system.

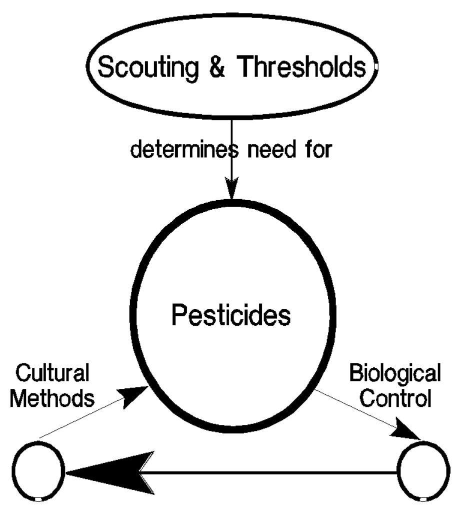


Figure 3.28 Prescriptive IPM depends largely on judicious use of pesticides as determined by regular field scouting to determine if pest infestations exceed critical threshold levels that justify pesticide application. The importance of each pest control tactic within the overall IPM system is depicted by its size relative to other tactics.

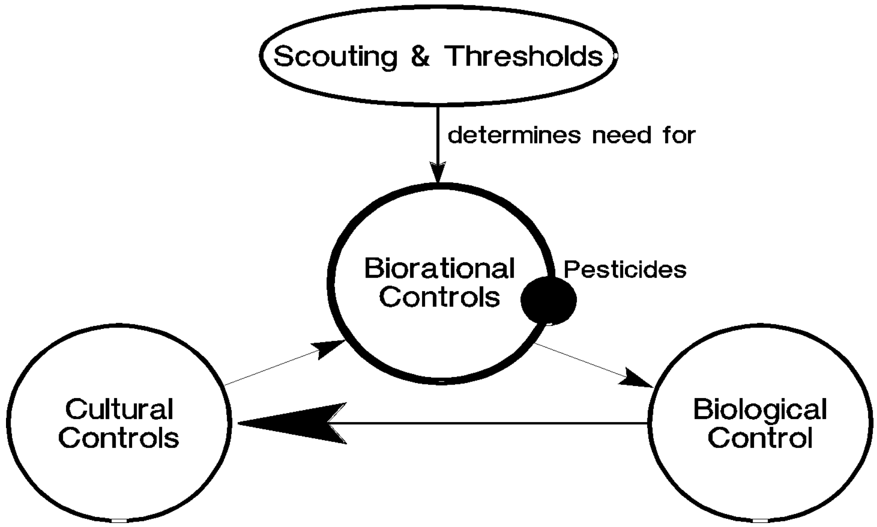


Figure 3.29 Bio-intensive IPM attempts to reduce use of conventional pesticides by looking first to biological and cultural alternatives as well as use of *least-toxic* bio-rational products that only kill the target pest. The importance each pest control tactic within the overall IPM system is depicted by its size relative to other tactics.

By definition, IPM deals with pests in the broadest sense: insects, mites, nematodes, pathogens, weeds, vertebrates, or any organism considered by people a nuisance or that injures humans, livestock and pest, crops, stored products, buildings, or possessions. In reality, this level of integration has proven difficult to achieve because of the complexity of potential antagonistic and synergistic interactions among pests. For example, planting wheat or barley the year following potatoes can reduce infestations of the Colorado potato beetles by serving as a physical barrier to adult beetles emerging from overwintering sites, but this same IPM option can increase infestations of wireworms, another key pest.

Management is the decisionmaking process to reduce pest status in a planned, systematic way by keeping their numbers below economically acceptable levels. The essence of Integrated Pest Management is decisionmaking: determining IF, WHEN, WHERE, and WHAT mix of control methods are needed.

NRCS policy defines Pest Management as “Utilizing environmentally sensitive prevention, avoidance, monitoring and suppression strategies to manage weeds, insects, diseases, animals, and other organisms (including invasive and non-invasive species) that directly or indirectly cause damage or annoyance”.

NRCS policy also contains the following definitions:

- *Prevention* is defined as “preventing pest populations (e.g., using pest-free seeds and transplants, cleaning tillage and harvesting equipment between fields, and scheduling irrigation to avoid situations conducive to disease development).”
- *Avoidance* is defined as “avoiding pest populations (e.g., using pest resistant varieties, crop rotation, trap crops).”
- *Monitoring* is defined as “identifying the extent of pest populations and/or the probability of future populations (e.g., pest scouting, soil testing, weather forecasting).”
- *Suppression* is defined as “suppressing a pest population or its impacts using cultural, biological, or chemical pest controls.”
- *Cultural Pest Control* is defined as “the use of farming practices other than chemical and biological controls to reduce a pest population or its impacts. Cultural controls include techniques, such as: rotating crops, using pest-free seed and transplants, using pest resistant varieties, using good sanitation practices, burning, and all forms of mechanical pest control (physical methods including cultivation, hoeing, hand weeding, mowing, pruning, vacuuming).”
- *Biological Pest Control* is defined as “the process of conserving, augmenting or introducing beneficial living organisms to reduce a pest population or its impacts. It includes the use of insects, nematodes, mites, plant pathogens, plants, vertebrates, and other living organisms.”

- *Chemical Pest Control* is defined as "the use of pesticides, such as herbicides, insecticides, or fungicides, to reduce a pest population or its impacts."

USDA Cooperative State Research Education and Extension Service uses "Prevention", "Avoidance", "Monitoring" and "Suppression" or "PAMS" for short, to quantify the adoption of IPM. From their IPM Webpage (http://www.reeusda.gov/ipm/whatisipm.html) under PAMS:

Determining the Practice of Integrated Pest Management

A Working Definition for the Year 2000 Goal

A key in the determination of whether the Administration's goal of 75 percent of U.S. cropland acres under integrated pest management (IPM) by the year 2000 has been reached is some rational definition of what growers must do in order to be considered as IPM practitioners. Adoption of IPM systems normally occurs along a continuum from largely reliant on prophylactic control measures and pesticides to multiple-strategy biologically intensive approaches, and is not usually an "either/or" situation. It is important to note that the practice of IPM is site-specific in nature, and individual tactics are determined by the particular crop-pest-environment scenario. Where appropriate, each site should have in place a management strategy **for Prevention, Avoidance, Monitoring, and Suppression** of pest populations (the **PAMS** approach). In order to qualify as IPM practitioners, growers should be utilizing tactics in three or more of the PAMS components.

Prevention is the practice of keeping a pest population from infesting a crop or field, and should be the first line of defense. It includes such tactics as using pest-free seeds and transplants, preventing weeds from reproducing, irrigation scheduling to avoid situations conducive to disease development, cleaning tillage and harvesting equipment between fields or operations, using field sanitation procedures, and eliminating alternate hosts or sites for insect pests and disease organisms.

Avoidance may be practiced when pest populations exist in a field or site but the impact of the pest on the crop can be avoided through some cultural practice. Examples of avoidance tactics include crop rotation such that the crop of choice is not a host for the pest, choosing cultivars with genetic resistance to pests, using trap crops or pheromone traps, choosing cultivars with maturity dates that may allow harvest before pest populations develop, fertilization programs to promote rapid crop development, and simply not planting certain areas of fields where pest populations are likely to cause crop failure. Some tactics for prevention and avoidance strategies may overlap in most systems.

Monitoring and proper identification of pests through surveys or scouting programs, including trapping, weather monitoring and soil testing where appropriate, should be performed as the basis for any suppression activities. Records should be kept of pest incidence and distribution for each field. Such records form the basis for crop rotation selection, economic thresholds, and suppressive actions.

Suppression of pest populations may become necessary to avoid economic loss if prevention and avoidance tactics are not successful. Suppressive tactics may include cultural practices such as narrow row spacings or optimized in-row plant populations, alternative tillage approaches such as no-till or strip- till systems, cover crops or mulches, or using crops with allelopathic potential in the rotation. Physical suppression tactics may include cultivation or mowing for weed control, baited or pheromone traps for certain insects, and temperature management or exclusion devices for insect and disease management. Biological controls, including mating disruption for insects, should be considered as alternatives to conventional pesticides, especially where long-term control of an especially troublesome pest species can be obtained. Where naturally-occurring biological controls exist, effort should be made to conserve these valuable tools. Chemical pesticides are important in IPM programs, and some use will remain necessary. However, pesticides should be applied as a last resort in suppression systems using the following sound management approach: (1) The cost:benefit should be confirmed prior to use (using economic thresholds where available); (2) Pesticides should be selected based on least negative effects on environment and human health in addition to efficacy and economics; (3) Where economically and technically feasible, precision agriculture or other appropriate new technology should be utilized to limit pesticide use to areas where pests actually exist or are reasonably expected; (4) Sprayers or other application devices should be calibrated prior to use and occasionally during the use season; (5) Chemicals with the same mode of action should not be used continuously on the same field in order to avoid resistance development; and (6) Vegetative buffers should be used around stream banks to minimize chemical movement to surface water.

Integrated Pest Management Committee
U.S. Department of Agriculture
October 1998

The USDA National Agricultural Statistics Service also used the "PAMS" approach to report the national adoption of IPM. Their 1999 report (http://usda.mannlib.cornell.edu/reports/nassr/other/pest/pestan99.pdf) used the following questions to identify practices in each of the four "PAMS" categories:

Prevention

- Did you use such practices as tilling, mowing, burning, or chopping of field lanes or roadways to manage pests?
- Did you remove or plow down crop residues to control pests?
- Did you clean tillage or harvesting implements after completing fieldwork for the purpose of reducing the spread of weeds, diseases, or other pests?
- Did you use such water management practices as controlled drainage or irrigation scheduling, excluding chemigation, to control pests?"

Avoidance

- Did you use any seed varieties with Bt (*Bacillus thuringiensis*) genes for insect resistance?
- Did you adjust planting or harvesting dates to control pests?
- Do you rotate crops for the purpose of controlling pests?
- Did you use seed varieties that were genetically modified to be resistant to plant pathogens or nematodes that cause plant diseases?

Monitoring

- Were any of the crops on this operation scouted for pests (weeds, insects, or disease) using a systematic method?
- Were electronic or written records kept to track the activity or numbers of different pests?
- Did you use field maps of previous weed problems to assist you in making weed management decisions?
- Did you use soil analysis to detect the presence of such pests as insects, disease, or nematodes?
- Did you use pheromones to monitor the presence of pests?
- Did you use weather monitoring to predict the need for pesticide applications?

Suppression

- Did you use any seed varieties that were genetically modified to be resistant to specific herbicides?
- Did you use scouting data and compare it to university or extension guidelines for infestation thresholds to determine when to take measures to control pests?
- Did you use such topically applied biological pesticides as Bt (*Bacillus thuringiensis*), insect growth regulators, neem or other natural products to control pests?

Student Activity 14

1. Is the ultimate objective of IPM to eliminate the use of agricultural pesticides?

2. Management is the decisionmaking process to reduce pest status in a planned, systematic way by keeping their numbers below economically acceptable levels. The essence of integrated pest management is decisionmaking, which involves determining what four things?

3. What is the goal of IPM?

4. Describe the "PAMS" approach to IPM and give an example for each PAMS category.

Module 3, Part G, Section 3— Alternative Approaches to IPM

Supporting Objective

- Define and differentiate between eradication, organic pest control, best management practices, sustainable agriculture, and integrated crop management

Definitions

Many terms have been coined to describe different approaches to pest control. *Eradication*, the total elimination of a pest, is the antithesis of integrated pest management. IPM holds that eradication seldom is desirable even if technically feasible. One strategy of IPM is to leave a *pest residue*, a permanent but economically insignificant population of the pest that serves as a food source for beneficial natural enemies of the pest. An exception to this rule is small, geographically localized infestations of exotic pests (such as an accidentally-introduced, highly-invasive foreign weed growing in a small patch). Here eradication (total elimination) and not IPM (reducing the infestation to tolerable levels) is the better strategy.

Organic pest control (or organic farming) might best be considered a subset of integrated pest management. Like IPM, organic pest control looks first to alternatives to pesticides as the best way to reduce pest populations to acceptable levels. But unlike IPM, organic pest control never uses synthetic or manufactured chemical pesticides. Instead, organic farmers only use such naturally occurring products as pesticides extracted from plants or mineral dusts mined from the earth.

BMPs (Best Management Practices) usually are defined as a system of farming practices designed to address specific resource concerns, such as to reduce soil erosion or to protect water quality. Examples include conservation tillage methods that increase crop residue on erodible soil or precision-farming practices that match nutrient inputs (fertilizer application rates) to variation in farm landscape. Like IPM methods, BMPs protect and enhance the quality of environment. But the relationship between BMPs and IPM is not simple. Some IPM methods and BMPs complement and enhance each other; others directly conflict and antagonize each other. It all depends on the situation.

Examples

Consider the following two examples:

Example 1

Some sugarbeet growers in Idaho prefer to apply insecticides at planting time to kill the larval stage of the sugarbeet root maggot, the most important insect pest of sugarbeets. But the problems with planting-time applications are two-fold:

- not knowing at planting time if insecticides are needed because root maggot flies do not invade beet fields and lay eggs until after the seeds germinate and plants subsequently grow to the 6+ leaf stage;
- several insecticides commonly used for at-planting root maggot control have a comparative high potential for leaching into ground water because they are highly soluble in water.

The IPM alternative to automatic insecticide application is to monitor fly populations with traps placed at field edges during April and May. Unless captures exceed 45 to 55 flies, insecticides are not needed. Beet growers in one county who used traps eliminated 87 percent of their at-planting applications of insecticides without decreases in crop yield or quality. In this case, IPM in fact becomes a BMP—use of traps reduces the need to for pesticides that pose a risk to ground water quality. Here the role for IPM in preventing contamination of ground water is two-fold: as a source-reduction technology and as a risk-abatement technology. Agricultural pesticides are potential pollution threats to surface and ground water quality. IPM can help protect water quality by minimizing the amounts of pesticides that farmers use and by helping farmers to apply pesticides in ways that decrease the risk of chemicals washing off fields into lakes and rivers or leaching into ground water.

Example 2

Hessian fly is an important insect pest of wheat in the Palouse region, an area of northern Idaho and eastern Washington. This area of the U.S. has the highest yield potential of any dryland (non-irrigated) wheat production area, as well as one of the most serious soil erosion problems. In some areas where conventional tillage practices are used, 12 bushels of topsoil (on a weight basis) are lost to erosion for every bushel of wheat produced. An effective IPM approach to Hessian fly control is to destroy the pest's overwintering site—the crop stubble—by either burning fields after harvest or by deep plowing to bury the stubble. Here IPM is at odds with BMPs that try to maximize crop residue on the soil surface. In most cases, alternative IPM methods can be identified as substitutes for those that conflict with the long-term goals of reducing soil erosion.

Hessian fly management in the Pacific Northwest is addressed in the PNW CONSERVATION TILLAGE HANDBOOK SERIES, Chap. 8, Crops and Varieties -No. 15, September 1993 (http://pnwsteep.wsu.edu/Tillage_Handbook/chapter8/081593.html)

Are Management Practices Compatible with Farm Conservation Plans?

Hessian fly is an exception to the general rule that insect pests of cereals in the Northwest are not influenced by choice of tillage and residue management. Conservation tillage systems leave more infested stubble and volunteer plants on or near the soil surface than under more intensive tillage practices. Because few fly larvae or puparia are buried to an adequate depth to prevent emergence, there can be a greater survival of the pest under conservation tillage. Fortunately, the potential for Hessian fly damage in the subsequent wheat crop depends more on management options for the following crops than it depends on tillage and residue management practices after an infested crop. Using an integrated approach, Hessian fly can be effectively managed under conservation tillage systems...

Management Options Under Conservation Tillage

Overview

For Hessian fly, as with most crop pests, there is no one management choice that will provide complete control. The most effective control will be through the use of an integrated management approach which takes into account all applicable management options. Growers need to balance control strategies with other yield limitations and management considerations. Management impacts on water conservation and erosion protection are just two examples.

Water Conservation—Management effects on water storage and resultant yield potential need to be considered. In this dryland production region with predominantly winter season precipitation, the amount of soil water stored overwinter is a primary yield-limiting factor. Consequently, the influence of the tillage and residue management practices on water storage must be considered when developing strategies for control of Hessian fly and other pests. Reduced water storage potential with intensive tillage and residue removal could limit yield more than fly damage.

Erosion Protection—Most farm conservation plans spell out the amounts of surface residue required to control wind and water erosion. Growers need to contact their local conservation district to make sure that the Hessian fly management practices they select will allow them to meet the goals of their farm conservation plans.

Summary

After harvest of a wheat crop infested with Hessian fly, growers should not significantly change tillage and residue management practices. Severe tillage to deeply bury infested residue should only be considered on cropland which is not highly erodible. Stubble burning is not recommended because of minimal reduction in fly survival and increased potential for soil erosion. Hessian fly can be managed within the tillage and residue management practices included in farm conservation plans. To control Hessian fly in conservation systems, growers should consider an integrated approach utilizing all feasible control options including: resistant spring wheat varieties, crop rotations with less susceptible or non-host crops, early control of volunteer wheat and host weeds, adjusted seeding dates and management for a healthy crop. In-furrow insecticides could be considered for reducing infestation potential during seedling establishment when other control options are not feasible.

A more recent term associated with pest control is *sustainable agriculture*. Sustainable agriculture tries to address concerns about pesticide residue on foods, contamination of drinking water, soil erosion, and high costs of farming, concerns that are causing some people to question the economic and ecological viability of U.S. agriculture. Agrichemicals comprise 15 to 50 percent of variable crop and livestock production costs. Soil erosion by wind and water on cropland reduces farm productivity and destroys wildlife habitat. Ground water is vulnerable to contamination by agricultural fertilizers and pesticides. How long can we afford a capital intensive, fossil-fuel dependent way of farming?

Sustainable agriculture believes that production inputs can be used in ways that maintain soil productivity while conserving natural resources and protecting human health, and at the same time, assuring farmer profitability. Sustainable agriculture, like IPM, is a philosophy and not a predetermined set of specific methods. It starts by considering the entire farming system rather than such individual questions as what rate of fertilizer to use or how to control a particular pest species in one crop. The systems approach recognizes that there are natural links and balances between crops, pests, beneficial species, and their physical environment. Without whole farm planning and analysis, a solution to one problem might be taken that produces an entirely different problem that could have been avoided. For example, excessive nitrogen fertilizer can increase populations of some insects by improving the nutritional quality of the plant for the pest. In the simplest sense, sustainable agriculture is the marriage of BMPs to IPM.

Although the methods of sustainable agriculture are specific to each farm, one guiding principle is to substitute renewable nutrient inputs and pest controls for those otherwise purchased off-farm. Examples include using animal or green manures, incorporating legumes in crop rotations, and conserving indigenous beneficial biocontrol agents. This does not mean that sustainable agriculture tries to eliminate chemical pesticides or synthetic fertilizers. It simply recognizes that inputs sometimes are used in amounts that cannot be justified economically or ecologically. Sustainable agriculture suggests that effective alternatives that can be produced on the farm should be used when possible.

Integrated Crop Management (ICM) is synonymous with sustainable agriculture. ICM is another way of saying that it is important to consider the entire cropping system when selecting farming practices.

Student Activity 15

1. What advice would you give to a producer if the BMPs required to reduce soil erosion also increased the severity of the pest infestation?

   ____

   ____

   ____

2. Define the following terms and describe the differences and similarities with IPM.

   Eradication ______________________________________

   ____

   ____

   ____

   ____

   Organic pest control ______________________________

   ____

   ____

   ____

   ____

   Best management practices __________________________

   ____

   ____

   ____

   ____

Sustainable agriculture ____________________________________

____

____

____

____

Integrated crop management ______________________________

____

____

____

____

Module 3, Part G, Section 4—Historical Perspective: Why do we need IPM?

Supporting Objectives

- Describe what is meant by the term *pesticide residue*.
- List the three R's of pesticide misuse.
- Name the fourth R of pesticide misuse.
- Describe three ways that pests can overcome the toxic effects of pesticides.
- Differentiate between resurgence and replacement. Show with a graph the difference between these two phenomena.
- Explain the pesticide treadmill (spiral) and its significance in pest management.
- Discuss the most common reason for pest resurgence and replacement.
- State the role played by Rachel Carson in the historical development of IPM.

Before the advent of synthetic organic insecticides during the 1940's, agricultural pesticides largely were limited to inorganic and botanical insecticides. Because these were difficult to use (to say nothing of not always being effective and sometimes even toxic to the plants they were meant to protect), farmers did not rely on insecticides alone. Instead, they used insecticides in combination with simple cultural and physical practices. But discovery of dichloro diphenyl trichloroethane (DDT) and its relatives changed pest control. The new synthetic pesticides were everything that old inorganic were not—inexpensive, easy to apply, seemingly safe to use (DDT saved millions of lives during WWII by controlling body lice that vector typhus) and most importantly, extremely effective. A single application gave season long control and a degree of insect control that far surpassed that of the old inorganics. Pesticide use became automatic, with applications based on a calendar schedule.

But nature fought back and problems with over reliance on insecticides soon appeared. The adverse consequences of over dependence on pesticides—resistance, resurgence, and replacement—collectively referred to as the *three R's of pesticide misuse*, began to occur with shocking regularity.

Resistance is the innate (genetically inherited) ability of organisms to evolve strains that can survive exposure to pesticides formerly lethal to earlier generations. Genetically inherited means that parents pass their own ability to resist a pesticide to their offspring. Resistance never occurs through habituation during the lifetime of a single individual. You cannot cause an individual to change from susceptible to resistant by "getting it used to the pesticide," by dosing it with increasing amounts of the chemical.

In theory, pests can develop resistance to any type of IPM tactic—biological, cultural, or chemical. In the Midwest, farmers routinely rotate corn with soybeans to break the infestation cycle of the corn rootworm, an insect that only feeds on grassy plants and so has become the key insect pest of field corn. Yet the rootworm has developed strains that overcome crop rotation by extending their overwintering resting stage in the soil from one winter to several winters and so are ready to attack corn the next time it is planted in the field. Still other rootworm populations have developed strains that feed both on corn and soybean.

In practice, the phenomenon most frequently occurs in response to pesticide use. Insects were the first group of pests to develop pesticide resistant strains. Worldwide, over 600 species are resistant to at least one insecticide; some are resistant to all the major classes of insecticides. Herbicide-resistant weeds now number more than 100 worldwide; fungicide-resistant plant pathogens too are known.

Pesticide resistance can develop when a single pesticide (or single class of chemically related pesticides) is applied repeatedly. As is depicted in figure 3.30, initial application typically causes heavy mortality in pest population. However, a few individuals in the pest population may have traits that allow them to survive. For example, a small portion of the pest population may be born with an enzyme system that detoxifies (renders harmless) the pesticide. Or rather than breaking the pesticide down into harmless chemicals, some individuals may be physiologically less sensitive than others; they may have thicker skins that reduce internal penetration of the pesticide to the target-receptor site, or they may have fewer target-site receptors. Mobile pests can develop behavioral resistance—by avoiding areas treated with pesticides.

Regardless of the mechanism for resistance, the survivors of pesticide application pass on that character to their offspring. A typical response by farmers to the increasing resistance within the pest population might be to increase the dosage or the frequency of application. The long-term consequence of repeated exposure is to increase selective pressure on the pest population. The result is an ever-increasing proportion of resistant individuals. In the worst case, the pest population becomes one of primarily resistant individuals unaffected by pesticides no matter the rate or frequency of application.

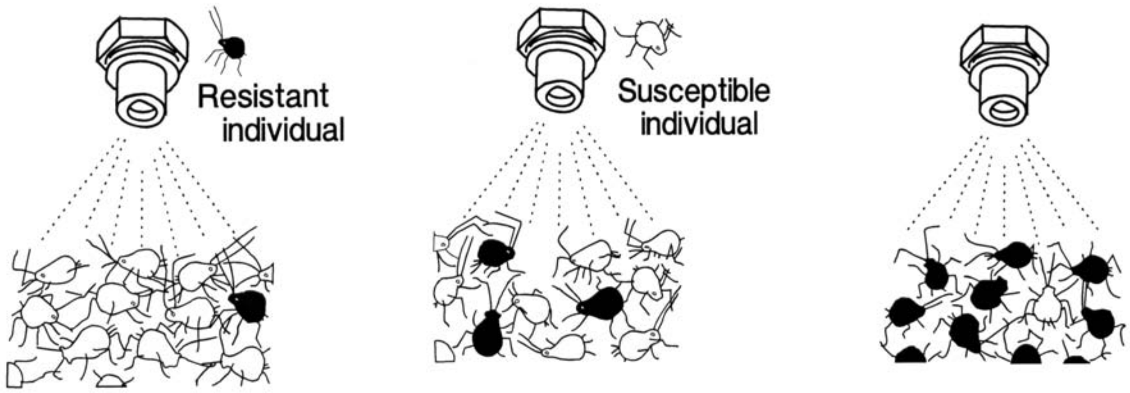


Figure 3.30 Resistance can develop when pesticide application kills susceptible individuals while allowing naturally resistant individuals to survive. These survivors pass to their offspring the genetically determined resistance trait. With repeated pesticide application, the pest population increasingly is comprised of resistant individuals (SOURCE: modified from The Safe and Effective Use of Pesticides, University of California).

Resurgence (figure 3.31) is the situation where insecticide application initially reduces an infestation, but soon afterwards the pest rebounds (resurges) to higher levels than before treatment. For example, if spraying an alfalfa field with a foliar insecticide at first knocks down aphid populations to less than damaging levels, but 2 weeks later the infestation is as high as it ever was, then this phenomenon would be considered resurgence.

Replacement or secondary pest outbreak (figure 3.32) is resurgence of non-target pests. It occurs when a pesticide is used to control the target pest, but afterwards a formerly insignificant pest replaces the target pest as an economic problem. For example, if the insecticide application directed at aphid control in alfalfa had in fact reduced the aphid infestation, but afterward was followed by an outbreak of spider mites (which to that point had been considered a non-pest), then this situation would be considered replacement. Here the primary pest (aphids) has been replaced by a new pest (mites) secondarily induced to outbreak levels by the pesticide application.

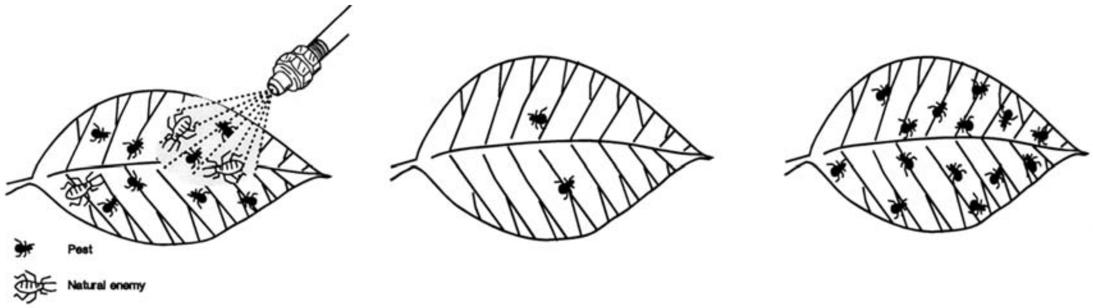


Figure 3.31 Resurgence can occur when insecticide applications directed at the primary pest unintentionally kill beneficial predatory and parasitic insects that help keep pest infestation levels in check (left leaf). In the absence of the controlling effects of their natural enemies, small pests surviving in unsprayed areas re-colonize plants (middle leaf) where they rebound to higher-than-ever infestation levels (right leaf) (SOURCE: modified from Entomology & Pest Management, Prentice Hall 1996).

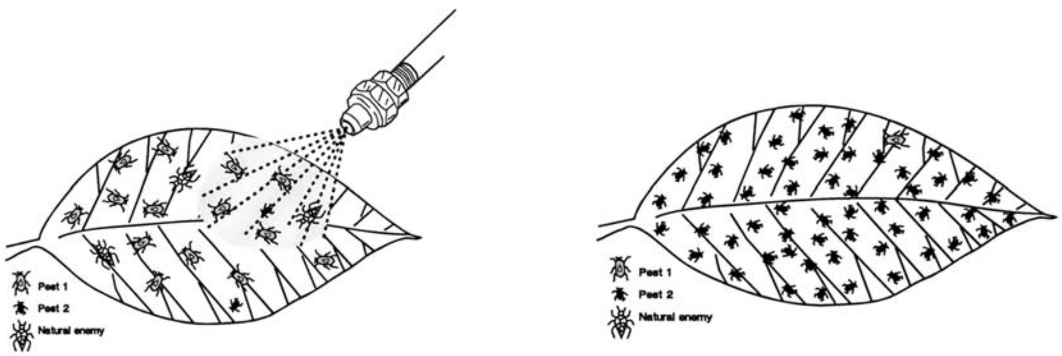


Figure 3.32 Replacement can occur when insecticide applications directed at a primary pest (Pest1) unintentionally kill beneficial predatory and parasitic insects that keep infestation levels of a potential pest (Pest 2) at low levels (left leaf). Although the insecticide application successfully reduces populations of the targeted pest, the previously insignificant secondary pest increases without checks in the absence of its natural enemies and so replaces the primary pest as the most important problem (right leaf) (SOURCE: modified from Entomology & Pest Management, Prentice Hall 1996).

Although there are several reasons that explain resurgence and replacement, reduction in numbers of natural biological control agents following insecticide use frequently is cited as the primary cause. In general, beneficial predators and parasitoids are innately susceptible to pesticides, often much more susceptible than the target pests. Hence, insecticides directed at the pest may virtually eliminate beneficials that had been contributing to pest mortality. The few pests that do survive pesticide application are released from limiting effects of their natural enemies. As a result, the pest population increases unchecked by natural limits. If the beneficial species eliminated had been holding back a population increase of the target pest, then resurgence can be the result. If the control agents eliminated had been holding a minor pest in check, then replacement can be the result.

In addition, to being directly toxic to beneficial organisms, insecticides have a double-whammy effect — they can indirectly kill control agents through starvation. By definition, recovery and population increase of biological control agents must always lag behind the pest because beneficial species rely on living prey or hosts to survive and reproduce. Simply stated, if the pesticide kills their food source, the beneficial organisms starve.

Other less common explanations for resurgence and replacement include the possibility of direct favorable effects from pesticides on the pest. This hormone like phenomenon, known as *hormoligosis* (hor-mo-li-go-sis), occurs when low, sub-lethal (too-small-to-kill) doses of pesticides stimulate pest reproductive rates, regardless of impact beneficials. Another explanation for replacement that does not involve biological control agents is removal of competitive species. If the primary pest were competing with another plant-attacking pest for the same food, habitat, or other resources, then removal of the primary species theoretically would permit the subordinate species to replace it.

Prior to the IPM era, a common response by farmers to the problems of the 3-R's was to apply even more insecticide, perhaps by increasing dose or frequency of application in response to pest resurgence and replacement, but ultimately switching to a new insecticide after resistance developed, only to repeat the cycle of resurgence, replacement, and resistance. This worst-case *addiction* of agriculture to chemical pesticides is referred to as the *pesticide treadmill* or *pesticide syndrome* (figure 3.33). Perhaps a *pesticide spiral* is more appropriate, because control problems keep becoming worse, as pesticides are relied upon more heavily. In other words, the more the pesticide is used, the less it works so the more of it must be used. At least a treadmill implies that you don't go anywhere, you just go back to exact the same place you started. This is far from true.

Do pest populations re-surge every time farmers use pesticides? Does replacement always occur whenever crops are sprayed with pesticides? Is it inevitable that a pest will develop resistance to a pesticide? Is the pesticide treadmill the ultimate destination of agriculture? The answer to all these questions is a most definitive NO! But are resistance, replacement and resurgence possible? Here the answer is a most definitive YES!

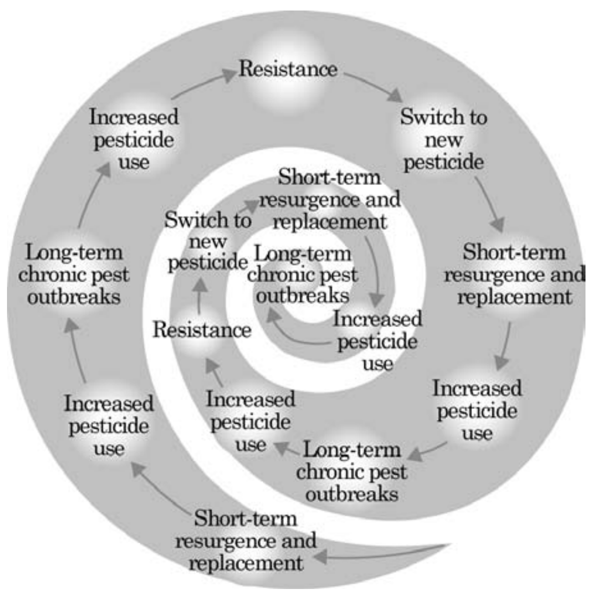


Figure 3.33 The pesticide treadmill (spiral)-over-reliance on pesticides creates an ever-increasing need to use pesticides.

Case study 1: The Canete Valley is one of several isolated valleys on the central coastal region of Peru. Covering 54,000 acres, this valley is the essence of an ecosystem—a self contained community of interacting organisms. At the turn of the century the chief agricultural crop was sugar cane, but by WWII it had become a monoculture of cotton, with up to 90 percent of the cultivated land in cotton. Primary insect pests included the leafworm and bud weevil; aphids, white scale, and cotton stainer occurred as minor pests. Pest control combined inorganic and botanical insecticides with mechanical methods (direct hand picking of pests as well as destruction of pest-infested plant materials) and took advantage of a complex of naturally occurring beneficial predators and parasitoids. In 1939, a new pest, the cotton bollworm, accidentally was introduced to the valley. Farmers responded by increasing the use of arsenic compounds, with relatively no effect. Within 10 years, yield losses were 35 percent greater, in part caused by the bollworm and in part because use of arsenicals resulted in rapid build up of aphids. When the Canete Farmers Association turned to local Agricultural Experiment Station to solve the bollworm problem, their answer was synthetic organic insecticides (DDT dust, benzene hexachloride (BHC), and toxaphene. Large scale use began in 1950; cotton yield immediately increased 35 percent. Large scale application continued in 1951 and 1952. But by 1952, this strategy of insecticide use was showing signs of losing its effectiveness. Aphids developed resistance to BHC, leafworms to toxaphene and cotton bollworm to both DDT and BHC. To remedy the situation, new insecticides were used (adrin, dieldrin, and endrin) and application frequency was increased. The result was the appearance of a new and larger complex of pests in damaging numbers. Insect pest problems increased from a three key species complex of bollworm, leafworm, and weevil to a six key species complex of the three original pests plus two types of leaf rollers and a second species of leafworm. Additional minor pests included a second species of bollworm, mealybugs, and a leaf perforator. Replacement (induced secondary pest outbreak) had occurred because of destruction of natural enemies. Farmers responded with a new group of insecticides, organophosphates, including parathion and others. By 1956 there was complete failure of the agricultural system. Cotton was no longer a viable crop economically. In spite of an average of 15 applications of insecticides during a growing season and as many as 25 applications per field, 50 percent of the cotton crop was lost in 1956.

By the mid-1950's, the hazards of pesticides misuse in agriculture were recognized and the need for alternatives to pesticides was acknowledged. The concept of *integrated control* was proposed as the integration of chemical pesticides with biological controls, the forerunner of IPM. But one additional event outside of agriculture provided the final impetus for adoption of IPM—the 1962 publication of the book, *Silent Spring*, by Rachel Carson.

Silent Spring essentially was an indictment against pesticides, explaining careless use and citing crop-centered problems (3-Rs). More importantly, Silent Spring presented the broader environmental problems of pesticide misuse and ultimately created an atmosphere of political urgency about pesticide problems. Carson drew public attention to hazards pesticides posed to wildlife, to environmental quality and human health. She added a *fourth R—pesticide residues*—and explained the concept of *biomagnification*, the accumulation of fat-soluble pesticides in non-target animals and the increasing concentration of these pesticides in food webs. Though pesticides residues on foodstuffs still concerns many people, the problem of biomagnification largely is a historic side note—because the fat-soluble, long-lived insecticides like DDT and its relatives have been replaced with short-lived products that do not accumulate in food chains.

Case study 2: One of the most famous cases of biomagnification occurred at Clear Lake, California, a summer resort town. Occasionally residents were bothered by high populations of a nonbiting but nuisance fly, the Clear Lake gnat. In 1949, a program to eradicate this insect was initiated. Authorities selected DDD (a pesticide not as toxic to fish as DDT). DDD applications to the lake provided 99 percent control of the midge. Treatments were repeated at increasingly intervals until 1954, when carcasses of Western Grebes, a species of diving birds, were found at the lake. Analysis showed that water in the lake contained only 0.02 parts per million (ppm) of DDD, which was not a toxic concentration. However, plankton living in the lake contained 5 ppm. Further, small fish which fed on plankton contained several hundred times that amount, while predatory fish concentrated 2000 ppm in their tissues. As biomass (food) transferred up the food chain from water to plankton to fish to birds, most DDD was transferred from one food-web level to the next. The diet of the fish-eating grebes was extremely toxic, resulting in an accumulation of DDD in their fat tissue 80,000 times the concentration applied to the lake.

Silent Spring raised awareness about the dangers of dependence on pesticides, and the result was public outcry for environmentally safe pest control. IPM arose within this context of insecticide misuse, as the response of entomologists to the problems of insecticide hazards. Today, IPM is encompassed by all plant protection disciplines. However, the entomological heritage is still apparent, resulting in a degree of erratic, uneven application of concepts.

Student Activity 16

1. Name the three R's.

____

____

____

2. What is the fourth R?

____

____

3. What topic was presented by Rachel Carson in her book, *Silent Spring*?

____

____

4. Describe three ways that pest can overcome the toxic effects of pesticides.

a. ______________________________

____

____

b. ______________________________

____

____

c. ______________________________

____

____

5. Explain the pesticide treadmill (spiral) and its significance in pest management.

Module 3, Part G, Section 5—Five Common-Sense IPM Principles

Supporting Objective

- Discuss the "common-sense" principles of integrated pest management.

Although by now you already know this, it still bears repeating: there is no single recipe for IPM. Instead, guidelines for managing specific insects, plant pathogens, weeds, and other pests are different. Nonetheless, the following principles broadly apply:

- PRINCIPLE #1. There is no silver bullet. Over-reliance on any single control measure can have undesirable effects. This especially has been documented for pesticides where over-reliance can lead to the "3-R's": resistance, resurgence, and replacement. IPM considers all possible control actions, including taking no action at all, and fits tactics together into mutually complementary strategies. The idea is to combine different control tactics into an overall strategy that balances the strengths of each against any individual weaknesses.

- PRINCIPLE #2. Tolerate, don't eradicate. IPM recognizes that keeping fields entirely pest-free is neither necessary nor desirable—it is not necessary to totally eliminate pests. Because most crops can tolerate low pest infestation levels without any loss in harvestable produce or quality, the presence of a pest does not necessarily mean that you have a pest problem. IPM seeks to reduce pest populations below levels that are economically damaging rather than to totally eliminate infestations.

- PRINCIPLE #3. Treat the causes of pest outbreaks, not the symptoms. IPM requires detailed understanding of pest biology and ecology so that the cropping system selectively can be manipulated to the pest's disadvantage. The idea is to make the crop less favorable for pest survival and reproduction with as little disturbance to the rest of the ecosystem as possible.

- PRINCIPLE #4. If you kill the natural enemies, you inherit their job. Naturally occurring predators, parasites, pathogens, antagonists, and competitors (collectively known as biological control agents) help keep many pest populations in check. IPM strives to enhance the impact of beneficials and other natural controls by conserving or augmenting those agents already present.

- PRINCIPLE #5. Pesticides are not a substitute for good farming. A vigorously growing plant better can defend itself against pests than a weak, stressed plant. IPM takes maximum advantage of farming practices that promote plant health and allow crops to escape or tolerate pest injury. IPM begins from the premise that killing pests is not the objective; protecting the commodity is. Pest status can be reduced by repelling the pest, by avoiding the pest, or by reducing its rate of colonization or invasion, as well as by directly killing the pest.

Student Activity 17

1. List the common sense principles of IPM.

Module 3, Part G, Section 6—Overview of Pest Management Practices

Supporting Objectives

- List the three steps to designing IPM programs.
- Define these terms and give examples of each: cultural control, biological control, pest-resistant variety.
- Discuss from an ecological standpoint the four basic ways that cultural controls can reduce pest problems.
- Differentiate among biological control via introduction, augmentation, and conservation.
- Calculate degree-day (°DD) and discuss how it can be used to predict the best time to scout fields or even forecast when to take IPM action.

Introduction

Farmers put IPM philosophy into practice by following these three-steps:

- Step 1. Use cultural methods, biological controls, and other alternatives to conventional chemical pesticides when practical.
- Step 2. Use field scouting, pest forecasting, and economic thresholds to ensure that pesticides only are used against real and not perceived pest problems.
- Step 3. Match pesticides with field site features so that the risk of contaminating water is minimized.

Step 1: Alternatives to Pesticides

Cultural Methods

Cultural methods are those “good farming” (or “good horticultural”) practices that break the infestation cycle by making the living and non-living environment less suitable for pest survival. By altering normal crop production practices, cultural methods may reduce the rate at which the pest arrives and establishes within a crop field, or once the pest is present, slow down its subsequent rate of population increase or spread. From an ecological standpoint, cultural methods achieve these goals in four basic ways:

- reduce the overall favorability of the habitat (by destroying pest overwintering sites and other infestation sources both in the crop field and alternate hosts or habitats);
- alter planting patterns to disrupt or interrupt in time and space the food or other habitat resources required by the pest;
- divert mobile pests away from the crop;
- enhance the vigor of the crop so that it can better tolerate pest injury.

Familiar examples of cultural controls widely used in IPM programs include *crop rotation*—planting unrelated crops each season rather than always planting the same crop in the same field. Many insects and plant pathogens spend the winter in the field itself, protected within the soil or under old plant debris in adjoining trashy areas. Here crop rotation breaks the infestation cycle of immobile pests like nematodes, disease organisms and other soil-borne pests. Recognize that crop volunteers which emerge after harvest may harbor pests from one growing season to the next.

Tillage operations that turn the soil and bury crop debris similarly can lower infestation levels of plant pathogens that spend the winter in the soil or beneath crop residues. Shredding, chopping and burning similarly can remove or destroy overwintering populations. Other commonly used cultural methods include *altering planting and harvest dates* so as to avoid pest infestations. Similarly, *seeding rates* can be manipulated to suppress pest densities as can changing *crop spacing*. Crops like barley and wheat can be given a competitive edge over wild oat and other weeds by increasing crop seeding rates and decreasing crop row widths. Proper *seedbed preparation, fertilizer application, and irrigation schedules* can give plants the head start needed to outgrow early-season pests as well as better defend itself later during the growing season. Such sanitation practices as cleaning tillage and harvesting equipment between fields or planting certified seed that is free of pathogens and weed seed reduce the chances of introducing pests.

But again, the situation seldom is simple. Excessive fertilization and watering can be as bad as not enough. For example, too much nitrogen and water creates a highly nutritious and succulent habitat that favors aphid outbreaks. Too little fertilizer and water diminishes the plant's ability to regrow and recover from pest damage.

Cultural methods include some of the oldest pest control measures known to man. Two old-but-improved methods are generating renewed interest: cover crops and trap crops. *Cover crops* such as sudangrass and rapeseed have shown promise for suppressing soil-borne diseases of potatoes. These cover crops are grown and then plowed into the soil before the primary crop is seeded. Decomposition products from the cover crops either are directly toxic to pathogens or indirectly reduce infection rates by favoring competing micro-organisms which colonize the root first and prevent the pathogen from gaining a foothold.

Trap crops attract and concentrate pests within a small portion of the field where they easily can be killed with minimal or even no pesticide. One tactic under development is control of sugarbeet cyst nematode with an oil-radish trap crop. Root secretions from the oil radish stimulate nematode eggs to hatch, but because the trap crop is not a suitable food source, the young nematodes never develop to the adult reproductive stage. Plowing-down the trap crop after eggs hatch eliminates the infestation.

Pest-Resistant Varieties

Plants that tolerate pest injury without yield loss, or that kill pests by producing toxic chemicals, or that have lowered attractiveness to pests are critical to long-term management of many otherwise devastating insects, nematodes, and pathogens. Idaho would not have a sugarbeet industry were it not for sugarbeet varieties with resistance to the curly top virus. Before resistant varieties, upwards of one-third of the sugarbeet acreage annually was abandoned because of curly top. Today, the industry protects itself by only planting varieties that meet minimum standards for disease resistance.

Resistance seldom implies complete immunity to a particular pest, let alone total resistance to the entire community of unrelated pests that might occur in a field during the growing season. Rather, the resistant variety may express fewer symptoms of pest injury or show more modest reduction in yield than susceptible varieties. Because they also vary in the agronomic characteristics, not all resistant varieties are equally suited to all production regions.

Enhanced host plant resistance can be achieved by using either traditional breeding methods or genetic engineering techniques. Considerable attention presently is being given to the development of transgenic plants that produce bio-pesticides or that resist virus infection by producing viral coat proteins or enzymes that disrupt viral replication. Cotton, corn, and potatoes genetically engineered to express the BT-toxin that kills certain caterpillars and beetles now are available commercially.

Biological Control

Biological control (also known as bio-control), uses living organisms (natural enemies) to suppress populations of other living organisms (pests). This makes biological control considerably more complicated than using chemical pesticides. You need to manage the natural enemies, give them the food, home, and the environment they need, or else they will not survive. On the farm, practical bio-control methods (especially ready-to-use products or commercially reared natural enemies) are more widely available for insect pests than for plant pathogens and weeds. This does not mean that bio-control only works against insects, but rather that commercial research and development of biological products has emphasized pest insects more than other types of pests.

The terminology used to describe natural enemies differs among the plant protection disciplines. Plant pathologists use the term *antagonist* to describe beneficial micro-organisms that reduce the activity, efficiency, and inoculum density of plant-attacking pathogens through antibiosis, competition, or exploitation. *Antibiosis* refers to biological pest control via metabolic products produced by one organism (the antagonist) that directly inhibit or kill another organism (the pest). *Competitors* are antagonists that compete with the pest for food and habitat. Some competitors are pests themselves, but can be beneficial if the damage they cause is negligible compared to the pest. *Exploitation* includes *predation*, defined as a free-living animal that exploits another organism (such as mites and certain amoebae that feed on fungi) and *hyperparasitism*, defined as a pasasite that preys upon another parasite (such as Trichoderma spp. mycoparasites). Successful antagonistic control of plant pathogens often depends on a narrow range of environmental conditions

Entomologists use the terms predators, parasitoids, and pathogens for the bio-control agents that attack insects.

Predators are free-living animals (most often other insects or arthropods but also birds, reptiles, and mammals) that eat other animals (the prey). Predatory insects and related arthropods commonly encountered in field and row crops include lady beetles, lacewings, pirate bugs, predatory mites, and spiders. Predators consume more than one prey during their lifetime and may in fact consume hundreds of prey during their life. Predators typically are generalists—they feed on a wide variety of prey, generally any small, soft-bodied insects they physically can overwhelm. The preying mantid is an example of a generalist predator. Some predators are specialists; they feed on one or a few related prey species. For example, some lady beetles specialize in feeding only on scale insects or only on whiteflies. Some species are predaceous only as immatures, others both as immatures and adults.

Parasitoids are insect (or related arthropods) parasites of other insects (or other arthropods). Most parasitoids are tiny wasps and flies. They differ zoologically from true *parasites* (such as fleas or lice or intestinal tapeworms) primarily in that parasitoids kill their host whereas parasites may weaken but seldom kill the host. Another difference is that parasitoids are parasitic during their immature stages but free-living (non-parasitic) as adults; true parasites live in or on the body of their host during most if not all their own life cycle. It is parasitoids and not parasites that are important to IPM programs in field and row crops.

Adult parasitoids lay eggs in or on their host. The parasitoid larva that emerges from the egg, feeds in or on the host body tissue. One host is sufficient to complete the parasitoid life cycle. Parasitoids usually are specialists; they only attack one pest species or a few related pest species. Among agricultural insect pests, aphids, and caterpillars often are attacked by parasitoids. But not all parasitoids are beneficial. Parasitoids themselves sometimes have their own parasitoids. *Hyperparasitoid* (or secondary parasitoid) refers to a parasitoid of another parasitoid. Because the hyperparasitoid kills the primary parasitoid that kills the pest, the hyper species might be considered a pest, in the sense that (turning around an old saying) a friend of my enemy is my own enemy.

Pathogens are disease-causing micro-organisms; they include viruses, bacteria, fungi, and nematodes. Pathogens can be important in the natural control of insect populations (and in the natural control of plant populations and even populations of other micro-organisms), though development of large scale disease epidemics in nature usually requires both large populations of host (the pest) and favorable environmental conditions. Some pathogens have are produced commercially and sold as microbial insecticides, most notably different strains of a bacterium, *Bacillus thuringiensis* (Bt).

Three basic approaches are involved in biological control:

- *Introduction* of biocontrol agents into areas they do not exist. Here the goal is to establish new populations that permanently reduce pest infestation levels;

- *Augmentation* of biocontrol agents already present via mass-releases. Here the goal is to supplement the effectiveness of natural populations during the current growing season by adding more natural enemies;

- *Conservation* of biocontrol agents already present. Here the goal is to maintain or enhance the impact of native species on pest infestations.

The differences between introduction, augmentation, and conservation start to blur in the field; in practice these strategies are not quite so distinctly different as formal definitions here suggest. Of the three, conservation presently is the most practical approach farmers can adopt in their own fields. In contrast, introduction requires technical and financial resources far beyond those of any individual farmer and so remains within the realm of public or governmental agencies. Augmentation holds great potential for agricultural IPM, but with few exceptions, is not yet widely practiced in commercial agriculture.

Introduction (also known as classical biological control) usually targets exotic, non-native pests accidentally introduced into new geographic areas. Often these “pests” go unnoticed in their native countries because they effectively are held at non-economic levels by a few key predators, parasitoids, or pathogens. When these same pests invade new areas and establish without these key natural enemies, pest numbers increase virtually without checks to outbreak levels. The objective then of introduction is to re-establish the balance that existed by importing and releasing the key natural enemies from the pest’s area of origin.

Assuming that pest identity is known (which is not always the case), the process of importation begins by determining the geographic home of the pest. With this information, exploratory searches for natural enemies can begin. Exploration and collection is followed quarantine processing to insure the *biocontrol agents (also known as bioagents)* themselves are free of their own natural enemies. After biological testing to determine their effectiveness and specialized environmental requirements, candidate agents are mass-reared and released with the objective of establishing permanent populations. The process of biological testing particularly is complex when the exotic target pest is a weed because it is necessary to show that the imported natural enemy will not attack a desired plant (such as a crop plant or a native wild protected species).

Importation of natural enemies from foreign countries is a task too large, too complicated, too time-consuming, and at least initially, too expensive to be undertaken by individual farmers as part of an IPM strategy. Exploration, quarantine, and release instead are conducted by State, Federal, and International

Government and public agencies. But individuals can play a role in introductions after new natural agents colonize and increase to high enough levels—by collecting and locally distributing bioagents to speed their spread. Anyone can collect beneficial biocontrol agents and release them in their areas. Be aware though that shipment of natural enemies across state lines requires special permits. Contact the state entomologist at your State Department of Agriculture or your state officer of the Plant Pest Quarantine section of the Animal and Plant Health Inspection Service (USDA-APHIS-PPQ).

When classical biological control is successful, it provides pest suppression that is permanent (because it is self-perpetuating) and essentially cost-free (at least in the sense of having no annual maintenance costs). However, introduction only fits situations where virtual elimination of a pest is not the goal. Introduction cannot eradicate pests because natural enemies cannot exist permanently in the absence of their prey or host; small populations of the pest are necessary to sustain the agents. With introduction, you must be able to tolerate the continued existence of the pest. This restriction is not a serious limitation because many agricultural crops can tolerate pest infestations at low levels. Some ecologists question the long-term wisdom of introducing exotic natural enemies. Their concern is that exotic natural enemies can themselves become a problem by out-competing and replacing native natural enemies that effectively regulate populations of other pests.

Augmentation can involve releases of exotic or native natural enemies according to either of two strategies: *inundative releases or inoculative releases*. As these terms suggest, the inundative strategy involves massive releases of natural enemies, literally thousands and sometimes millions or more per acre. With inundation, the idea is to use natural enemies as if they were a living biological pesticide—to immediately overwhelm the pest population with little regard to whether the natural enemies persist or not. Microbial pesticides, defined as pathogens of weeds and insect pests that are produced commercially and formulated as microbial herbicides and microbial insecticides, usually are used inundatively for quick one-shot pest control. Some predatory insects such as lady beetles and lacewings too are used inundatively. About one dozen microbial insecticides are used in agricultural field and row crops, primarily caterpillar and beetle-killing products containing the beneficial bacteria *Bacillus thuringiensis* variety *kurstaki* or variety *tenebrionis*, respectively. In contrast, commercially available *microbial herbicides (also known as mycoherbicides)* are limited to three products (Casst, Collego and DeVine). The extreme high selectivity of these microbial herbicides limits their use to small regional markets. For example, DeVine is used only sporadically to control stranglervine in Florida citrus orchards.

In contrast to inundative releases, the inoculative approach involves releasing fewer numbers of natural enemies, often several times during the season. Here the goal is to at least temporarily (perhaps for a growing season) establish reproducing populations of natural enemies that suppress pest infestations. Inoculative release of predatory mites and parasitic wasps to suppress greenhouse pests is becoming standard IPM practice in many areas. Biological fungicides containing the bacterium *Bacillus subtillus* (sold commercially as Kodiak and Quantum) or *Trichoderma* fungi similarly are used as inoculative seed treatments; these beneficial micro-organisms colonize the crop root system where they compete with and suppress certain root rot pathogens. Inoculative releases of plant-attacking insects also can be made for weed control; however, because these insects may require years to reach levels high enough to reduce weed infestations, releases primarily are restricted to rangeland, roadside right-of-ways, and other non-crop lands where slow killing action is acceptable.

Several dozen species of beneficial insects, mites, and other organisms can be purchased from commercial insectaries for inundative and inoculative releases. The California Environmental Protection Agency maintains a World Wide Web catalog (figure 3.34) of names, addresses, and phone numbers for 132 commercial suppliers of 120 different beneficial insects in North America. The Web address is http:/www.cdpr.ca.gov/docs/dprodocs/goodbug/organism.htm. You also can purchase and import beneficial organisms from Canada or other countries, but this requires a special permit from USDA-APHIS-PPQ. Contact the PPQ Officer-in-Charge in your state for more information.

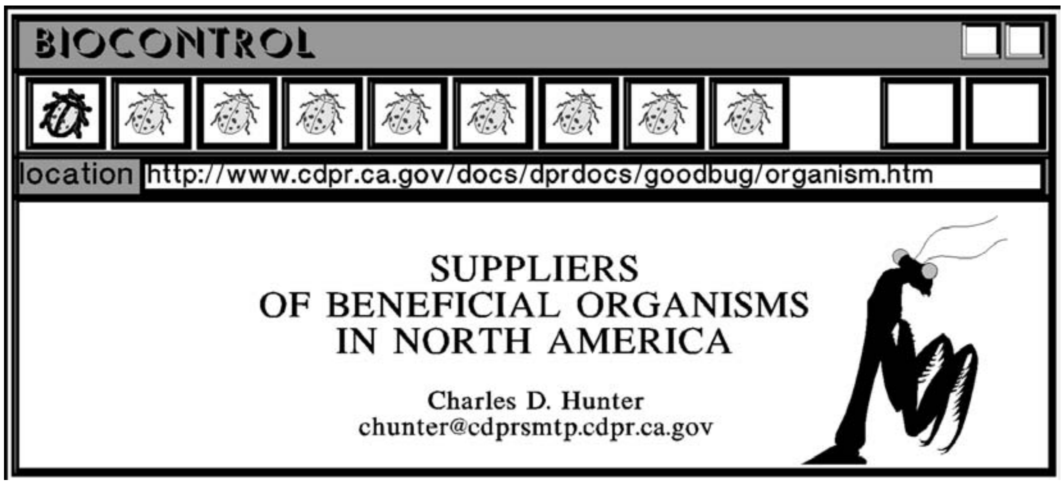


Figure 3.34. Among the many Internet IPM resources is this home page that lists names, addresses, and phone numbers for 132 commercial suppliers of 120 different biocontrol agents.

Most of the agents commercially available attack insect pests; some are available for weed control. Among the insect-attacking agents, lady bugs (= lady beetles) and praying mantids widely are available commercially but often provide less-than-reliable control. Adult mantids generally eat large flying insects and even other beneficials instead of the more important agricultural pests. Lady bug larvae and adults feed on a wide variety of soft-bodied insect pests. But because the adult beetles are highly mobile, they commonly migrate quickly from the fields after release. However, lady beetles can be effective when released in greenhouses. Some more promising biocontrol agents for use in agricultural crops include:

- *Trichogramma* wasps, tiny non-stinging beneficials that parasitize eggs of leaf-feeding caterpillars;

- green lacewings, known by the scientific names *Chrysoperla carnea* and *Chrysoperla rufilabris*, which are general predators (but only during the larval stage) of aphids, thrips, and mites;
- predatory mites (especially *Phytoseiulus persimilis*, *Amblyseius californicus*, *Amblyseius cucumeris*, *Metaseiulus occidentalis*) for control of pest mites and thrips.

Interest is high among farmers in augmentative releases of biocontrol agents but adoption remains quite low. Price is a major factor that limits wide-scale use. Biocontrol agents usually cost several-fold the price of traditional chemical insecticides. From a practical standpoint, releasing hundreds of thousands of living parasitic wasps or some other agent is far more difficult than spraying a field with pesticide. Growers too are justifiably skeptical about the effectiveness of releases. Many of the commercially available beneficials have been formally tested for effectiveness under commercial growing conditions. Instead, recommendations about release rates and timing as well as the most appropriate species to use generally are set by the vendors themselves rather than from scientific experiments. This does not mean that augmentation cannot work. It does suggest a prudent, small-trial approach.

Conservation of natural enemies already present probably is the biocontrol approach most practical on the farm. Diverse communities of predatory and parasitic insects occur in many field and row crops every year where they help to keep damaging insects in check. But with the exception of flashy-colored lady beetles, the role of these bioagents in naturally keeping pest species in check often goes unnoticed. The key to intensifying impact of beneficials already present is to minimize use of *broad spectrum insecticides* (insecticides that kill broad variety of insects). With few exceptions, the commonly used agricultural insecticides are at least moderately lethal to the common predators and parasitoids. Many are highly toxic to beneficials. Indiscriminate or excessive insecticide application contributes to pest outbreaks by eliminating natural enemies and allowing pests to rebound without checks. This does not mean that conventional chemical insecticides automatically are incompatible with biological controls. Sometimes broad spectrum insecticides can be used in ecologically selective ways that minimize risks to beneficial natural enemies.

The general principle involved in using broad spectrum insecticides in ecologically selective ways is to reduce exposure to beneficial control agents, either by altering application placement, rate or timing, or by selecting insecticide formulations that change mode of action from contact poison to stomach poison. For example, if scouting shows that insecticides are necessary, farmers sometimes can spot treat field margins or other infestation hotspots rather than blanket the entire field with a broadcast application of the insecticide. Spot spraying creates reservoirs where natural enemies survive insecticide application and from which they later re-colonize the entire field. Likewise, if a pesticide label gives a range of application rates, then farmers who use the lowest rate (vs. the highest rate) can increase survival of beneficial species. Sometimes it is possible to take advantage of differences in susceptibility among life stages of natural enemies. The inactive stages (eggs and pupae) of some beneficial insects tolerate insecticides better than the active immature or adult stages; if possible, growers can time sprays when the most vulnerable stages are absent.

Properties of the pesticide itself can change the target spectrum from broad to narrow spectrum. In particular, a single insecticides may be sold commercially as several different formulations (products which contain the same pest-killing active ingredient, but which are manufactured as several different physical forms) perhaps as a liquid spray formulation to be applied to crop foliage and as a dry, systemic granular formulation to be incorporated into the soil, absorbed by the roots, and translocated internally within the plant. Whereas the liquid spray kills on contact, the systemic in contrast only kills those insects that suck sap from the treated plants. The former formulation would be lethal to bioagents, the latter would not.

An alternative to ecologically selective application of broad spectrum insecticides is use of physiologically selective insecticides; insecticides that only kill the target pest or a narrow spectrum of insects. In agricultural field and row crops, such physiologically selective insecticides largely are limited to microbials like *Bacillus thuringiensis*. Organic insecticides (naturally occurring chemicals such as botanical insecticides extracted from plants, inorganic and abrasive dusts, insecticidal soaps and oils) tend to have better selectivity than synthetic insecticides (manufactured products). This is because organic products have short residual activity, they tend to break down and deactivate quickly when exposed to sunlight and water, often within a day or two of application. In contrast, synthetic insecticides generally have longer residual activity, up to several months in some cases. The trade-off between short and long residual activity is crop protection versus exposure of natural enemies. Because they disappear so quickly, organics tend to be safer for beneficials but likely require repeated applications to protect the crop.

Many natural enemies of insects require nectar and pollen to complete their life cycle. In theory, natural biological control can be enhanced with fencerow plantings of small-flowered crops that bloom through the season. Preliminary studies in some cropping systems have shown that border plantings of alfalfa, buckwheat, clover, and vetch can increase populations of natural enemies. These plantings also provide refuges that allow beneficials to escape insecticide sprays. But such border plantings can be a two-edged sword. They may harbor pest species (both insects and disease agents) that threaten the neighboring crop, or they themselves can become weeds that invade adjacent cropland. Artificial food supplements called wheast (sold commercially as BugPro, Pred Food and others) too have shown some promise increasing densities of some predatory insects when applied as foliar sprays.

Step 2: Field Scouting, Pest Forecasts and Thresholds

Introduction

Inevitably, there are fields where cultural methods or biological controls by themselves fail to keep pest populations from reaching damaging levels. Here pesticides are necessary to prevent crops from yield and quality losses. A *pesticide* formally, is defined as a chemical poison that kills pests. It is a generic term that includes several specific categories, depending on the pest target. From a regulatory standpoint, the U.S. EPA classifies as a pesticide any substance used to repel, destroy, or mitigate pest problems.

The agricultural pesticides commonly used by farmers include *herbicides* (pesticides that kill weeds), *insecticides* (pesticides that kill insects), *fungicides* (pesticides that kill disease-causing fungi) and *nematicides* (pesticides that kill nematodes). Farmers use pesticides for several reasons, including convenience (pesticides are easy to use and locally available), effectiveness (pesticide kill rates commonly exceed 90-95%) and corrective action (pesticides often are the only control option once pests reach outbreak levels).

A key principle of IPM is that pesticides only should be used when field examination or *scouting* shows that infestations exceed *economic thresholds*, guidelines that differentiate economically insignificant infestations from intolerable populations. Indeed, scouting has become such an integral part of IPM that it has become virtually synonymous with the definition of IPM. Some critics argue that IPM is nothing more than count-and-spray pest control that pays but lip service to non-chemical controls. In some high value crops like potatoes, private consultants provide farmers with pest scouting services and management recommendations on a fee basis. In other field and row crops, industry field staff and the farmers themselves do the scouting. Scouting and thresholds play important roles in protecting environmental quality when they replace preventative or “just-in-case” pesticide application with “just-in-time” application. The pay-off is that pesticides are used only when and where they really are needed.

Checking the Pulse: Field Scouting and Predicting

To apply the principles of pest management is impossible unless you first know which pests and how many pests are present. There are two fundamentally different reasons for sampling in pest management: parameter estimation and decisionmaking. Parameter estimation is data collection for pest management research; here the objective is to estimate pest density or to determine spatial patterns. Decisionmaking is data collection for an immediate and specific pest management case; here the objective is to classify the status of a pest population into a category (such as spray or don't spray, high or low, treat or do not treat). Why distinguish? The design of a sampling program depends on the purpose. IPM decisionmaking requires immediate answers. Above all, scouting must be rapid, simple, and inexpensive. In contrast, IPM research especially values precision of estimates. Delays in results are more acceptable and sampling cost is less important.

IPM sampling examines a small subset of a population that is assumed to be representative of the entire population. A *population* formally is defined as a group of individuals of the same species in some defined area. *Population density* is the number of individuals in a defined area. Hence, we can identify a population of Colorado potato beetles in a given field and state population density in terms of the number of beetles per plant. We scout because it usually is too expensive or too tedious to conduct a census, which is a count of every individual in an entire population. Density can be stated directly in terms of pest numbers (number of weeds per row-foot) and indirectly as pest products (percent defoliation). For small, difficult to locate pests (such as spider mites), sampling may involve only counting the proportion of sampling units occupied by the pest. Such so-called binomial sampling plans save time and labor over complete counts.

IPM scouting programs combine sampling techniques (methods, tools, or devices) with sampling plans (protocols that describe how to use the technique—when and where to begin and end sampling, how many samples to take, how to interpret data and make an IPM decision). Techniques can be categorized into three basic types: *absolute methods, relative methods,* and *indirect methods.*

- *Absolute methods* express density as numbers of pests per unit area (or unit volume), such as the number of weeds per foot of crop row. Direct visual counts from plants or soil are commonly used absolute techniques in IPM scouting.

- *Relative method* sampling techniques express density as the number of pests in units other than area or habitat, such as number per sampling device or number per sampling effort. They are the most widely used techniques for sampling small, highly mobile insects in pest management programs because they are simple to use, inexpensive, and provide rapid results. Common examples include insect traps and sweepnets. Results from these methods are relative. They only can be compared directly to estimates from other places or other times using the same such sampling technique as numbers of pests per trap in field #1 versus field #2 or insects per sweepnet sample on day #1 versus day #2. The effectiveness of many relative methods depends on insect behavior; this can complicate interpretation of sampling data because results combine pest activity with population density. For example, some farmers monitor wireworm infestations by using bait stations—a handful of grain buried a few inches below the soil surface before planting at several sites across the field. The idea is that wireworms present in the soil will move to these bait stations where they readily can be counted and an IPM decision made: fields with many wireworms require insecticide while fields with few wireworms do not. However, pest counts per station depend both on the overall infestation level as well as wireworm activity. Cool soil, dry soil, wet soil, and soils high in organic matter all reduce the effectiveness of baits. This means that if you bait two fields and detect wireworms in one field but not in the other, you cannot know for sure if wireworm infestations really differ between fields. Infestations might have been the same in both fields, but cool temperatures in one field or dry soil in the other could have prevented larvae from moving through the soil to the bait.

- *Indirect method* scouting techniques measure the effects or products of pest infestations. Rather than directly providing estimates of pest density, these methods provide indices that indirectly measure pest presence. Examples include percent defoliation and percent plants that have disease symptoms. Like relative, indirect methods usually are simple, inexpensive and fast; they are especially used to monitor disease progress and tiny, tedious-to-sample insects. Caution must be taken when using indices to make IPM control decisions: if the pest no longer is present at sample time, control action is not justified no matter how severe the crop injury.

No single pest scouting plan is appropriate for all situations. However, the following three rules generally apply to field and row crops:

- *Sample randomly*. Random means that every plant in the field has exactly the same chance of being inspected for insects or diseases, or that each unit of ground surface area or length of crop row is no more likely than any other to be surveyed for weeds. IPM scouts neither seek out the best-looking plants nor do they intentionally avoid the worst parts of a field. Such non-random sampling likely will produce biased conclusions data that either underestimate actual infestation levels or, that exaggerate pest status. A simple way to apply this principle is to walk a zig-zag "W" pattern across a field, keeping your eyes fixed on the horizon. Then, without looking, stop at random intervals, and make the inspection. Field and row crops typically are scouted several times during the growing season (if not weekly). Walk a different path through a field each time it is scouted (rather than always returning to the same area).

One exception to random sampling is scouting to determine pest presence. Sometimes an IPM decision can be made simply by knowing if a pest is present, regardless of its density. Here it is far more cost-effective to deliberately seek out those parts of the field where the pest most likely occurs or to only examine plants showing characteristic symptoms of pest injury. For example, management of late blight of potatoes often involves application of fungicides that must be applied before the fungus infects the foliage. It is critical that growers detect the initial late blight infection so that the rest of the field can be protected. Hence, IPM scouting for late blight is non-random; it specifically focuses on wet swales and low spots or areas where water routinely drips from irrigation equipment because these sites are most conducive to disease development.

- *Spread out* samples across the entire field. Pest infestations seldom if ever occur uniformly across a field, and if sampling is restricted to limited areas of a field, then biased conclusions are likely about overall pest status. Samples should be representative of pest conditions in the entire field. In general, divide large, highly variable fields into uniform, homogeneous blocks, sample randomly within each block, and make separate IPM decisions in each. Use knowledge of pest biology to delineate blocks within fields. For example, experience has shown that Russian wheat aphid infestations often begin downwind along field edges from previously infested fields or Conservation Reserve Program lands; here it would be wise to keep two scouting records of aphid density—one record of average density along the field edge and the other of average density across the remainder of the field. It may only be necessary to apply pest controls along the border. Figure 3.35 shows how the principles of random and representative sampling can be applied.

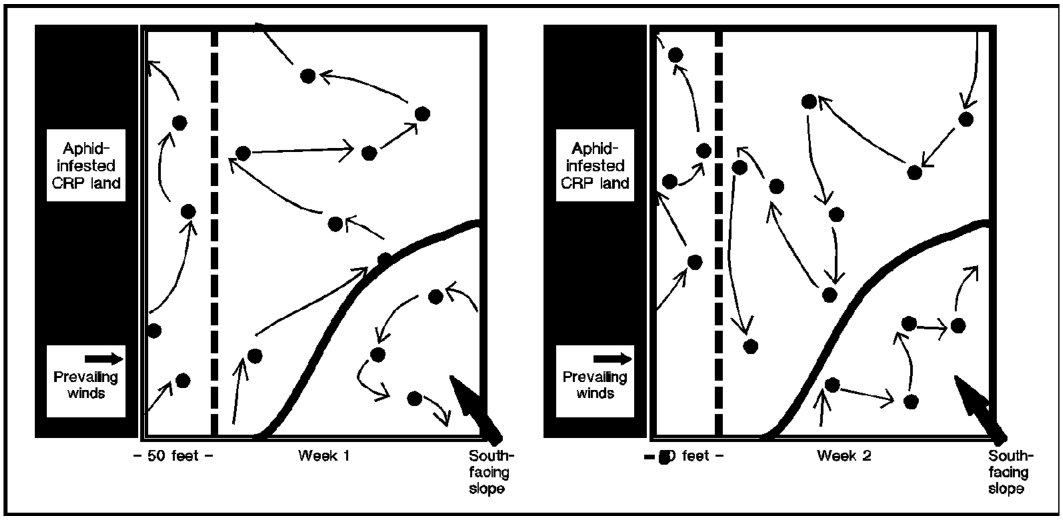


Figure 3.35 Pest scouting generally should be both random and representative. The IPM scout has used an understanding of pest biology to divide a large and variable wheat field into three subsections wherein aphid density likely is somewhat uniform—the first 50-feet of field margin next to an aphid infestation source, a south-facing slope where infestations often reach levels higher than other exposures, and the remainder of the field. Samples then are spread across each subsection at random intervals, and separate IPM control decisions are made in each section. Note that in this example of weekly sampling, the scout deliberately walks a different path through the field.

- *As a rule-of-thumb (unless otherwise instructed) always take at least five samples and preferably 25 to 30 per field (or block).* Express pest density as the statistical mean (average) of all samples. Note that increasing the number of samples increases the precision of pest density estimates but does not necessarily improve the accuracy of the estimates. Precision refers to the spread or repeatability of pest density estimates. Think of precision as the pattern of bullets fired at a target. Precise estimates show a tight, narrow spread of shots on the target; shot repeatability is high. Imprecise estimates show a broad spread on the target; shot repeatability is poor. Accuracy, in contrast, refers to how close the estimated pest density is to the true or actual pest. From the target-shooting analogy, accurate estimates fall close to the bull's-eye while inaccurate estimates grossly miss the bull's-eye. Various statistical formulas can be used to compute sampling precision; when solved for sample size, these formulas can be used to compute the number of samples needed for a desired level of precision. Ideally, IPM decision-making is based on data from samples with at least 25 percent precision (where precision is expressed as the mean, plus or minus 25 percent). In practice, the minimum number of samples required to achieve 25 percent precision usually is far more than can be practically examined. There is no similar formula that can be used to compute accuracy. By definition, if we knew true pest density, there would be no need to sample in the first place.

Regional pest monitoring systems can complement scouting individual fields by warning farmers of impending outbreaks. One successful system is Idaho's BEACON program (BEAn Cutworm Outlook and Notification). BEACON uses a regional network of insect light traps that provides bean and sweet corn growers with advance warning of damage expected from the western bean cutworm. High moth captures in traps pinpoint cutworm damage potential. Farmers use timely alerts published in local newspapers to make cutworm control decisions. Under BEACON, the acreage treated with insecticides has decreased from 45,000 acres to 6,000 acres annually.

Sometimes you can predict the best time to scout fields or even forecast when to take IPM action by using the *degree-day (°DD)* or heat-unit (HU) approach. The biological principle involved is straightforward: developmental rates of cold-blooded organisms (such as crop plants and their pests) primarily depend on the temperature. Mathematically, rate of development is directly proportional to temperature. This means that as temperature increases, growth is more rapid progressively fewer days are required for each life stage to develop to the next stage. Conversely, as temperature decreases, rate of development also decreases—progressively more days are required for the organism to develop through each stage. If temperature is lowered enough, development stops. The organism does not necessarily die but rather only ceases to continue its development. If these limits are known, then one can predict from daily temperatures developmental stages of crops and pests. For example, you might be able to predict when insect eggs will hatch or when caterpillars will mature and stop feeding or when weed seedlings will emerge. Such phenological predictions (predictions based on how climate effects growth, development, and behavior patterns of living organisms), can be useful because it might tell you when to begin pest scouting, or when to stop pest scouting, or when to apply a pesticide for maximum pest control.

The temperature at which growth stops is termed the *developmental threshold*. The developmental threshold is a species-specific constant. For example, the developmental threshold for the sugarbeet root maggot is 47.5°F. That is, root maggots do not grow and develop unless temperature is above 47.5°F. The higher the temperature is above this developmental threshold, the faster the rate of development. Other insects and plants have different developmental thresholds. A *degree-day (°DD)* is a measure of the amount of heat an organism experiences during a 24-hour period above its developmental threshold.

Several ways are available to compute degree-days, but the easiest is as the arithmetic difference between average daily temperature and the developmental threshold:

$$\text{degree-days} = [(\text{daily high} + \text{daily low})/2] - \text{developmental threshold}$$

Here the average daily temperature is computed as the sum of the high and low temperatures divided by two. As an example, consider a day with a high temperature of 73°F and a low of 50°F. Fourteen root maggot degree-days accumulate during that day, computed as:

$$\begin{aligned} \text{degree-days} &= [(73 + 50)/2] - 47.5 \\ &= 14\ ^\circ\text{DD} \end{aligned}$$

There are two additional rules to remember when computing degree-days:

- Rule 1—if the high temperature is less than the developmental threshold, then no degree-days accumulate during that day.

  Example (using root maggot developmental threshold of 47.5°F)

  low = 10°F
  high = 41°F
  DD = 0

- Rule 2—when the low temperature is less than the developmental threshold, then calculate degree-days by substituting the developmental threshold for the observed low temperature.

  Example (using root maggot developmental threshold of 47.5°F)

  low = 28°F
  high = 55°F
  DD = [(47.5 + 55)/2] – 47.5 = 3.75 degree-days

The usefulness of tracking degree days is that they allow us to forecast events in the pest life cycle. For this root maggot example, research has shown that it takes 360 degree-days after March 1 for root maggot larvae overwintering in the soil to complete development and emerge as adult flies. In this example, knowing in advance the day of fly emergence is important because the best time to apply insecticides to kill the larvae (which hatch from eggs laid by the newly emerged adult flies) is during a 20-day window—from 10 days before the majority of overwintering flies emerge until 10 days after peak emergence.

Making localized predictions of peak fly capture dates requires that you compute degree-days beginning with March 1. Daily high and lows can be monitored on-site by using max:min thermometers or they can be obtained from local newspapers, radio reports, cable weather stations, the Internet, and similar sources. Growers keep a daily running tally of cumulative degree days. When the running tally since March 1 reaches 360, they stop tracking daily degree days and predict that peak fly capture will occur.

Consider the following example:

Date	Daily high (°F)	Daily low (°F)	Degree Days	Cumulative Degree Days
March 1	44	15	0	0
March 2	45	19	0	0
March 3	54	22	3.25	3.25
March 4	57	29	4.75	8.0
March 5	37	9	0	8.0
(intervening dates and degree-day sums omitted for ease of illustration)				
May 29	77	45	14.75	335.0
May 30	82	50	18.5	353.5
May 31	66	47	9.25	362.75

Here high and low temperatures were recorded daily beginning with March 1 and degree-days computed according to the rules described previously. Cumulative degree-days since March 1 (tracked in the far right column) reached 360 on May 31. This is the predicted date of peak capture. If cumulative fly captures on sticky stakes through May 31 had been greater than the economic threshold of 40 to 45 flies, then insecticide use would have been warranted for maggot control. Optimal time for application would have been through June 10. Note that if extended weather forecasts are available (such as 4- or 7-day temperature outlooks), then you also could forecast degree-day accumulations and predict future dates of peak fly capture. Doing this could allow farmers to anticipate the need for control action.

Of course, prediction accuracy depends on using temperatures representative of the crop:pest environment. Microhabitat differences even within a single crop field (let alone among different fields within a larger geographic area) reduce prediction accuracy.

Decision Rules

Economic injury levels (EIL) and economic thresholds (ET) (figure 3.36) are numeric guidelines that identify when pesticide use is and is not necessary. The EIL formally is the economic break-even point, the number of pests that cause crop damage exactly to the applied pesticides is when pest density reaches the ET value; pesticide application here keeps infestations from increasing to the break-even EIL value. The shaded portion of the pest population curve shows actual pest density while the dotted curve shows pest population increase in the absence of control.

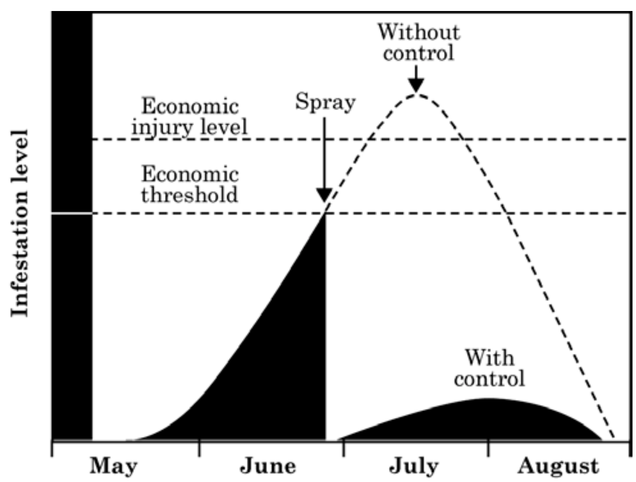


Figure 3.36 Generalized relationship between the Economic Injury Level (EIL), Economic Threshold (ET) and seasonal pest population growth. The only time to take control action depends on the cost of pest control. Hence, if it costs $20 per acre to purchase and apply a pesticide, the EIL then is the number of pests that otherwise would cause a $20 per acre yield loss in the absence of control.

The ET (also called the action threshold) is the time to take control action to prevent the pest population from increasing beyond the EIL. IPM uses pesticides, but only when field scouting shows that pest density exceeds the ET.

In theory, EILs and ETs fluctuate with changes in crop market value, pest control costs, control efficacy and crop susceptibility to pest damage. The EIL value for any particular pest increases as control costs increase; it takes increasingly more pests to economically justify use of a pesticide that costs $40 per acre versus $20 per acre. In contrast, the EIL for any particular pest decreases as crop market value increases, as crop susceptibility to pest injury increases, and as control efficacy (percent pest kill) increases; it takes fewer pests to justify pesticide application. In practice, EILs and ETs often are simple static constants, primarily because we do not have the research base necessary to precisely compute their values. In theory, EIL and ET values can be computed for any type of agricultural pest. In practice, guidelines generally are limited to the key insect pests; relatively few exist for plant pathogens, weeds or nematodes.

Step 3: Site-Specific Pesticide Selection

The final component of IPM is selection of pesticides that pose the least risk of leaching through soil or being transported from fields in runoff water and sediment or drifting as spray particles on the wind. The potential for water contamination depends on two primary factors:

- local environmental features, particularly soil texture, permeability and organic matter, and
- properties of the pesticide itself.

These factors have been combined into a “risk matrix” table that compares the relative risks posed by different pesticides to ground and surface water. The matrices, as well as supporting pesticide and soils data, are available statewide at local NRCS offices and at local Cooperative Extension System offices of your state's Land Grant University.

Excessive irrigation also can increase the potential for pesticide leaching and surface runoff. If the rate of water application is higher than needed to recharge the water storage capacity of the soil, then excess water and dissolved pesticides may percolate beyond the crop root zone and contaminate ground water.

Student Activity 18

1. List the three steps to designing IPM programs.

____

____

____

2. Define and give example of:

   a. cultural control methods ______________________________

   ____

   ____

   b. biological control methods ______________________________

   ____

   ____

   c. host-plant resistance ______________________________

   ____

   ____

3. Discuss from an ecological standpoint the four basic ways that cultural controls can reduce pest problems.

____

____

____

____

____

____

4. List three groups of biological control agents.

5. List the three basic approaches to biological control and differentiate among these basic approaches.

6. Which of the three basic approaches to biological control is the most practical for farmers to adapt? Discuss this approach and why it is most practical.

7. What steps need to be taken to reduce the impact of pesticides on biological control agents?

8. The developmental threshold for cotton boll weevil is 60°F. Calculate the degree days (DD) accumulated for one day in which the high temperature is 92°F and the low is 65°F.

____

____

____

____

____

9. Calculate the degree days if the night time low is 56°.

____

____

____

____

____

10. Discuss the importance of site specific pesticide selection to environmental concerns.

____

____

____

____

____

Module 3, Part G, Section 7—Putting It All Together: A Recap and an Example

Supporting Objectives

- Identify the major objective of IPM in controlling pest and describe the IPM tactics currently most useful to agriculture.
- Describe the three general categories of pest status (noneconomic pests, occasional pests and severe pests) and the appropriate pest control strategy for each.

Management Strategies

Selection of IPM methods requires detailed knowledge of pest biology and ecology. The idea is to identify weak links in the pest life cycle or vulnerable life stages that selectively can be exploited with minimal disturbance to the rest of the system. Among the tactics currently most useful to agriculture are these:

- Protection and enhancement of naturally occurring insect predators and parasites by controlling pests with physiologically selective insecticides (microbial insecticides) or ecologically selective use of broad spectrum pesticides (altering application time, rate, and placement).
- Crop management practices that make the environment less favorable for pest colonization, establishment, and survival, especially manipulation of crop rotations, planting and harvest dates, site selection, cultivation, irrigation, and fertility regimes.
- Pest resistant/tolerant crop varieties.

The exact mix of tactics depends on pest status. For *non-economic pests* (pests that consistently remain below economic thresholds) (figure 3.37) the appropriate action is no control action; regional monitoring of pest levels is adequate. *Occasional pests* (figure 3.38) are those species that normally remain below the ET but sporadically exceed the threshold. Here an appropriate strategy is early detection and prediction through field scouting and remedial use of pesticides when the threshold is reached. The most difficult species to manage are classified as *severe pests* (figure 3.39). These include many weeds and plant pathogens whose average densities are extremely high or pests that cause cosmetic damage to high-value fruits and vegetables. Pesticide use against severe pests is not justified except as a short-term, stop-gap measure because the frequent applications necessary for control inevitably result in environmental problems. Instead, long-term management requires combinations of methods that permanently reduce environmental carrying capacity and dampen pest levels below threshold levels (figure 3.40).

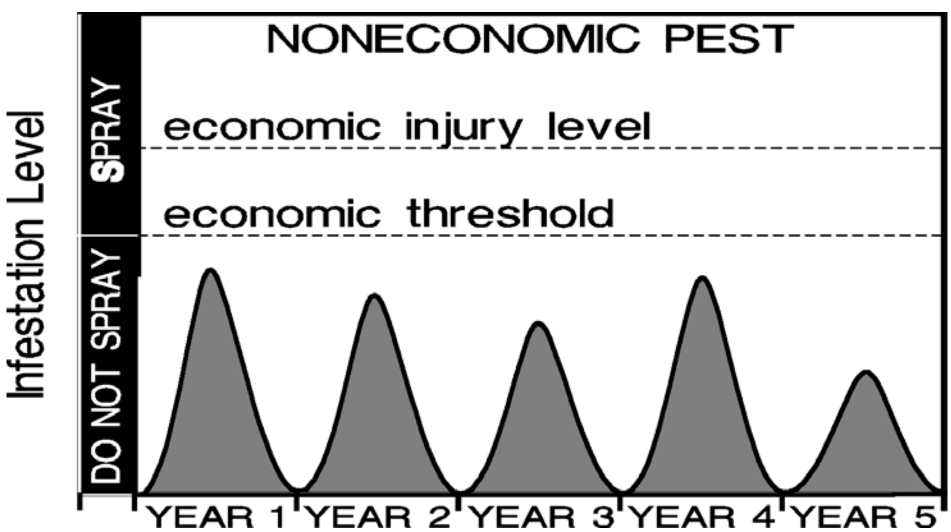


Figure 3.37 Seasonal infestation levels of non-economic pests (shaded graphs) never reach levels that require specific IPM action. Their presence in fields causes such insignificant crop damage that the costs of pest control outweigh the benefits of control. Many pests fall within this category.

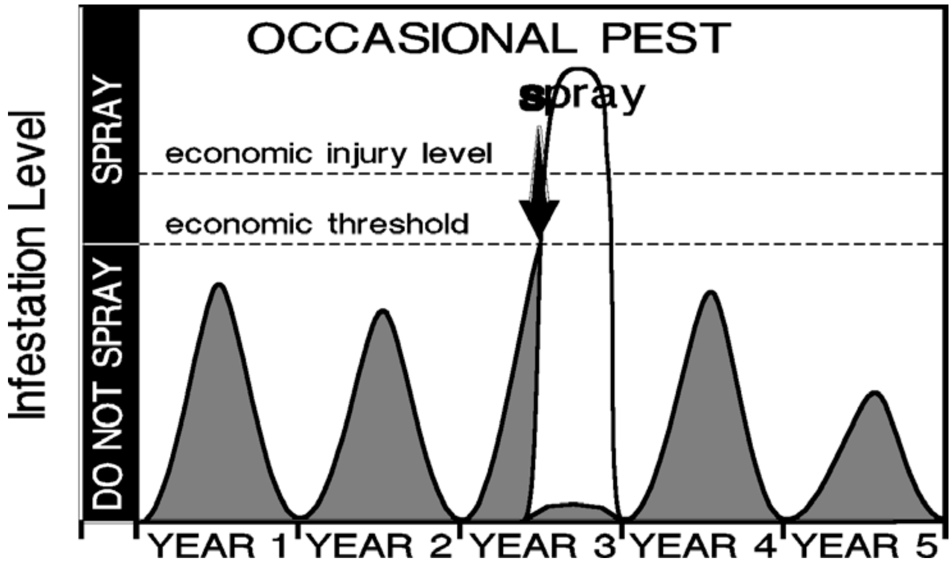


Figure 3.38 Seasonal infestation levels of occasional pests (shaded graphs) usually are below levels that require IPM action. Because their populations only occasionally cause significant crop damage, occasional pests can be managed with rather simple prescriptive IPM approaches that depend on pest forecasting systems and field scouting to identify problem fields requiring pesticide application.

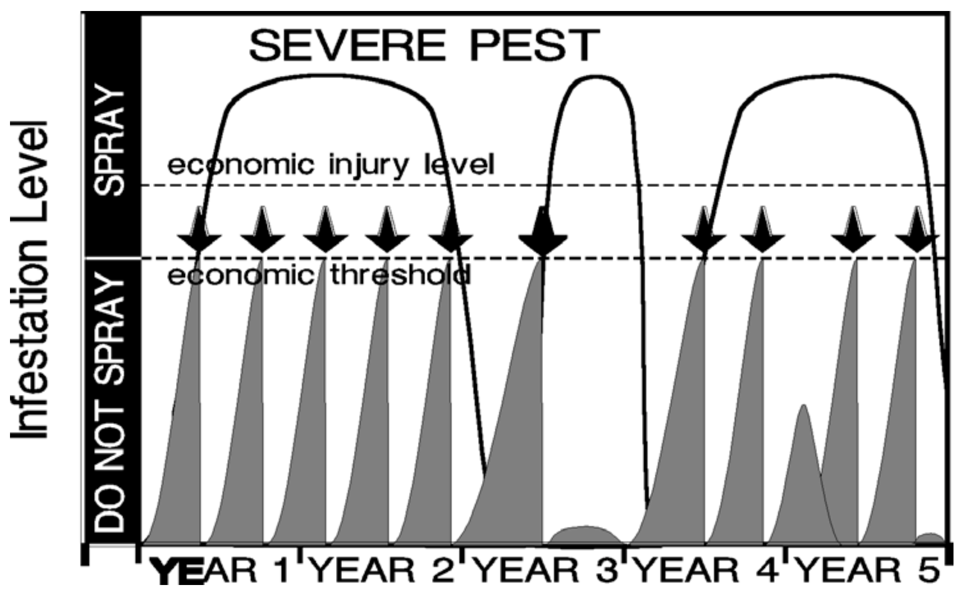


Figure 3.39 Seasonal infestation levels of severe pests (shaded graphs) routinely exceed economic thresholds. Here reliance on pesticides is ill-advised because the many applications needed during the season greatly increase the risk of resurgence, replacement and resistance.

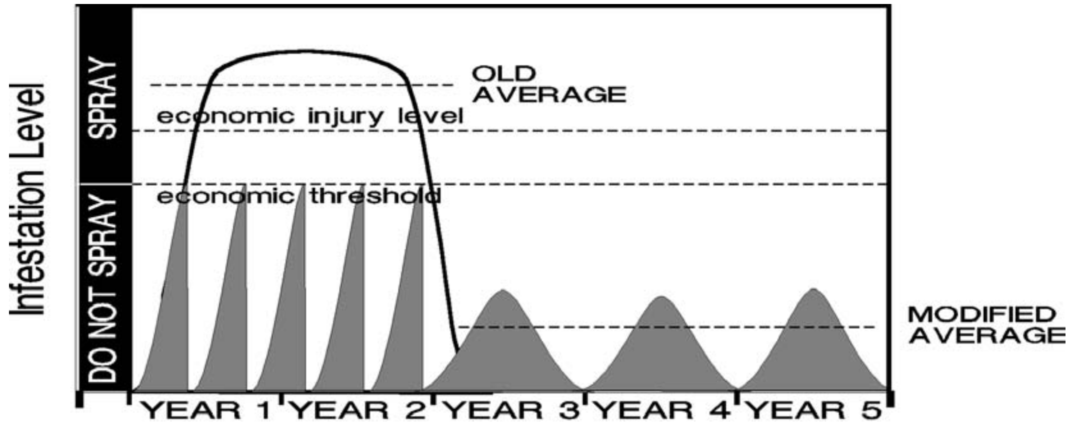


Figure 3.40 IPM strategies for severe pests typically require combinations of cultural and biological controls that reduce overall environmental favorableness to the pest. Here the long-term average pest population before IPM (OLD AVERAGE) has been reduced from levels that perennially exceeded the economic threshold to levels after IPM that never exceed threshold values (MODIFIED AVERAGE).

It really does deserve repeating—there is no single recipe for IPM. The specific mix of control tactics varies with each crop, each insect, each disease, each weed, or other pest. One example of an IPM strategy is the program for Russian wheat aphid management in wheat and barley (figure 3.41). This IPM program relies on biological and cultural methods. It only looks to insecticides as a last resort if non-chemical alternatives fail.

Pest management for Russian wheat aphids starts at planting time with cultural methods. Farmers break the aphid infestation cycle by planting fall-seeded wheat and barley as late as agronomically feasible. This tactic allows the crop to escape pest colonization by avoiding incoming flights of aphids that occur when summer crops are harvested. The converse (plant as early as possible) is true for spring-seeded crops. These early plantings allow wheat and barley plants to develop beyond the highly susceptible seedling stage before aphids arrive. Field selection also can contribute to Russian wheat aphid suppression. Here the idea is to avoid planting cereal crops in fields immediately adjacent to rangeland or large grassy expanses. These areas can serve as reservoirs where aphids survive and multiply during the summer dry season from crop harvest until the next crop is planted.

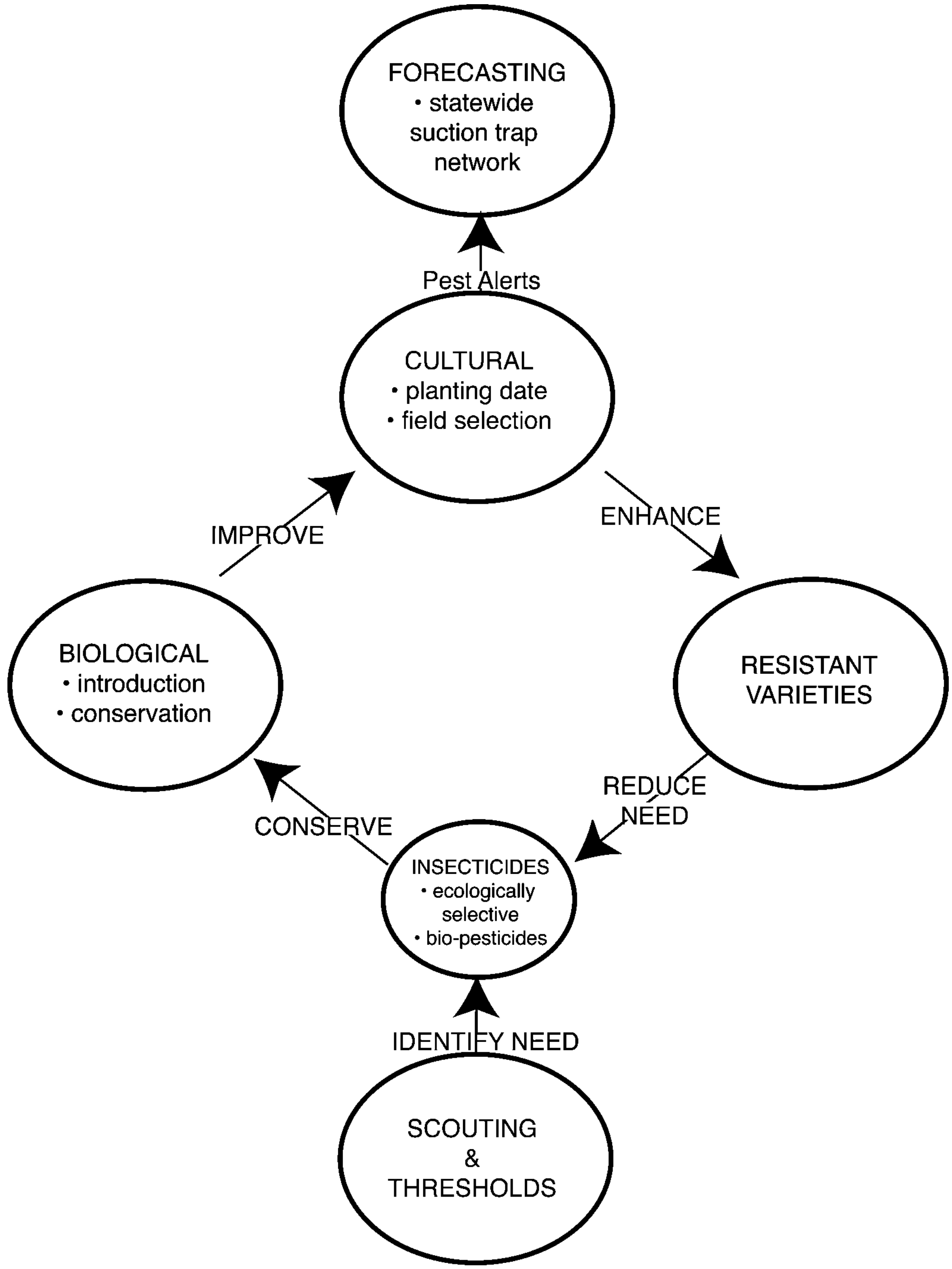


Figure 3.41 IPM system for the Russian wheat aphid on barley and wheat in the western U.S. The system depends on biological, cultural and plant-resistance measures. Insecticides are relegated to a secondary role; they only are used when justified by field scouting and thresholds. Differences in sizes of component circles identify the relative importance of each tactic in the overall IPM system; italics identify tactics still largely under research and development.

Several aphid-resistant wheat and barley varieties first became commercially available during 1997. Work is ongoing on importing and releasing exotic parasitic wasps and ladybeetles for Russian wheat aphid control and on use of aphid-killing fungi as a biological insecticide.

Insecticides for Russian wheat aphid control can be applied according to two strategies: incorporation into the soil at planting time or sprayed over the top of rows later during the growing season. But rather than automatically applying pesticides, wheat and barley growers use scouting and forecasting to decide if pesticides really are needed. The need for insecticides at planting time can be gauged from a statewide network of traps that monitor aphid flights. Use of insecticides at planting is recommended only if aphid flights are heavy and planting dates cannot be delayed to avoid incoming aphids.

Later during the growing season, farmers can scout fields by using a system of decision cards that quickly and accurately identify fields requiring treatment. Because Russian wheat aphid infestations often begin at field edges, spot-spraying a 50-ft wide strip along the fencerow (vs. broadcast application over the entire field) may be all that is required. Spot-spraying has the added benefit of allowing biocontrol agents to survive in unsprayed portions of the field. For both soil and foliage-applied insecticides, growers can consult “risk-matrix” tables to determine the relative likelihood that a specific pesticide will move into surface or groundwater.

Current Issues and the Future

IPM has come full circle since its beginnings 20 years ago. Initially envisioned as the best solution to the problem of environmental contamination by insecticides, IPM shifted its focus from environmental to economic concerns (competitiveness and profitability) during the 1980’s. The 1990’s best could be characterized as the decade of the environment, with a renewal of public scrutiny of agricultural pesticides. Concern especially is growing about pesticide residues on foods, ground water contamination by agrichemicals and farm worker safety. Food processors already are limiting the types of pesticides that their growers can use, whether these uses are legal or not. The inevitable consequence will be further restrictions on the use of pesticides. In addition, the re-registration process may reduce 40,000 current uses of 600 active ingredients to 14,000 uses with small acreage crops (including potatoes, alfalfa and fruits) perhaps losing 25 to 50 percent of currently registered uses. The role of IPM must be as a source-reduction strategy: to provide farmers with alternative control strategies that minimize pesticide use. Failure of agriculture to voluntarily adopt IPM approaches may lead to legally mandated practices. Indeed, some argue that it already is too late. Legislative initiatives and policy options now under consideration in the U.S. Congress range from pesticide use by prescription only to taxes on pesticide users to crop insurance and tax credits for IPM users and IPM-labeled fruits and vegetables.

Student Activity 19

1. Identify the major objective of IPM in controlling pest and the IPM tactics currently most useful to agriculture.

2. The exact mix of IPM tactics depends on pest status. Describe the three general categories of pest status (non-economic pests, occasional pests, and severe) and the appropriate pest control action for each category.

3. Is there a single recipe for IPM?

Module 3, Part G, Section 8—USDA National IPM Initiative

Note: This section is optional and does not include student activities.

Supporting Objectives

- List the national goals (acreage and timetable) for IPM adoption in the U.S.
- State in a sentence the objectives of the National IPM Initiative.
- Contrast activities planned/completed under Phase I, II and III of the National IPM Initiative.
- Name some public and private organizations responsible for delivering IPM training, advice, and recommendations to farmers.
- Discuss why it might be difficult to measure the rate of IPM adoption in the U.S.

On June 25, 1993, the Clinton Administration responded to consumer concerns about potential health and environmental risks associated with agricultural pesticide use and to farmer concerns about profitability and long-term competitiveness by proposing sweeping changes to U.S. pesticide-use regulations. Among the strategies identified by the President to reduce use of high-risk pesticides (particularly those pesticides present [albeit in trace amounts] in the diets of infants and children) was increased use of IPM methods by U.S. agriculture. Subsequently, the United States Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA), and the Food and Drug Administration

(FDA) responded to the President's proposal by jointly calling for the *voluntary goal of implementing IPM methods on 75 percent of U.S. cropland by the year 2000*. This voluntary approach to reducing pesticide risks contrasts with mandatory pesticide reduction strategies adopted by several European governments in the early 1990's.

To achieve the 75 percent adoption goal, the USDA announced on December 14, 1994 its National IPM Initiative. The Initiative is based on two simple premises:

- Involving farmers and other pest control advisors from the beginning in the development of IPM programs will increase the adoption of IPM methods;
- IPM benefits both consumers and farmers: it can reduce environmental and food safety risks from pesticides and increase farmer profitability by ensuring pest controls are used in the most judicious way.

In essence, the National IPM Initiative seeks to develop new IPM tools and then move them to the farm where they can be applied to solving priority pest control problems identified by farmers. Grower-identified research and extension needs and voluntary implementation are two key features. The Initiative seeks to coordinate federal research, education and regulatory programs with state-based Agricultural Experiment Station and Extension service programs at every land grant university, all in a cooperative effort that directly involves farmers, private consultants, agricultural industry field staff, and others who advise farmers about pest control. Key to this coordination is the USDA IPM Program Subcommittee chaired by the USDA IPM Program Coordinator. The IPM Program Subcommittee has representation from the Agricultural Research Service ARS), Animal and Plant Health Inspection Service (APHIS), Forest Service (FS), Farm Services Administration (FSA), Agricultural Marketing Service (AMS), National Resources Conservation Service (NRCS), Cooperative State Research Education and Extension Service

(CSREES), Economic Research Service (ERS), National Agricultural Statistics Service (NASS), Office of Budget and Policy Analysis (OBPA) and EPA. Within NRCS, overall leadership for pest management policy is the responsibility of the Pest Management Specialist in the Ecological Sciences Division at National Headquarters in Washington, DC.

Priorities for the USDA IPM Initiative have been established at several levels. Particularly important are those research and educational needs identified by those people ultimately responsible for practicing pest management: farmers and those professionals who advise growers about pest control. Other priorities are current pesticide uses jeopardized by either impending regulations or by pesticide resistance.

The three basic components of the Initiative are need assessment, technology development and delivery, and privatization. Each is carried out in three consecutive phases.

Phase I of the National IPM Implementation Program established 23 multi-state IPM during 1995. These production-region teams developed detailed plans to guide the implementation of IPM systems over 5 to 6 years on such large-acreage crops as alfalfa, wheat, corn, cotton, and soybeans as well as potatoes, processing and fresh market vegetables, apples, and greenhouse and nursery crops. Teams devised indicators to measure progress toward the 75 percent adoption goal as well as a strategy for IPM privatization that turns over implementation to pest consultants, industry field staff, and other private sector pest control advisors.

In addition to these regional IPM teams that focus on large crop production areas, Phase I also directed Cooperative Extension Services in each state to organize state-level IPM teams to identify specific IPM needs in local production systems. State teams deliberately sought out the advice of farmers to identify the most important research and education priorities. State teams also included university research and extension faculty, crop consultants, agribusiness, state and federal agency personnel, and consumers. The idea is that State teams best can identify local information gaps and constraints to increased IPM adoption. To date, local IPM teams of 4,267 IPM customers (including 3,210 farmers) have identified research and education needs for 64 key commodities in 46 states. Prioritized needs lists are accessible at http://www.reeusda.gov/ipm.

Phase II of the National IPM Initiative (which has yet to be appropriated by Congress) will provide federal funding for large scale, 5-to-6-year IPM research and education projects that address state and regional IPM needs identified during Phase I. An important component of Phase II projects is assessment of economic, environmental, public health, and social impacts of IPM. This emphasis on benefits assessment reflects the imperative to definitively show in this time of increasingly scarce resources how public investment in agricultural research and education benefits all U.S. citizens

Finally, Phase III calls for private sector implementation of IPM systems developed during Phase II. During the past 2 decades, a primary goal of public (tax-supported) IPM research and extension programs in the U.S. has been to accelerate IPM adoption by helping private sector IPM pest control advisors deliver pest management advice. IPM program design and transfer to farmers depends on producers and private businesses working cooperatively with public and government agencies. Public leadership for educational outreach primarily rests with the Cooperative Extension System (CES), a national network of Federal employees and faculty at state land-grant universities charged with moving research-based knowledge into local communities. State departments of agriculture and staff at other State and Federal regulatory agencies contribute to IPM educational programs. Within the private sector, growers who have neither the technical skills nor management time to personally scout their fields look for assistance from crop management associations, for-hire private consultants, and agricultural industry field staff. Growers often simultaneously depend on Extension personnel, industry field staff, and consultants for their pest management advice.

Agricultural chemical dealers often are a significant source of pest control recommendations for farmers in many areas, as are some food processors. They provide technical IPM support to their contract growers through professional field staff. Approximately 2,000 to 7,000 private (for-hire) consultants provide farmers with IPM advice and recommendations in at least 38 states. The proportion of farmers served by consultants varies from 5 to 99 percent, depending on the region specific crop. A large percentage of cotton growers and vegetable producers hire private consultants; only a small percentage of Midwest corn and soybean producers hire consultants.

Extension's role in IPM has changed considerably since the first federally-supported demonstration projects in North Carolina and Arizona during 1971. Since 1979 when Extension IPM programs became national in scope, each U.S. state and protectorate annually has received special funding from the Extension Service of the U.S. Department of Agriculture to conduct educational programs in integrated pest management. When these programs began, the objective was to implement practical methods for monitoring pests in farmers' fields. The legislative intent was that federal support serve as cost-share monies to encourage farmers to adopt scouting programs, but with the mandate that scouting eventually be privatized by requiring growers themselves to assume all costs after a trial period. Accordingly, most state IPM programs have included Extension-sponsored pilot scouting services for growers that since have been turned over to the private sector.

The integrated pest management program for alfalfa seed in the Pacific Northwest chronicles this privatization process. Formal Extension IPM programs for the regional alfalfa seed industry began in Washington state during 1973 with a two-fold focus: weekly field scouting of four key insect pests and their natural enemies, and management of the pollinating bees required for alfalfa seed production.

Following Washington's lead, Extension entomologists in Idaho introduced these methods in 1976 as a 4-year demonstration program in five counties. During that first year, 23 commercial seed growers in Idaho entered 945 acres into the pilot program for a $3.00 per acre fee. Augmented with ES-USDA IPM funds, these fees paid for scout wages, travel expenses, supervisor salary, and related operating expenses. Acreage scouted by extension doubled the second year (1977) to 2,500 acres and doubled again to 5,300 acres in 1978. Simultaneously, fees assessed growers increased to $4.50 per acre in 1978 and $6.50 per acre in 1979, the last year of direct Extension sponsorship.

Privatization of scouting services in Idaho began during 1979 with one private IPM consulting business and one seed company scouting 1,200 acres. By 1980, scouting services were provided by six private IPM consultants, five alfalfa seed companies, and five agrichemical supply and service companies. Extension withdrew its financial sponsorship in 1980 and thereafter provided educational programming by convening annual scout training schools and by producing IPM manuals and videos. These relationships continue today. Private consultants and seed companies still offer pest scouting and Extension provides the educational programs.

How will we know if U.S agriculture indeed has reached the 75 percent target? As you might imagine, the question of what specific practices constitute IPM for a particular crop or in a certain production area is open to interpretation, if not heated argument. A 1994 study conducted by the USDA Economic Research Service (ERS) concluded that slightly over half the acreage in the U.S. of fruit, vegetable, and field crops can be categorized as IPM. Here farmers were classified as practicing IPM if they monitored pest populations and used economic thresholds before making pest control decisions. Some critics have characterized this definition as too lax and conclude that the ERS estimate overestimates current use of IPM adoption. It is important to recognize that IPM farmers fall along a continuum, from low-level IPM users who only use the most basic prescriptive IPM methods, to high-level users who use the most advanced biointensive IPM methods available. Hence, depending on how one defines integrated pest management, the same set of data can yield totally different rates of IPM adoption.

Food for Thought

- How will the National IPM Initiative specifically impact your job responsibilities?
- Would it not be better if the National IPM Initiative mandated (legally required) use of IPM methods by farmers rather than letting growers voluntarily decide about IPM adoption?
- What are the pros and cons of publicly funded IPM educational outreach programs for farmers?

References

Introduction to Integrated Pest Management by Mary Louise Flint & Robert van den Bosch. 1983. ISBN 0-306-40682-9. A 240-page textbook for the nonspecialist who wants a more detailed background on IPM principles.

The IPM Practitioner. Published ten times a year, this newsletter highlights practical IPM methods and products in settings ranging from agricultural, landscape, structural, medical, range, veterinary and forest. Regular features include State-of-the-Art IPM Reviews, Research Notes, Conference Highlights, Journal Abstracts, Book Reviews, Products & Services, Reader's Column, Calendar and Educational/Employment Opportunities. $25/year from Bio-Integral Resource Center, P.O. Box 7414, Berkeley, CA 94707 (415) 524-2567.

The following three reference texts are excellent introductions to the plant protection disciplines involved in integrated pest management. These texts were written for college students and professionals working in agriculture.

Applied Weed Science by Merrill A. Ross and Carole A. Lembi. 1985. ISBN 0-02-403911-X. Coverage of herbicides now is dated, but otherwise good presentation of weed management philosophy and methods. Especially good at showing how to apply principles and practical factual information to solving weed problems in the field.

Entomology & Pest Management by Larry P. Pedigo. 1996. Second edition. ISBN 0-13-373531-1. Combines elements of general entomology with IPM principles and up-to-date discussion of management tools for insects. Highly readable.

Plant Pathology by George N. Agrios. 1988. Third edition. ISBN 0-12-044563-8. The college standard for undergraduates.

Module 3, Part H—Pesticides

Supporting Objectives

- Rank the three most common pesticide classes in terms of active ingredient used.
- List three precautions when using emulsifiable concentrate formulations.
- Define adjuvants.
- State the precautions to be taken when using adjuvants.
- List an insecticide mode of action that can affect both insects and mammals.
- List three herbicide categories based upon application timing.

Classes

Pesticides are defined as "any substance used for controlling, preventing, destroying, repelling, or mitigating any pest." Listed below are some common *pesticide classes* as defined by the target pest. The three most common pesticide classes, in terms of active ingredient used, are *herbicides, insecticides,* and *fungicides*.

Table 3.10 Pesticides

Pesticide class	Target pest
Acaricide	mites
Avicide	birds (kills or repells)
Bactericide	bacteria
Fungicide	fungi
Herbicide	weeds
Insectacide	insects
Larvicide	larvae (usually mosquito)
Miticide	mites
Nematicide	nematodes
Ovicide	eggs
Rodenticide	rodents

Chemistry

Pesticides represent a broad range of chemistry, with the only common attribute being the ability to control or kill pests. Pesticides are often grouped according to common structure, which usually determines similar mode of action, persistence in the environment, bioaccumulation, and pest control properties. Structural similarity may or may not determine similar toxicity. Pesticides are known by their trade name and their common name. Also on the label is the chemical name. For example, the chemical O,O-diethyl O-(3,5,6-trichloro-2-pyridinyl) phosphorothioate has the trade name Lorsban and the common name chlorpyrifos.

Pesticide structural groups, or families, are classified according to their pest control properties. In terms of amount of active ingredient used, the classes herbicides, insecticides, and fungicides represent over 93 percent of pesticides used in U.S. and world markets. Herbicides typically represent over 50 percent of all pesticide use, followed by insecticides (23-35 percent), and fungicides (11-14 percent). Further discussion of pesticide classes will be limited to herbicides, insecticides, and fungicides.

Herbicides

The following table lists the herbicide families and examples by common name.

Table 3.11 Herbicides

Herbicide Family	Example Herbicide(s)
Acetanilides	metolachlor, alachlor
Amides or Substituted Amides	propanil
Arsenicals	MSMA
Benziocs or Arylaliphatic Acids	dicamba
Benzonitriles or Substituted Nitriles	dichlobenil, bromoxynil
Benzothiadiazoles	bentazon
Bipyridyliums	diquat, paraquat
Carbanilates or Carbamates	chlorpropham
Chlorinated Aliphatic Acids	dalapon
Cyclohexenones	sethoxydim
Dinitroanalines or Nitroanilines	triflurailn, pendamethalin
Diphenyl Ethers	lactofen
Imidazoles or Imidazolinones	imazapyr
Oxyphenoxy Acid Esters	fluazifop-butyl
Phenoxy Acids	2,4-D
Phenylureas or Substituted Ureas	diuron, linuron
Phosphono Amino Acids	glyphosate
Pyridazinones and Pyridinones	clomazone, oxadiazon
Pyridinoxy and Picolinic Acids	picloram, triclopyr
Sulfonylureas	metsulfuron-methyl, thiameturon-methyl
Thiocarbamates	EPTC, thiobencarb
Triazines	atrazine, simazine
Uracils or Substituted Uracils	bromacil, terbacil

Insecticides

The following table lists insecticide families and examples by common name.

Table 3.12 Herbicides

Insecticide Family	Example Insecticide
Organochlorines	methoxychlor, docofol
Organophosphates	methyl Parathion, chlorpyrifos
Carbamates	carbaryl, methomyl, bendiocarb
Formamidines	chlordimeform, amitraz
Botanicals	neem, pyrethrum
Synthetic Pyrethroids	esfenvalerate, permethrin
Acylureas	chlorfluazuron
Synergists*	piperonyl butoxide
Antibiotics	abamectin, avermectin
Fumigants	methyl bromide, telone
* Synergists are materials that enhance the activity of insecticides	

Fungicides

The following table lists fungicide families and examples by common name.

Table 3.13 Fungicides

Fungicide Family	Example Fungicide
Inorganic Fungicides	sulfur, copper
Dithiocarbamates	thiram, zineb
Substituted Aromatics	PCNB, chlorothalonil
Systemic Fungicides	
Oxathiins	carboxin
Benzimidazoles	benomyl, thiabendazole
Phenylamides	metalaxyl
Triazoles	triadimefon
Organophosphates	foretyl -Al
Dicarboxamides	iprodione, vinclozolin
Dinitrophenols	dinocap

Formulations

Most end-use pesticide products are not 100 percent active ingredient. Typically they are diluted with water, oil, air, or chemically inactive (inert) solids so they can be handled by application equipment and spread evenly over the area to be treated. Because the basic chemical usually cannot be added directly to water or mixed in the field with solids, manufacturers must further modify their products by combining them with such other materials as solvents, wetting agents, stickers, powders, or granules. The final product is called a pesticide *formulation* and is ready for use either as packaged or after being diluted with water or other carriers.

Formulation types

A single pesticide is often sold in several different formulations. The applicator must choose the formulation that will best meet the requirements for a particular job. When deciding on a pesticide formulation, consider the habits of the pest; the plant, animal, or surface to be protected; application equipment; the danger of drift and runoff; possible injury to the protected surface; and the effectiveness against the pest.

Abbreviations are often used to describe the type of formulation involved. These abbreviations are used on labels and in recommendations. Some common ones are:

Table 3.14 Liquid Formulations

Abbreviation	Formulation
WP	wettable powder
S	solutions
F	flowable
G	granules or granular
D	dusts
SP	soluble powder
EC	emulsifiable concentrate

Emusifiable Concentrates (EC or E)

These solutions contain a high concentration of pesticide. Most of them are designed to be mixed with water or oil and contain wetting agents, stickers, and other additives. They may contain as much as 25 to 75 percent (2 to 8 pounds per gallon) of a pesticide active ingredient.

Advantages

Because these formulations contain a high concentration of pesticide, the price per pound of active ingredient is relatively low. Only moderate agitation is required in the tank, so they are especially suitable for low-pressure, low-volume sprayers; mist blowers; and small, home ground sprayers. They are not abrasive and do not settle out when the sprayer is not running. There is little visible residue on the treated surface. Because of the high pesticide content, the applicator is not required to store, transport, or handle a large bulk of chemical for a particular job.

Disadvantages

These pesticides are highly concentrated; therefore it is easy to mix them incorrectly. Mixtures of emulsifiable concentrates may be phytotoxic. Mix these carefully. Because they are highly concentrated and are liquid, they are easily absorbed through the skin and may be a hazard to the applicator. Improperly stored concentrates can also be extremely hazardous. Emulsifiable concentrates contain solvents that cause rubber hoses, gaskets, and pump parts to deteriorate rapidly unless they are made of neoprene rubber. Some formulations even cause pitting of car finishes.

Principal Uses

Emulsifiable concentrates can be diluted and used on fruit, vegetables, shade trees, farm animals, and to control structural pests. Household sprayers, hydraulic sprayers, low-volume ground sprayers, mist blowers, low-volume agricultural aircraft sprayers, and ultralow-volume sprayers can all spray high concentrate liquids.

Solutions (S)

Some pesticide active ingredients dissolve readily in a liquid solvent such as water or a petroleum-based solvent. When mixed with the solvent, they form a solution that will not settle out or separate. Formulations of these pesticides usually contain the active ingredient, the solvent, and one or more other ingredients. Solutions may be used in various types of sprayed indoors or outdoors.

Ready-To-Use (RTU) [Low Concentration Solutions]

These preparations are primarily solutions of highly refined oils and low concentrations of pesticide. They are generally used as purchased.

Advantages

Low concentrate solutions are designed to be sprayed as purchased. No mixing is necessary, which lessens the chance for making a mistake. Household formulations have no unpleasant odors, and the liquid carrier usually evaporates quickly and does not stain fabrics and furniture.

Disadvantages

Low concentrate formulations are usually fairly expensive for the amount of actual pesticide bought. There are few uses for low concentrate formulations.

Principal Uses

Low concentrate solutions may be used in the household for flying or crawling insects and for mothproofing clothes. In barns, they may be used as space sprays and fly sprays for livestock. They are also used as prepared sprays for mosquito control and shade tree insect control. Ready-to-use prepackaged bottles of some herbicides are also available to the homeowner.

Concentrate Solutions (C or LC)

Other solutions are sold as concentrates that must be further diluted with a liquid solvent before they are applied. Occasionally the solvent is water, but more often it is a specially refined oil- or petroleum-based solvent.

Advantages

No agitation is necessary. Other advantages of solutions vary depending on the solvent used, the concentration of the active ingredient, and the type of application involved.

Disadvantages

A limited number of formulations of this type are available.

Principal Uses

Solutions are used for structural and institutional pest control, control of some household pests, livestock and poultry pest control, space sprays in barns and warehouses, shade tree pest control, and mosquito control.

Ultralow-Volume (ULV)

These concentrates may approach 100 percent active ingredient. They are designed to be used as is or to be diluted with only small quantities of specified solvents.

Advantages

These formulations are relatively easy to handle, transport and store. Little agitation is required, and they are not abrasive to equipment. ULV formulations do not plug screens and nozzles. They leave little visible residue on treated surfaces.

Disadvantages

Because of high drift hazard, ULV formulations are difficult to keep on the target site. Specialized, precisely metered equipment is required. Solvents used in the formulations—or the concentrated form of the active ingredient itself—can cause rubber or plastic hoses, gaskets, and pump parts and surfaces to deteriorate. There is substantial hazard to the handler because of the concentrated pesticide in these formulations, and the ready tendency to be absorbed through the skin.

Principal Uses

These special-purpose formulations are used mostly in such outdoor applications as in agricultural, forestry, ornamental, and mosquito control programs.

Aerosols (A)

Aerosols are sold in small pressurized cans, sometimes called bug bombs, that contain a small amount of pesticide or a combination of pesticides. When the nozzle is triggered, the mixture is driven through a fine opening by a chemically inactive gas under pressure.

Advantages

Aerosols are convenient because they are always ready to use. They are also a convenient way to buy small quantities of pesticide. They are easily stored, and the pesticides do not lose their strength while in storage.

Disadvantages

Aerosols are only practical for use in small areas. A can contains little active ingredient, making this an expensive way to buy pesticides. Unfortunately, aerosols are also attractive playthings for small children and, if left in reach, are a hazard. Aerosols can be dangerous if punctured or overheated, and may explode and injure someone. Never burn aerosol cans.

Principal Uses: Aerosols are most often used in households, backyards, tents, and other small areas. They may be used either as space sprays for flying insects or as residual sprays. Usually they are used against insects, but some are designed for plant diseases or weeds. Commercial models are available for use in greenhouses, barns, and other large indoor areas. These hold 5 to 10 pounds of pesticide, and are usually refillable.

Dry Formulations

Dusts (D)

A prepared dust is a finely ground, dry mixture combining a low concentration of the pesticide with a carrier such as talc, clay, or volcanic ash. There is a wide range in size of the dust particles in any one formulation.

Advantages

Dusts are ready to use as purchased and require no mixing. Even in commercial use they can be applied with simple, lightweight equipment.

Disadvantages

Because dust particles are finely ground, they may drift long distances from the treated area and may contaminate off-target areas. When used outside, they can be easily dislodged from the treated surface by wind and rain and soon become inactive. Never apply dust formulations on a windy day.

Principal Uses

Because of drift, dusts are not recommended for large scale outdoor use. Outside, they are used mostly for spot treatments and home gardens, and they work best when applied to dewy surfaces in the early morning. Inside, they are used in cracks and crevices to control roaches and other domestic insects. Dusts are also used to control lice, fleas, and other external parasites on pets and livestock.

Poisonous Baits

A poisonous bait is a pesticide mixed with a food or other substance that will attract and be eaten by pests, eventually causing their death.

Advantages

Baits are useful for controlling flies, rats, and other pests that range over a large area. Often the whole area need not be covered, just the spots where the pests gather. Baits must be carefully placed in homes, gardens, granaries, and other agricultural buildings so they do not contaminate food or feed, and can be removed after use. Usually only small amounts of pesticide are used in comparison to the total area treated, so potential environmental pollution is minimized.

Disadvantages

Within the home, baits are often attractive to children and pets and therefore must be used with care. Outdoors, they may kill domestic animals and wildlife. The pest will often prefer the protected crop or food rather than the bait, so the bait may be ineffective. When larger pests are killed by baits, the bodies must be disposed of so they do not cause an odor or sanitation problem. Unfortunately, other animals feeding on poisoned pests can also be poisoned.

Principal Uses

Baits are used inside buildings for such pests as ants, roaches, flies, rats, and mice. Outdoors, they may be used in gardens to control slugs, in dumps and similar areas to control rats, and in fields to control gophers, orchard mice (voles), slugs, and insects.

Granules (G)

Like dusts, pesticide granules are dry, ready-to-use, low-concentrate mixtures of pesticide and inert carriers. However, unlike dusts, almost all of the particles in a granular formulation are about the same size, and are larger than those making up a dust. A fine granular pesticide pours like ordinary salt or sugar.

Advantages

Granules are ready to use as purchased, with no further mixing necessary. Because the particles are large, relatively heavy, and more or less the same size, they drift less than most other formulations. Little toxic dust will drift into the operator's face, where it could be inhaled. Granules can often be applied with simple, multipurpose equipment such as seeders or fertilizer spreaders. They also will work their way through dense foliage to a target underneath.

Disadvantages

With few exceptions, granulars are not suitable for treating foliage because they will not stick to it. They may need moisture to start pesticidal action. Granules may be hazardous to non-target species, especially waterfowl and other birds that feed on the grain or seedlike granules.

Principal Uses

Granular pesticides are often used for soil treatments to control pests living at ground level or underground. They may be used as soil systemics, that is, formulations applied to soil that are absorbed into the plant through the roots and carried throughout the plant. Granular herbicides and insecticides are frequently applied in combination with fertilizer on turf, thereby saving labor. Granular formulations may be the choice when applied by agricultural aircraft where drift is a problem, or when treating water for mosquitoes where there is a heavy foliage cover over the water.

Pellets (P or PS)

Most pellet formulations are similar to granular formulations; in fact, the terms are often used interchangeably. In a pellet formulation, however, all the particles are about the same weight and shape. The uniformity of the particles allows them to be applied by precision applicators such as those being used for precision planting of pelleted seed. A few fumigants are formulated as pellets; however, these will be clearly labeled as fumigants and should not be confused with non-fumigant, granule-like pellets.

Wettable or Soluble Powders (WP or SP)

Wettable powders and soluble powders are dry preparations containing a relatively high concentration of pesticides. Wettable powders are mixed with water to form suspensions. Soluble powders dissolve in water to form solutions. The amount of pesticide in these powders varies from 15 percent to 95 percent.

Advantages

As is true with liquid concentrates, the pesticides in wettable powders are relatively low in cost and easy to store, transport, and handle. They are safer to use on tender foliage and usually do not absorb through the skin as rapidly as liquid concentrates. They are easily measured and mixed when preparing spray suspensions.

Disadvantages

Wettable powders may be hazardous if the applicator inhales their concentrated dust while mixing. They require good agitation (usually mechanical) in the sprayer tank and will settle quickly if the sprayer is turned off. They cause some pumps to wear out quickly. Their residue is more subject to weathering than liquid concentrates. Because they are more visible they may soil cars, windows, and other finished surfaces.

Principal Uses

Liquid concentrates and wettable powders are the formulations most widely used by commercial applicators. Like liquid concentrates, wettable powders can be used for most pest problems and in most spray machinery. Where toxicity to the plant or absorption through the skin of an animal is a problem, use a wettable powder suspension rather than a liquid emulsion or solution of the pesticide.

Microencapsulated Pesticides (M)

Microencapsulated formulations are small amounts of pesticides (liquid or dry) surrounded by a plastic-like coating to form a small (micro) capsule. The formulation product is mixed with water, then applied as a spray. Once applied, the capsule slowly releases the pesticide. The encapsulation process can prolong the life of the pesticide by providing a timed release of the active ingredient.

Advantages

These formulations generally provide increased safety to the applicator. They are easy to mix, handle, and apply. The timed release extends the useful life of the pesticide.

Disadvantages

Constant agitation of the spray in the tank is necessary to prevent settling. Some bees may pick up the capsules and carry them back to their hive, where the released pesticide may poison the entire hive.

Water-Dispersible Granules (Dry Flowables) (WDG or DF)

Some pesticides can be manufactured only as solid materials, not as liquids. Dry flowables and dispersible granules are different names for formulations consisting of small particles that disperse into a suspension, just as a normal flowable disperses when added to water. When these formulations are mixed with water, they have characteristics similar to wettable powders. Once in water, the granules break apart into fine particles. The formulation requires constant agitation to keep it suspended in water. Water-dispersible granules share the advantages and disadvantages of wettable powders except they are more easily measured and mixed, and they are less likely to be inhaled by the applicator during pouring and mixing.

Fumigants

Fumigants are pesticides in the form of poisonous gases that kill when absorbed or inhaled.

Advantages

A single fumigant may be toxic to many different forms and types of pests. Therefore, a single treatment with one fumigant may kill insects, weed seeds, nematodes, and fungi. Fumigants penetrate into cracks, crevices, burrows, partitions, soil, and other areas that are not gas tight and expose hidden pests to the killing action of the pesticide.

Disadvantages

The area to be fumigated usually must be enclosed. Even in outdoor treatments, the area either must be covered by a tarp or the fumigant incorporated into the soil so it doesn't escape. Fumigants are highly toxic, and nonselective, resulting in a loss of beneficial organisms from the treated area. Proper techniques and all recommended protective gear must be used when applying them. Most fumigants burn the skin.

Principal Uses

Fumigants are used inside dwellings or other buildings to control vermin that cannot easily be reached by other pesticide formulations. They are used in ports of entry and at state borders for treatment of plants and other materials to prevent the introduction of new pests into an area. Stored grain pests are often controlled by fumigants. Soil is fumigated to sterilize it from pests before planting.

Adjuvants

Adjuvants are chemicals that are added to a pesticide formulation or spray mixture to improve performance and/or safety. Most pesticide formulations contain at least a small percentage of one or more adjuvants. Spray adjuvants are added to the spray tank at the time of mixing. Adjuvants are represented by hundreds of products representing diverse and complex chemical types. In addition, adjuvant terminology not standardized and often confusing. Some of the most common adjuvants are **surfactants—surf**ace **act**ive ag**ents**—that alter the dispersing, spreading, and/or wetting properties of spray droplets. Here are some common adjuvants:

- Wetting agents allow wettable powders to mix with water.
- Emulsifiers allow petroleum-based pesticides (ECs) to mix with water.
- Invert emulsifiers allow water-based pesticides to mix with petroleum carrier.
- Spreaders allow pesticide to form a uniform coating layer over the treated surface.
- Stickers allow pesticide to stay on the treated surface for a longer time without being dislodged.
- Penetrants allow the pesticide to get through the outer surface to the inside of the treated target.
- Foaming agents reduce drift.
- Thickeners reduce drift by increasing droplet size.
- Safeners reduce the toxicity of a pesticide formulation to the pesticide handler or to the treated surface.
- Compatibility agents aid in combining pesticides effectively.
- Buffers allow pesticides to be mixed with diluents or other pesticides of different acidity or alkalinity.
- Antifoaming agents reduce foaming or spray mixtures that require vigorous agitation.

Care should be exercised before using adjuvants. Some labels clearly prohibit their use; others are quite specific as to the type of adjuvant that can be used and when it should be added to a spray mixture. Failure to use adjuvants properly can result in poor pest control, or conversely, crop damage.

Mode of Action

Pesticides are generally intended to kill selected organisms. Some are more specific to their intended target than others. The level of specificity of a pesticide is directly related to its mode of action. Mode of action comprises the sum of anatomical, physiological, and biochemical responses that make up the total toxic action of a chemical, as well as the physical (location) and molecular (degradation) fate of the chemical in the organism. The following information is intended to provide an introduction to the various modes of action for several pesticide classes.

Insecticides

In terms of their modes of action, insecticides fall into seven classes: physical toxicants, protoplasmic poisons, nerve poisons, metabolic inhibitors, cytolytic toxins, muscle poisons, and alkylating agents.

Physical toxicants act by blocking physiological processes mechanically. Examples of physical toxicants include oils that block or clog respiratory processes in mosquito larvae, or such inert, abrasive dusts as boric acid, diatomaceous earth, and other materials that act as desiccants.

Nerve poisons, such as pyrethrins, organophosphates, and carbamates achieve their actions by interfering with nervous system function. As discussed in Module 2, organophosphates and carbamates exert their toxic effects by inhibiting important enzymes of the nervous system called *cholinesterases*. Cholinesterases clear acetylcholine from nerve synapses, allowing the nerve to continue functioning normally. Depressed cholinesterase activity results in a build up of acetylcholine in the central nervous system neurons, leading to paralysis and death in insects. Mammals also are affected by cholinesterase inhibitors, as the neuromuscular junction is cholinergic. Symptoms include rapid twitching of voluntary muscles, nausea, vomiting, tremors or convulsions, paralysis, and death.

Organophosphates and carbamates are acutely toxic to mammals, but dormant oils and desiccants are practically non-toxic. Although both may kill insects, there is a significant difference in environmental and occupational risk associated with their use. This difference is largely based on mode of action. To have some understanding of the mode of action of a pesticide is important when considering crop protection options.

Herbicides

Before discussing the mode of action of herbicides, it is important to make a few general distinctions in herbicidal behavior. *Nonselective herbicides* are toxic to all plants. *Selective herbicides* kill specific types of plants, such as broadleaf plants. Some herbicides are *systemic*, and others are *non-systemic*. Systemic herbicides may be absorbed through the foliage, or if they are soil applied, may be absorbed through the roots. The herbicides may then be translocated or move to various locations within the plant, where they exert their herbicidal activity. Non-systemic or contact herbicides achieve their effects without being translocated throughout the plant.

Herbicides may be *physical toxicants*, have *auxin like activity*, be *metabolic inhibitors* or *photosynthetic inhibitors*. Physical toxicants such as petroleum oils are a good example of non-systemic herbicides. The oils act by disrupting cellular membranes, resulting in the death of the plant. Phenoxy acids such as 2,4-D and MCPA are systemic herbicides that act like auxins (plant growth hormones), and promote rapid cell division, resulting in a large number of structural and biochemical reactions involving prolonged abnormal growth.

Fungicides

Fungicides are chemicals used to control the fungi that cause molds, rots, and plant diseases. Fungicides must come in contact with the fungus to be effective. They are usually applied over a large surface area in an attempt to directly hit every fungus. Most fungicides prevent *spore germination* or kill the spore immediately following germination. This action is achieved through *metabolic inhibition*, which can be divided into four groups: inhibitors of the electron transport chain, inhibitors of enzymes, inhibitors of nucleic acid and protein synthesis, and inhibitors of sterol synthesis.

Application Timing

Herbicides

Herbicides may be applied at different times relative to crop phenology, and when weed pests are most likely to cause economic damage.

Preplant application—when the chemical is applied before the crop is planted—may be made either to seed beds or incorporated into the soil.

Preemergence application—when a treatment is made before the crop and weed appear—may be made either before both the crop and weed appear, or after the crop appears but before the weeds appear. The label will state "preemergence to the crop", "preemergence to the weeds", or "preemergence to both crop and weeds."

Postemergence application—when the treatment is made after the crops or weeds appear. Postemergence applications must be highly selective to control the weeds but leave the crop unharmed.

Insecticides

Insecticides may be applied at various times related to the crop phenology, and when insect pests are most likely to cause damage. Because many insect pests have developed survival strategies based on the annual cycles of certain crops, application timing should be targeted to maximize efficacy. For example, given below is the pesticide application schedule for apples.

Dormant spray

Dormant oil sprays and lime sulfur or polysulfide compounds are applied in the winter to control scale and eggs of various insect pests.

Dormant and delayed dormant sprays

Dormant oil sprays plus organophosphates and sometimes *Bacillus thuringiensis* are applied in the dormant period to control scale, the eggs of various insect pests, as well as the pandemis leafroller, and the grape mealybug.

Prepink and tight cluster

Organophosphates are applied at this time to control aphids, cutworms, grape mealybugs, leafrollers, scales, true bugs, western tentiform leafminer, apple rust mite, campylomma bug, green fruitworm, and western flower thirps.

Petal Fall

Insecticides such as Sevin, Carzol, and Asana XL are applied to control leafhoppers at petal fall.

Spring and summer sprays

A variety of insecticides are applied in the spring and summer to control various insect pests including aphids, wooly apple aphid, apple maggot, apple rust mite, apple and thorn skeletonizer, blister mite, coddling moth, cutworms, eyespotted bud moth, grape mealtbug, leafhoppers, leafrollers, lesser appleworm, lygus bugs, pacific flathead borer, pandemis leafroller, scale insects, shothole borer, spider mites, stinkbugs, tent caterpillars, tentiform leafminer, and treehoppers.

Fungicides

Fungicides may be applied at various times related to the crop phenology, and when diseases are most likely to cause damage. For example, fungicide applications may be required to treat powdery mildew and scab at pre-pink, pink, petal fall, and ten days to two weeks after petal fall. A Preharvest application to prevent storage rots may also be required, as well as a postharvest treatment for anthracnose.

Student Activity 20

1. Rank the three most common pesticide classes, both in the U.S. and worldwide, in terms of active ingredient used.

2. What are the two most widely used formulations by commercial applicators?

3. List three precautions when using emulsifiable concentrate formulations.

4. What are adjuvants?

5. What precautions should be taken when using adjuvants?

6. List an insecticide modes of action that affects both insects and mammals.

____

____

____

____

____

7. List the three herbicide categories based upon application timing.

____

____

____

References

The Pesticide Book. 4th Edition. George W. Ware. Thomson Publications. Fresno, CA.

1995 Pacific Northwest Plant Disease Handbook. Paul A. Koepsell and Jay W. Pscheidt, Eds.

1995 Pacific Northwest Insect Control Handbook.

Miller, T. *Oregon Pesticide Applicator Manual*. 1993. Oregon State University Extension Publication 8532.

Congratulations! You have completed Modules 1–3. Before continuing on to Modules 4–6, go to the NEDC web site and take the posttest for Modules 1–3. This test is located at the following URL: http://www.ftw.nrcs.usda.gov/iris/nutrient_pest.html

Nutrient Management—Activity Answers

Student Activity 1

1. Describe the difference between a natural ecosystem and an agro-ecosystem?

   A natural ecosystem is self-organizing, supports a variety of plant and animal species, and is self-regulating. An agro-ecosystem is managed by humans typically as a monoculture with manual inputs (energy, fuel, sometimes water) to support one primary species grown for food or fuel. Competing organisms ("pest") are often artificially supressed.

2. Define Liebig's Law of the Minimum?

   Liebig's Law of the Minimum states that all growth factors are essential. If any one is missing, even if the others are present, the plant cannot grow. When any one essential nutrient is limiting from a plant growth medium, the plant cannot grow to its genetic potential.

3. List six stress factors.

   - *mechanical harvest or grazing*
   - *surplus or lack of soil moisture*
   - *nutrient deficiency*
   - *temperature extremes*
   - *chemicaland physical conditions of the soil*
   - *pest competition*

4. How do these stress factors influence plant growth?

They reduces the rate of photosynthesis and biomass production.

5. List and describe the five growth stages as they relate to essential growth requirements of water and nutrients.

   Germination—Seed germination. Sufficient water must be present, but water and nutrient absorption during germination are very small. If possible nutrient applications during this stage of growth should be minimal.

   Seedling development—Leaf tissue increases and roots expand into the soil profile. Water and mineral nutrient use begins to increase, but the total water and nutrient requirements are still relatively small. If possible nutrient applications during this stage of growth should also be minimal.

   Vegetative development—Roots, shoots, and leaves expand to their maximum, and water and nutrients must be continuously supplied to meet the needs of the rapidly growing plant. The most rapid rate of plant nutrient and water uptake occur during this stage of plant growth. Nutrient applications must therefore be sufficient to compensate for what is not available in the soil relative to what the plant requires for maximum yield and quality.

   Flowering/fruiting—Flowering and fruiting. The reproductive part of the growth cycle where energy is directed from vegetative production to the creation of new plants. Water and nutrient uptake rates do not increase but continue at a high level. Nutrients and carbohydrates are redistributed within the plant from other plant parts to the fruiting organs. Nutrient applications should be adequate to compensate for what is not available in the soil relative to what the plant requires for maximum yield and quality. Because the plant is nearing the final stages of plant growth, nutrient *applications are optimized to only compensate for what is not present in the soil already. Excess nutrient applications may be lost to the environment before subsequent plant uptake.*

Senescence—Plants begin to reach final maturity and plant height and canopy begin to decrease. Both nutrient and water uptake also decrease. Some or all plant parts may die and begin to decompose, releasing nutrients back into the soil. Typically the availability of nutrients in the soil are adequate to meet the needs of the plant and nutrient applications are unnecessary.

6. The two crop stages when nutrient uptake is at its peak are *vegetative development* and *flowering/fruiting*.

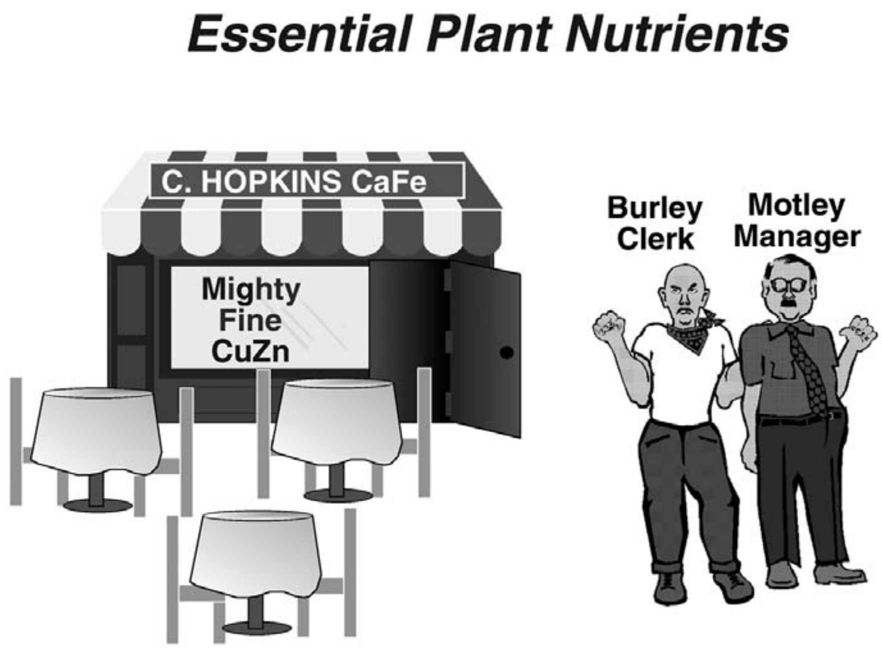
Student Activity 2

Rank the following soil textures in order of magnitude of the following soil properties (1 being highest). The clay content characteristic has been completed for you.

	Runoff Potential	**Leaching Potential**	**Clay Content**	**CEC**	**Organic Matter**
Sand	3	1	3	3	3
Loam	2	2	2	2	1*
Clay	1	3	1	1	1*
*Can vary by soil type.					

Student Activity 3

1. Find the 16 essential plant nutrients in this figure.



Remember the phrase used to remember the 16 essential plant nutrients.

C. HOPKiN'S CaFe, Mighty fine CuZine, Motley Manager, Burley Clerk.

Carbon (C), Hydrogen (H), Oxygen (O), Phosphorus (P), Potassium (K), Nitrogen (N), Sulfur (S), Calcium (Ca), Iron (Fe), Magnesium (Mg), Copper (Cu), Zinc (Zn), Molybdenum (Mo), Manganese (Mn), Boron (B), and Clorine (Cl).

2. Of these essential nutrients, which are considered the primary or macronutrients?

Nitrogen (N), Phosphorus (P), and Potassium (K).

3. For three of the essential plant nutrients, describe their role in plant metabolism and identify distinctive deficiency symptoms.

Nitrogen (N) is a ***critical component of proteins*** *that* ***controls the metabolic processes*** *required for* ***plant growth****. It is also an integral part of the* ***chlorophyll molecule*** *and thus plays a key role in* ***photosynthesis****. An adequate supply of nitrogen is associated with vigorous vegetative growth and a plant ís dark green color. Nitrogen deficiency is characterized by* ***reduced plant growth*** *and a* ***pale green or yellow color****. This yellowing generally begins at the tip of the leaf and goes down the middle of the leaf. If the deficiency is severe, the affected area eventually turns brown and dies. Because nitrogen is mobile in the plant, older leaves show the first symptoms of nitrogen deficiency.*

Phosphorus (P) is a critical component of ***nucleic acids****, so it plays a vital role* ***in plant reproduction****, of which* ***grain production*** *is an important result. Considered essential to* ***seed formation****, this mineral is often found in large quantities in seed and fruit. Phosphorus is essential to the* ***biological energy transfer processes*** *that are so vital to life and growth. Adequate phosphorus is characterized by improved crop quality, greater straw strength, increased root growth, and earlier crop maturity. Phosphorus deficiency is indicated by* ***reduced plant growth, delayed maturity,*** *and* ***small fruit set****. These symptoms may be accompanied by a* ***purple coloring****, particularly in young plants. This purpling is often seen in relationship to cold wet soils.*
If soil phosphorus levels are adequate this is usually temporary and does not affect yields. Like nitrogen, phosphorus is mobile in the plant; therefore, any deficiency symptoms show up on the older leaves first.

*Potassium (K) is not an integral part of any major plant component, but it does play a key role in a vast array of physiological processes vital to plant growth, **from protein synthesis to maintenance of plant water balance**. Potassium deficiency is characterized by reduced plant growth and a **yellowing and/or burning of leaf edges**. Since potassium is mobile in the plant, the symptoms appear on the older leaves first. Another indication of potassium deficiency is **reduced straw or stalk strength**, which results in **lodging problems**, **reduced disease resistance**, and **reduced winter hardiness** of perennial or winter annual crops. Other plant nutrient refer to the text.*

4. As the soil pH decreases, availability of most micronutrients <u>*increases*</u>. The exception to this relationship is molybdenum.

5. Define grass tetany and describe the condition that can cause it to occur.

   Grass tetany is a serious disorder in lactating ruminants caused by low magnesium content in forages. It is caused by early season applications of organic materials with high nitrogen and potassium content to low magnesium soil. This can cause early growth of forages to have increased uptake of nitrogen and potassium, especially grasses, leading to an imbalance of potassium to magnesium in the forage.

Student Activity 4

1. Define the following terms:

   a. *Mineralization—the process of conversion of an element (N, P, S, etc.) from organic forms to inorganic forms.*

   b. *Immobilization—assimilation of inorganic forms of elements to organic forms.*

c. *Nitrification—conversion of ammonium nitrogen to nitrate nitrogen by soil bacteria.*

d. *Denitrification—conversion of nitrates to nitrogen gases.*

e. *Carbon–nitrogen–ratio—the relative amount of carbon to nitrogen in an organic material.*

2. List the forms of nitrogen that can be taken up by plants.

   - *Ammonium nitrogen*
   - *Nitrate nitrogen*

3. A farmer adds one ton of wheat straw to a ton of manure. Calculate the resulting C:N ratio if the wheat straw has a C:N ratio of 80:1 and the manure has a C:N ratio of 20:1.

   1 ton of wheat straw contains 1,975 lb of C and 25 lb of N (80:1 ratio).

   1 ton of manure contains 1,905 lb of C and 95 lb of N (20:1).

   (1,975 lb. + 1,905 lb)C / (25 lb + 95 lb)N = 3,880/120 = 32.0.

4. Will this mixture result in a net increase or net loss of soil nitrogen?

   Because 32 is greater than 30, the mixture will result in a net loss (immobilization) of soil nitrogen.

5. List six characteristics of a site that should be evaluated to determine the potential for phosphorus loss. The Phosphorus Index has been developed using these site characteristics.

   - *Soil erosion*
   - *Irrigation induced erosion*
   - *Soil runoff class*
   - *Distance from watercourse*
   - *Soil test phosphorus level*
   - *Phosphorus fertilizer application rate*
   - *Phosphorus fertilizer application method*
   - *Organic phosphorus application rate*
   - *Organic phosphorus application method*

6. List the plant-available forms of the following elements:

   Phosphorus .... PO_4^{-2} (Orthophosphate)

   Potassium ...... K^+

   Sulfur .... SO_4^{-2}

7. Which of the following elements is typically the most limiting in the environment for plant growth: nitrogen, phosphorus, potassium, or sulfur?

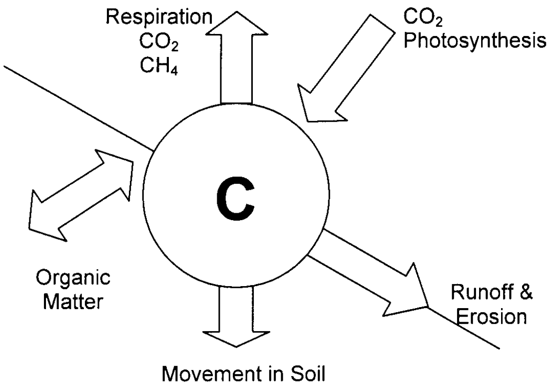
   Phosphorus

8. For each of the nutrient elements given, determine a source of that nutrient, a sink of that nutrient, and a possible path for loss of that nutrient as a potential pollutant in the environment.

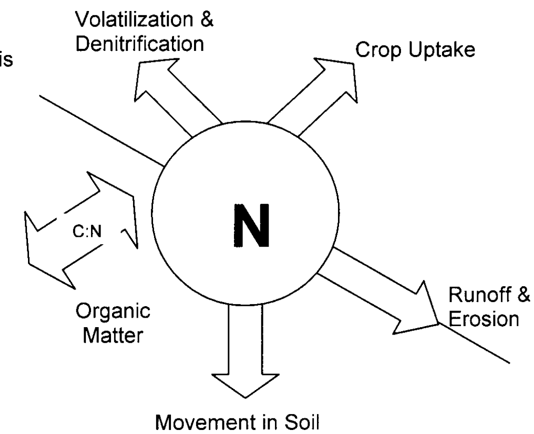
Nutrient	Carbon	Nitrogen	Phosphorus	Potassium	Sulfur
Source	Atmospheric Crop Residue Manure Animal residue	Atmospheric Fertilizer Manure Plant residue Irrigation	Fertilize Manure Plant residue	Fertilizer Manure Plant residue Irrigation	Fertilizer Atmospheric Irrigation Plant residue Manure
Sink	Soil OM Peat, coal, gas & oil	Atmosphere Soil OM Clay minerals Soil organisms	Soil Minerals Soil OM Soil organisms Soil solution	Clay minerals Soil OM Soil organisms Soil solution	Atmosphere OM Soil Minerals
Pathways to become a pollutant	Runoff/Erosion Combustion Leaching	Volatilization Runoff/Erosion Leaching	Runoff/Erosion Leaching	Runoff/ Erosion Leaching*	Volatilization Runoff/Erosion* Leaching*

* Generally not considered a pollution problem.

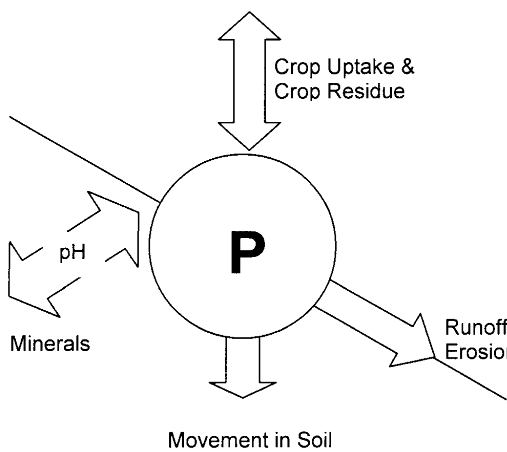
9. Using the blank nutrient cycles provided, label each cycle with the appropriate nutrient (K, N, P, S and C) and major pathways of movement.



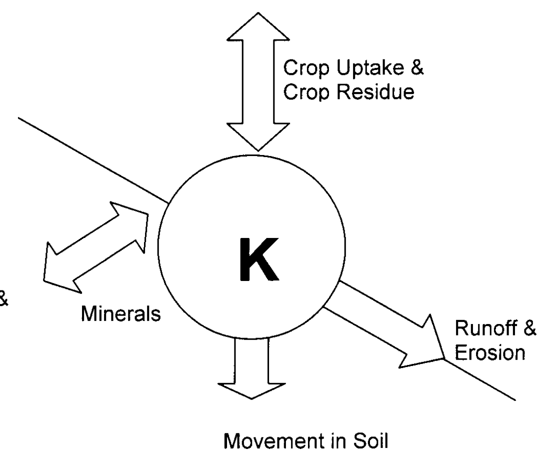
Simple Carbon Cycle



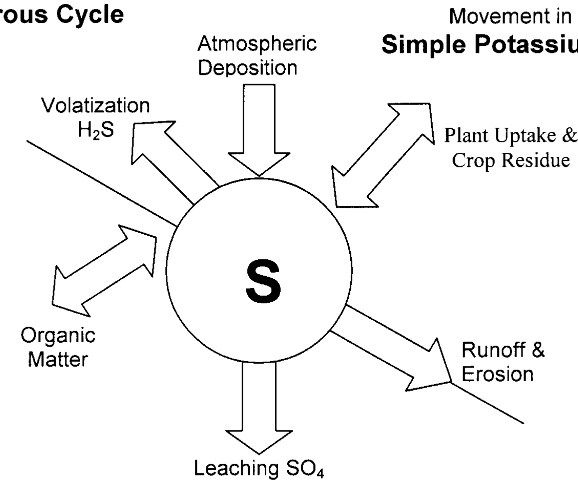
Simple Nitrogen Cycle



Simple Phosphorous Cycle



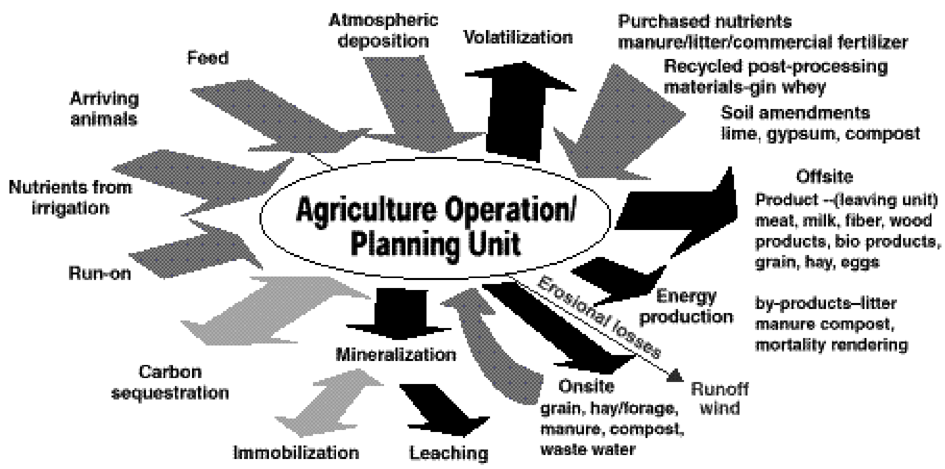
Simple Potassium Cycle



Simple Sulphur Cycle

Student Activity 5

1. Using the following diagram for an Agricultural Operation, label possible inputs and outputs (fertilizer, hay, milk, runoff, volatilization). Using a crop/dairy operation for an example, specifically identify materials that are brought on to and carried off of the operation.



Brought on to the dairy farm: commercial fertilizer, alfalfa hay, corn grain.

Carried off the dairy farm: milk, male calves, old cows.

2. Describe how the inputs and outputs would change if it were a poultry farm with no cropland?

Poultry farm inputs: prepared poultry feeds, baby chicks, litter material

Poultry farm outputs: eggs, chickens, manure, dead chickens

Refer to figure 3.16, Part A, Continuous Corn

3. What occurs to the nitrogen, phosphorus, and potassium when manure is applied to meet the nitrogen requirements of the continuous corn crop?

   When nitrogen requirements are met by the manure, phosphorus and potassium are in excess of crop requirements.

4. If the manure is applied to meet the phosphorus needs of the crop, how does that affect the nitrogen requirement?

   When manure is applied to meet phosphorus requirements, the nitrogen applied in the manure is insufficient to meet the needs of the crop.

Refer to figure 3.16, Part A, Corn/Alfalfa rotation

5. Why is the crop requirement for nitrogen reduced in the corn/alfalfa rotation?

   Alfalfa is a legume capable of producing nitrogen to meet the nitrogen demand of the alfalfa. A significant amount of nitrogen will be contained in the alfalfa roots when it is tilled under to prepare for the following corn crop. Much of this nitrogen will be released into the soil residual nitrogen pool and will be available to meet some if not all of the nitrogen requirements for the following corn crop.

6. How would this figure change if the corn were harvested for silage?

   If the corn were harvested for silage, much more nitrogen, phosphorus, and potassium would be removed during harvest, so the application requirement for these nutrients would likely increase for the subsequent crops in the rotation.

Student Activity 6

Farmer Pea had a soil test on his corn field that indicated that all nutrients were adequate for the crop being grown. He wants to do a plant tissue test to see if his crop nitrogen uptake is sufficient.

1. Using table 3.5, give a recommendation for his sampling procedure and the desired results.

   Sample the ear leaf at time of silking. Take 10 samples throughout the field, combine, and send to a lab. If the nitrogen levels are within 2.75–3.50 percent, the crop is getting enough nitrogen.

2. A plant tissue test from the same field indicated that a nutrient was deficient. Suggest possible reasons for this result.

   Even though nutrients may be available in the soil, the crop must be able to access and acquire it. Any condition that slows plant growth (whether it be cold weather, drought, or lack of other nutrients) can prevent the crop from acquiring the needed nutrients.

Student Activity 7

Figure 3.20 shows a 40-acre area divided into four 10-acre fields each with a different cropping sequence. The 40-acre field has three soil types (A-C) as shown in the field map.

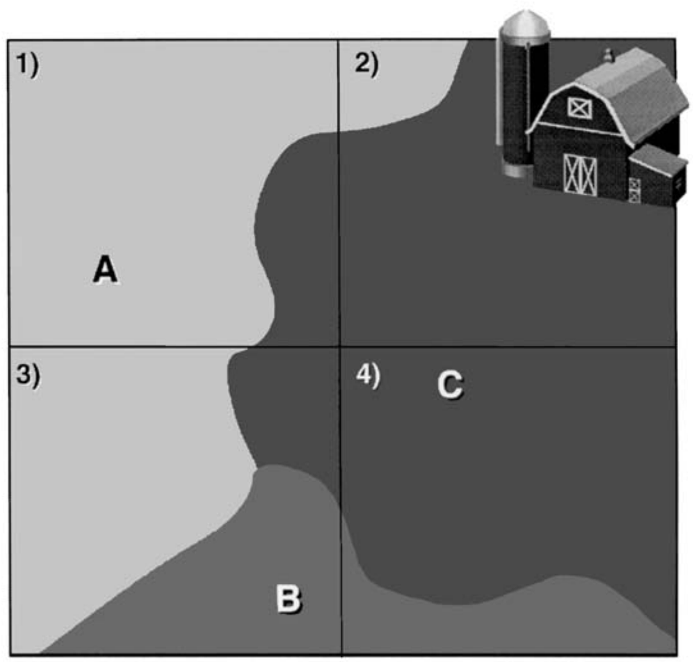


Figure 3.20

1. How many samples would be necessary to characterize the forty acres?

   At least 7: 1A, 2A, 2C, 3A, 3B, 4B, and 4C

2. How many sub-samples would be necessary to make up each composite sample?

   20-30 sub-samples combined into one composite sample

3. How would you handle the barnyard area in your sampling scheme?

Because of concentrated livestock previously at the site, the old barnyard should be sampled separately from sample 2C. No subsample from the barnyard should be included in the composite of 2C.

Student Activity 8

1. If a phosphorus recommendation was 20 lb/acre phosphorus, how much P_2O_5 fertilizer would need to be applied?

   20 lb/acre phosphorus x 2.3 = 46 lb/acre P_2O_5

2. The Extension Service ranges for phosphorus levels in the soil are shown below:

   0–40 ppm = LOW, 40–60ppm = Optimum, > 60 ppm = HIGH

   The formula for phosphorus recommendation by Extension Service for a sorghum crop with a yield expectation of 5,000 lb/acre is:

   $$\frac{80 - (\text{Soil sample P (ppm)} + 30)}{0.44} = \text{recommended lb } P_2O_5 \text{ per acre}$$

   The soil sample analysis has been returned from the laboratory indicating that the soil sample contained 70 ppm phosphorus.

   a. Would you recommend phosphorus for the crop? If so how much?

   No. The soil test is HIGH (>60 ppm), and:

   $$\frac{80 - (70 + 30)}{0.44} = -46 \text{ lb } P_2O_5 \text{ per acre}$$

   This negative result indicates that the soil can supply adequate P for the crop.

   b. If the soil test result was 20 ppm, would phosphorus fertilizer be recommended? If so how much?

Yes.

$$\frac{80 - (20 + 30)}{0.44} = 68 \text{ lbs or approximately 70 lbs. } P_2O_5 \text{ per acre}$$

3. Define soil test critical level and optimum range.

   The soil test critical level is the point at which the soil nutrient level no longer limits crop yield. Optimum range is the soil test levels that lie just above the critical level where yield response is optimum.

Student Activity 9

1. Draw a graph of yield versus soil test level. On this graph sketch a soil test crop response curve including the critical level and general soil test interpretation categories. Discuss the significance of this curve to crop production.

   Refer to figure 3.21.

   Theoretically this critical level is the optimum soil test level for the given crop and the conditions. Because of the variation in natural systems like the soil plant system in a field, an optimum range rather than just a point is used for practical interpretation of a soil test. This optimum range is the soil test levels that lie just above the critical level. As soil test levels increase above the optimum range into the high range there is no further increase in yield and in fact under some conditions there may be a decrease in yield at very high soil test levels

2. Does a high soil test result indicate a high likelihood of some sort of environmental threat?

   No. Crop response interpretations are based on the probability of an economic response by the crop to adding additional nutrients. Just because a soil test is rated as high based on crop response to a nutrient does *not mean that it is also an environmental threat. It is possible that a soil that is rated as low for crop response could be an environmental threat. Thus, it is not possible to directly use a soil test interpretation for crop response to make an environmental interpretation*

3. For the three soil test categories (LOW, OPTIMUM and HIGH) based on crop response , describe general nutrient recommendations.

   LOW—Add nutrients to build the soil nutrient level into the optimum range.

   OPTIMUM—No additional nutrients are necessary. Some nutrients like phosphorus may be added to raise the soil phosphorus level in preparation for a subsequent crop with a high phosphorus requirement.

   HIGH—No additional nutrients are necessary.

Student Activity 10

1. List three situations when a manure nutrient analysis should be done.

   - *Characterizing types of animal manure on an operation for the first time.*
   - *Change in feed or ration.*
   - *New storage structure or to characterize variations in manure as storage structure is emptied.*

2. Describe how to assess available nutrients in agricultural waste.

Nutrient assessment procedures use three methods to determine the nutrient content of agricultural waste. They are (1) laboratory analysis of waste samples; (2) use of published tables (data); and (3) use of data on the feed intake of the animals producing the waste. The first method and most accurate estimates of nutrient content are obtained through laboratory analysis of a representative waste sample by a qualified laboratory. The laboratory's results depend upon proper collection and handling of waste samples. Samples are obtained by field sampling during land application of waste, or from waste sources such as waste storage ponds, lagoons, dry stacked manure or litter, and composting facilities. In the absence of specific laboratory analysis results, the second method, published tables (data) is used. For example, Section IV of the Field Office Technical Guide presents tables showing average values for the nutrient content of various agricultural wastes.

Group Activity 1—Optional

1. Describe four methods of monitoring for nutrients in agriculture. Outline an example of a situation in which each type of monitoring might be used and discuss its relationship to any associated agricultural and environmental concerns.

   (1) Water testing

   Typically in agriculture, irrigation water is the only source of water sampled. The chemical properties of irrigation water supplies can significantly impact their effectiveness in irrigated agriculture. All irrigation waters should be analyzed to determine nutrient loading and chemical characteristics. Irrigation water should be analyzed for pH, electrical conductivity, dissolved salts, calcium, magnesium, sodium, sulfur, nitrate nitrogen, boron, chloride, carbonate, and bicarbonate. These properties can effect the use of water for irrigation practices. In *some areas ground water can contain enough nitrate and potassium to effect fertilization rates. In these cases it should be tested and considered in the nutrient recommendation.*

Environmentally, nutrient levels in ground water used for irrigation will reflect natural conditions or the impacts of management. High nitrate levels in ground water with no natural source and influenced primarily by agriculture would likely indicate significant nitrogen leaching had occurred under past management. Likewise, nutrient level in field runoff or root zone leachate will reflect the impacts of management. It is the goal of nutrient management to manage nutrients within the crop field and root zone thus minimizing nutrient losses from runoff and leaching.

(2) Plant tissue testing

Analysis of plant tissue can indicate the success of a soil fertility program and help to avoid potential problems. Plant tissue analysis complements soil testing by measuring the nutrients actually taken up by the plant. In addition, secondary nutrients and micronutrients that currently are not routinely measured in soils can be reliably measured in plants. However, plant nutrient content represents the effects not only of soil nutrient status but of all the factors controlling plant growth such as moisture status, climate, and crop variety. Yield and plant analysis at harvest can be used to estimate nutrient removal by the crop. This may be important in determining nutrient balance as part of nutrient management planning. By monitor plant nutrients, plant tissue testing can help to maximize crop yield and quality, while at the same time minimizing excess nutrients in the environment. As nutrient management programs become more restrictive, plant tissue testing will become increasingly important for preventing nutrient deficiencies and resulting crop damage.

(3) Soil testing

Soil testing is perhaps the best and most used way of monitoring for nutrients in agriculture. As soil test level increases the yield increases up to a point where the soil nutrient level is no longer limiting yield of the crop. As soil test levels increase above an optimum range into the high range there is no further increase in yield and in fact under some conditions there may be a decrease in yield and quality at very high soil test levels. Theoretically at low soil test levels there is a low potential for negative environmental impact. As the soil test level is increased the corresponding threat of environmental impact begins to increase. Eventually if the soil test gets high enough the probability of negative environmental impact may increase dramatically. Soil testing is used in many state now to track nutrient status in the soil, especially for nitrogen and phosphorus. Many states are currently using phosphorus thresholds to determine phosphorus application rates as well as trends in the soil over time. The 1999 national nutrient management standard includes new guidance on the use of phosphorus thresholds.

(4) Organic waste testing

Actual manure characteristics can easily range almost 100 percent above or below average values, and the volume that a handling system must accommodate may be much larger because of the addition of water and bedding. Because the figures listed in tables are approximate, each livestock farm should have its manure analyzed, at least once for each manure group, and following any change in feed or ration. Organic waste testing will help to assure that organic nutrient applications match expected crop nutrient requirements and that excess nutrients are not available for potential losses to runoff and leaching.

2. List four factors in addition to testing results that should be considered and integrated into any fertilizer recommendation.

Additional factors that must be considered and integrated into any fertilizer recommendation include obvious factors such as the crop, expected crop yield and quality, other soil characteristics, climate, cultural practices, nutrient sources, and economics. There are less obvious factors such as management skill of the farmer, availability of nutrient sources, aversion to risk, and philosophy.

3. Describe general approaches to making a nutrient recommendation based on soil test results and general soil test interpretation categories.

   At low soil test levels, recommendations are usually based on the expected response of the crop to adding the nutrient. Some of these recommendations are based on recommending the minimum amount needed to get the optimum immediate economic crop response and other recommendations may also include an amount to either rapidly or gradually build the soil out of the low range and into the optimum range.

   In the optimum range there are generally two common approaches to making recommendations. Remember that the definition of an optimum soil test level is that the nutrient is adequate and there is a low probability of an economic yield response to adding a nutrient. Thus, a logical and valid recommendation would be that no additional nutrients are needed. However, the crop will remove nutrients from the soil resulting in a drop in the soil test level by the end of the growing season. Therefore, a new test must be run for the following year so that this crop removal is accounted for in the next recommendation. Thus annual soil testing or using some estimate of the change in the soil test level because crop removal must be used. Unfortunately, few farmers are willing to soil test every year. Therefore, an alternative approach to recommendations when the soil is in the optimum range is to include an amount of *nutrient equal to the expected crop removal. The objective of this type of recommendation is to offset the crop removal and thus maintain the soil in the optimum range over time. With this approach soils only need to be tested every few years. Theoretically, if they are based on sound calibration research, over the long run, both of these approaches should result in similar amounts of nutrients being applied.*

In the high range there is generally good agreement that little or no nutrients are usually recommended because by definition the nutrients are already more than adequate and there is a low probability of getting an economic response to adding more nutrients.

Student Activity 11

1. How much N, P_2O_5, and K_2O are in one gallon of this fertilizer?

   Most liquid fertilizers weigh 10 to 11 pounds per gallon. The analysis of liquid fertilizers is based on a weight, not volume basis. One gallon of 10-34-0 ammonium polyphosphate, weighs 10 pounds. Since 1 gallon weighs 10 lb, and the analysis is 10-34-0, there would be 1 lb N, 3.4 lb P_2O_5, and 0 lb K_2O in one gallon of this fertilizer.

2. How much N, P_2O_5, and K_2O are in one ton of liquid ammonium polyphosphate?

   Since 1 ton is 2,000 lb, there would be 200 lb N, 680 lb P_2O_5, and 0 lb K_2O in a ton of this material.

   Use this information to answer the following questions.

Manure analysis:			
	N	=	10 lb/ton
	P_2O_5	=	4 lb/ton
	K_2O	=	8 lb/ton

Manure nutrient availability for the current crop:

Crop requirement:	N	=	125 lb/acre
	P_2O_5	=	40 lb/acre
	K_2O	=	80 lb/acre

Incorporation	N	P_2O_5	K_2O
--------------------Percent available to crop--------------------			
Immediate incorporation	50	100	100
No incorporation	20	100	100

3. If manure is applied and incorporated immediately, how much N is available per ton?

   5 lb/ton

4. If the manure is applied and incorporated immediately, how much manure is needed to meet the N requirement of this crop?

   25 tons

5. Based on this rate of application how much available P_2O_5 and K_2O would be applied?

   100 lb P_2O_5; 200 lb K_2O

6. How does this compare with the crop needs for P_2O_5 and K_2O?

   P_2O_5 and K_2O would be applied in excess of crop needs. Crop requirements are 40 and 80 lb/acre, respectively.

Student Activity 12

1. How can nutrient application timing maximize application efficiency and reduce a potential environmental hazard?

By matching nutrient applications to crop requirements we can potentially reduce the amount of time nutrients are available for loss. This can be extremely important if we can minimize the amount of nutrient present during vulnerable period where loss is most likely to occur.

2. List five advantages to fertigation over conventional fertilizer application methods.

   - *Soil compaction is avoided because heavy equipment never enters the field.*
   - *The crop is not damaged by root pruning, breakage of leaves, or bending of the plants as occurs with conventional chemical field application techniques.*
   - *Less equipment may be required to apply the chemical.*
   - *Less energy is expended in applying the chemical.*
   - *Usually less labor is needed to supervise the application.*
   - *The supply of nutrients can be more carefully regulated and monitored.*
   - *The nutrients can be distributed more evenly throughout the entire root zone or soil profile.*
   - *The nutrients can be supplied incrementally throughout the season to meet the actual nutritional requirements of the crop.*
   - *Nutrients can be applied to the soil when crop or soil conditions would otherwise prohibit entry into the field with conventional equipment.*

3. List the four major components of nutrient application management.

   - *Application rate*

- *Nutrient form*
- *Application timing*
- *Method of application*

Group Activity 2—Optional

1. List and discuss the 4 major components of nutrient application management in a group setting.

   - *Application rate*
   - *Nutrient form*
   - *Application timing*
   - *Method of application*

   (1) Application rate

   Matching the nutrient application rate to the expected crop requirement is a primary goal of nutrient application management. The nutrient needs of a crop are determined by the expected yield. A crucial factor in setting realistic yield expectations is the yield potential of the soil, which is a function of soil properties independent of manure or fertilizer application. Records of yields produced in the past are a good starting point for determining realistic yield expectations for the future. The amount of nitrogen, phosphate, and potash (N, P_2O_5, and K_2O) per unit of yield taken up by various crops can be found in various references. These can be used with the expected yield to estimate crop nutrient removal in the harvested portion of the crop. Perhaps the best references for determining nutrient application rates are university fertilizer guides that are typically based on expected yields and some sort of budgeting approach.

   (2) Nutrient form

Nutrients occur in many different forms. Nutrients used for fertilizers fall into two general categories, inorganic and organic fertilizer. Inorganic fertilizer mainly includes many different chemical and physical forms of nitrogen, phosphorus, and potassium either alone or in different combinations.

Inorganic fertilizers

Nitrogen fertilizer: The nitrogen in most farm-grade fertilizers is readily available. Typical inorganic forms of nitrogen include anhydrous ammonia (NH_3, 82-0-0), ammonium nitrate (NO_3NH_4, 33-0-0), nitrogen solutions (UAN, 28-0-0) (Urea+NH_4NO_3+Water, 32-0-0), ammonium sulfate ($(NH_4)_2SO_4$, 21-0-0) or Urea (NH_2-CO-NH_2, 46-0-0). Plants can use nitrogen in one of two forms: ammonium nitrogen (NH_4+) or nitrate nitrogen (NO_3^-). Ammonium nitrogen (NH_4^+) carries a positive charge and is adsorbed onto soil particles. In this chemical form, leaching of nitrogen will not occur. However, NH_4^+ is changed to the NO_3^- form by bacteria. This process occurs rapidly (beginning within 2 to 3 days) as the soil temperature climbs above 50°F. Complete conversion from NH_4^+ to NO_3^- occurs rapidly under ideal conditions. Nitrate nitrogen (NO_3^-) carries a negative charge and is not adsorbed onto soil particles; it is free to be leached from the soil. Nitrate nitrogen can also be lost to the atmosphere through denitrification when soils become water-saturated.

Urea nitrogen is readily available to plants upon application to the soil. When surface applied, significant quantities of nitrogen as ammonia may be lost through volatilization. Losses are accelerated by warm moist soil, high pH, and surface organic matter. Losses are higher on low cation exchange capacity (CEC) or sandy soils than on soils with a high CEC, a heavy clay content, or a high organic matter content. Thus, urea or nitrogen solutions (which are approximately 50 percent urea) *should be incorporated into the soil by mechanical mixing or by water movement. Light tillage or one-half inch of rain or irrigation is usually adequate. Research also has shown that volatilization losses from nitrogen solution can be reduced significantly by dribbling in a band on the surface, rather than spraying it over the entire soil surface. This can be accomplished by using drop tubes on a conventional sprayer. Urea and urea-blended fertilizers are not recommended as starter fertilizers because of possible ammonia toxicity to germinating seeds, which results in reduced plant stand.*

Phosphorus fertilizer: The chemistry of phosphorus in fertilizer and in the soil is very complex. Plants absorb most of their phosphorus from the soil solution as orthophosphate ($H_2PO_4^-$), regardless of the original source of phosphorus. With a negative charge, $H_2PO_4^-$ is not held on the soil cation exchange sites. However, it reacts readily in the soil, primarily with iron, aluminum, and calcium, to form products that over time become insoluble and thus unavailable to plants. A major factor controlling this reaction is the soil pH. At low or high pH, the solubility of phosphorus is very low. Maximum availability of phosphorus in the soil occurs in the 6.0 to 7.0 pH range.

The most common phosphate fertilizers are triple superphosphate (0-46-0), monoammonium phosphate (11-48-0 or 11-52-0), diammonium phosphate (18-46-0), and ammonium polyphosphate (10-34-0 liquid or 11-55-0 solid). All of these materials are highly water-soluble. The ammonium phosphates are also excellent nitrogen sources. Monoammonium phosphate and ammonium polyphosphate, either alone or with some added potassium, make excellent starter fertilizers because of their high P to N ratios, high water-solubility, and low free ammonia. Diammonium phosphate (DAP) is not recommended as a starter material because it produces free ammonia, which can harm the seed. However, many *starter fertilizers contain DAP; thus it is critical that the starter is accurately placed a safe distance from the seed (about 2 inches) and high rates are avoided.*

Potassium fertilizers: Potassium occurs in the soil in three forms: as exchangeable (available) potassium (K^+) adsorbed onto the soil CEC; fixed by certain minerals from which it is released to available form very slowly; and in unavailable mineral forms (most of the potassium in soil). Plants take up potassium as the K^+ ion. The common source of the fertilizer potassium is muriate of potash (0-0-60), which chemically is potassium chloride (KCl). Potassium chloride is highly water-soluble. At excessive rates, muriate of potash can cause salt damage to plants. Other potassium materials used in specialty fertilizers include potassium sulfate (K_2SO_4,0-0-50), potassium nitrate(KNO_3, 13-0-45), potassium hydroxide (KOH, 0-0-70) and sulfate of potash magnesia (Sul-K-Mag or K-Mag, 0-0-22).

Organic nutrient sources

Plant nutrients can be added in the form of many different organic amendments such as manure, composts, and such biosolids as sewage sludge. The availability of nutrients in these materials is controlled by the microbial processes. Therefore, their availability to plants may be quite dependent upon the organic source, climate conditions, and handling practices. When these nutrients have been released to the soil solution, they react the same as nutrients from commercial fertilizers.

Organic nitrogen: The availability of nitrogen in organic materials, such as manure, varies depending upon whether the nitrogen is contained in the urine or in the feces. The nitrogen in urine breaks down faster and is more likely to dissipate as ammonia gas. In urine, the nitrogen is in the form of urea, the same compound that makes up urea fertilizers. Urea is unstable, and as the manure dries and the urea breaks down into ammonium *nitrogen on a barn floor, in a manure pile, or in the soil, it creates the high pH alkaline conditions that favor ammonia production. If the urea is exposed to the air as it dries, the nitrogen in the ammonia gas will be lost to the air. When properly handled and incorporated into soil, however, the unstable nitrogen in manure is as effective as commercial nitrogen fertilizers for providing nitrogen to crops. Nitrogen availability factors must be used to estimate the available nitrogen in manure. These factors are necessary to account for management factors such as different times between application and* incorporation, application at different times of the year.

The organic nitrogen in the solid fraction of the manure decomposes into ammonium nitrogen more slowly, so the nitrogen is more likely to be used by the crop before it is lost. In soil, the decomposition is greatest during the first year after manure is applied. Residual nitrogen also becomes available for plants during succeeding years. Experimentally determined factors are used for estimating the availability of this residual nitrogen. Mineralization of this organic nitrogen varies with the type of manure and the soil and climate conditions. Each state may have its own procedure for calculating nitrogen availability from manure. Nitrogen release factors for your area can be obtained from your local cooperative extension, NRCS, or conservation district offices.

Organic phosphorus: Organic phosphorus becomes soluble and available to plants when the organic matter is broken down. In manure, phosphorus is present chiefly in feces in insoluble inorganic and organic forms. Over time, phosphorus from manure is as efficiently used by plants as phosphorus from broadcast fertilizer. Thus, for building soil phosphorus levels, manure phosphorus can be substituted on a one for one basis for broadcast fertilizer phosphorus in meeting crop requirements. However, because it breaks down slowly, the organic phosphorus in manure is not a substitute for starter *fertilizer.*

Organic potassium: Organic potassium is readily available and is equivalent to fertilizer potassium and is thus available for plant growth in the year that it is applied. Manure potassium is chiefly present in the urine fraction of manure and is readily available.

(3) Application timing

Ideally nutrients should be applied as close as possible to the time that the crop needs them to assure maximum efficiency and to reduce potential environmental hazards. Proper timing will vary depending on the crop, the nutrient, the soil, and the climate. For practical reasons compromise will often be necessary in making timing decisions. Best management practices such as use of soil and plant analysis, split applications, fertigation, and foliar feeding improve our ability to meet crop demands and reduce environmental impact. Matching nutrient applications at a time when crop demand is greatest and probability of loss from runoff or leaching is lowest will help to meet the crop demand while minimizing potential environmental loss.

(4) Method of application

Method of fertilizer application and placement can have significant influence on crop growth, fertilizer use efficiency, and environmental impact of applied nutrients. Application and placement methods selected will depend upon cropping system, form of nutrient source, and soil properties and anticipated climatic conditions.

Use of urea fertilizer as an N source can result in N losses if the fertilizer is not incorporated. Loss of urea N because of volatilization may be eliminated by immediate mechanical or water (rainfall or irrigation) incorporation. Two common nitrogen application methods *include preplant and sidedress applications. If N is applied without incorporation, applications should be to a dry soil surface, preferably just before a rain. In areas with low rainfall surface sidedress applications may be less effective than subsurface banding because nitrogen will not move down into the active root zone available for plant uptake. More efficient use of fertilizer N, in terms of total N availability, can be obtained with sidedress banding. Banding conserves the N applied and provides more uniform distribution of N across the field.*

Phosphorus placement—Because of phosphorus immobility and soil fixation, placement of fertilizer phosphorus can affect its availability to plants. Fertilizer that is broadcast and plowed down is mixed uniformly with a large amount of soil. Thus, the probability of root contact with the fertilizer is maximized. So too, though, is fertilizer contact with absorbing surfaces in the soil. When the fertilizer is applied as a concentrated band, contact with the soil, and thus fixation, is minimized; however, lack of phosphorus movement from point of placement also means that the number of roots in contact with the fertilizer may also be minimized. The greater the ability of the soil to fix phosphorus, the greater too the importance in overriding that fixation capacity with a concentrated band. Crop response to fertilizer phosphorus placement is further complicated by crop root characteristics, soil phosphorus levels, and soil temperature.

On soils with optimum to high levels of phosphorus, banding has less advantage and broadcast applications are generally adequate (sometimes superior to banding). Row crops in general, and corn in particular, appear to yield better when soils contain relatively high levels of phosphorus throughout the rooting profile. In tests with the recommended phosphorus application split between band and broadcast, versus all by one method, the maximum yields have been obtained with some *combination. The advantage to building up the general soil level of phosphorus results from the need of all roots to take up some phosphorus. Crops with limited rooting systems have less capacity to explore soil. Therefore, phosphorus placement seems more critical for shallow rooted crops than for deep rooted or perennial crops. Greater yield response to banded-P is common, especially on low phosphorus soils or soils with a greater ability to fix phosphorus.*

Starter fertilizer is a specific band application at a specific time. Even if you are planning to broadcast the majority of the required nutrients, a banded starter application is important for spring-planted crops, particularly corn. However, on soils that have excessive nutrient levels or for late planting on soils that have optimum or high nutrient levels, a starter fertilizer may not be necessary. Limited root growth combined with cold and wet soils early in the season, especially in no-till fields, reduces the availability of phosphorus and the plant's uptake ability. Early plant vigor, and often final yield, are improved by starter-P applied close to seedling roots, even when soil phosphorus levels are high or when manure has been applied. Ammonium phosphate materials are used regularly in starter formulations, and monoammonium phosphate (MAP) is an excellent material for this purpose. However, reactions producing free ammonia (NH_3) occur with diammonium phosphate (DAP). Ammonia is toxic to seedling roots, and this material is safe for starter use only when the rate is kept low and the material is placed 2 inches away from the seed. For this same reason, urea, which produces more free ammonia, should never be used in a starter fertilizer application. Subtract nutrients applied in the starter from the total amount recommended.

Fertigation is the practice of applying plant nutrients through irrigation water. Fertigation offers distinct *advantages in comparison to conventional application methods. Fertigation is applicable in some form to all types of irrigation. It is important to remember that with fertigation the uniformity of nutrient application is only as good as the uniformity of the water application. Fertigation is used extensively with sprinkler irrigation. The major advantages of this management practice is the ability to put the nutrient where the water is and thus increase nutrient use efficiency. Being able to apply nutrients, especially nitrogen, throughout the growing season as required by the plant significantly increases nitrogen uptake and use efficiency and reduces the potential for leaching losses. Drip irrigation and micro sprinkler irrigation techniques limit the volume of soil explored by the plant root system. Therefore, fertigation that puts the nutrients where the water has been applied is a physiological necessity.*

Nitrogen is the primary nutrient added through fertigation. Other nutrients such as phosphorus and potassium are applied in some areas. The quality of the irrigation water plays an important role in fertigation.

Foliar fertilization—Fertilizer solutions in the proper nutrient concentrations can be applied directly to the leaf surface of the plant. A portion of the applied nutrient can be absorbed through the foliage. Urea, potassium, and zinc are taken rapidly into the plant through the leaf tissue. The effectiveness of foliar application is dependent upon the crop, the form of the nutrient, and the climatic conditions.

2. List three major agronomic crops in your area and describe the timing and placement alternatives for optimum production and minimum environmental impact.

   Varies with location and crops.

Pest Management—Activity Answers

Student Activity 13

List the five common pest groups of agriculture and horticulture and give an example of each including the damage they may cause.

Pathogens—disease-causing bacteria, fungi, viruses and related organisms. Most pathogens are too small to be seen with the naked eye, although the diseases they cause produce visual symptoms in the plant.

Insects and arthropods—such invertebrate animals as caterpillars, bugs, beetles and mites that cause injury by feeding on plants and animals and by serving as a vector for (transmitting) pathogens that cause diseases.

Weeds—undesirable plants that reduce crop yield and quality by competing for space, water, and nutrients; weeds also may harbor crop-attacking insects and pathogens.

Nematodes—microscopic, multicellular, unsegmented roundworms that parasitize animals and plants. Most nematodes that attack agricultural crops feed on the roots; a few feed above-ground on inside stems and leaves.

Vertebrates—Any native or introduced, wild or feral, non-human species of vertebrate animal that is detrimental to one or more persons as a health hazard, general nuisance, or by destroying food, fiber, or natural resources. The majority of direct damage is caused by vertebrate feeding in agricultural crops, including such animals as mice, rats, and birds.

Group Activity 3—Optional

Note to Student: Group activities will be handled in a facilitated session.

1. What is the worst pest in the world; in your area?

   No specific answer. Remember that ecologically speaking, no organism is born a pest; it all depends on human perspective. This question is only meant to stimulate thought and to support the management of pest problems within an ecosystem approach where pest are controlled by considering ecological interactions between crops, pest, beneficial organisms, and the physical environment.

2. What pest do you find the greatest nuisance?

   Group/student specific answer

3. List some examples from your area of plant, insect, or other organisms that are a pest in one situation and not in another.

   Locally specific answers.

Student Activity 14

1. Is the ultimate objective of IPM to eliminate the use of agricultural pesticides?

   No, the objective is to integrate the pest control methods that combines biological, cultural, and other alternatives with judicious use of conventional synthetic pesticides. Pesticides never are applied according to a preset schedule or spray calendar in an IPM program. Instead, they only are used if close inspection shows they really are needed to prevent severe damage.

2. <u>Management</u> is the decisionmaking process to reduce pest status in a planned, systematic way by keeping their numbers below economically acceptable levels. The essence of integrated pest management is decisionmaking, that involves determining what four things?

- *If*
- *When*
- *Where*
- *What*

3. List four general goals of IPM.

- *Reduce pest damages to crops*
- *Protect and enhance water, soil, and environmental quality*
- *Minimize risk to human health*
- *Maximize profits to farmers*

	Runoff Potential	Leaching Potential	Clay Content	CEC	Organic Matter
Sand	3	1	3	3	3
Loam	2	2	2	2	1*
Clay	1	3	1	1	1*
*Can vary by soil type.					

Student Activity 15

1. What advice would you give to a producer if the BMP's required to reduce soil erosion also increased the severity of the pest infestation?

   Answer will vary amongst students. Most likely the BMP's for controlling soil erosion will still be recommended together with IPM practices for preventing or controlling the severity of the pest infestation below economically damaging levels.

   (This answer needs explanation if there is variation among students; not sure this is appropriate for self-study reinforcement?)

2. Define the following terms and describe the differences and similarities with IPM.

   - *Eradication is the total elimination of a pest. This is in conflict with the concept of IPM, that generally seeks to control rather than eliminate a pest.*

   - *Organic pest control is a subset of IPM. Like IPM, organic pest control looks first to alternatives to pesticides as the best way to reduce pest populations to acceptable levels. But unlike IPM, organic pest control never uses synthetic or manufactured chemical pesticides. Instead, organic farmers only use naturally occurring products such as pesticides extracted from plants or mineral dusts mined from the earth.*

   - *Best Management Practices (BMPs) usually are defined as farming practices designed to reduce soil erosion or to protect water quality. Like IPM methods, BMPs protect and enhance the quality of environment. But the relationship between BMPs and IPM is not simple. Some IPM methods and BMPs complement and enhance each other; others directly* *conflict and antagonize each other. It all depends on the situation.*

- *Sustainable agriculture is a philosophy of farming that seeks to develop a whole farm system that conserves natural resources, protects human health, and assures farmer profitability. Sustainable agriculture seeks to reduce off-farm inputs, such as pesticides, but does not require that they be eliminated. In this way IPM can be considered a component of sustainable agriculture.*

- *Integrated Crop Management (ICM) is synonymous with sustainable agriculture. ICM is another way of saying that it is important to consider the entire cropping system when selecting farming practices.*

Student Activity 16

1. Name the three R's.

   - *Resistance*
   - *Resurgence*
   - *Replacement*

2. What is the fourth R?

   Residue from pesticide

3. What topic was presented by Rachel Carson in her book, Silent Spring?

   Silent Spring was an indictment against pesticides, their careless use, and environmental problems of misuse.

4. Describe three ways that pest can overcome the toxic effects of pesticides.

   - *Insecticides can eliminate beneficial insects along with the target species, thus allowing the pest population to resurge.*
   - *Insecticides are toxic to the pest, thereby almost eliminating the food supply of the predator.*
   - *Low, sublethal doses of pesticides stimulate increased pest reproduction rates.*

Student Activity 17

1. List the common sense principles of IPM.

   - *there is no silver bullet*
   - *tolerate, don't eradicate*
   - *treat the cause of pest outbreaks, not the symptoms*
   - *if you kill the natural enemies of pest, you inherit their job*
   - *pesticides are not a substitute for good farming*

Student Activity 18

1. List the three steps to designing IPM programs.

   - *Step 1. Use cultural methods, biological controls, and other alternatives to conventional chemical pesticides when practical*
   - *Step 2. Use field scouting, pest forecasting, and economic thresholds to ensure that pesticides only are used against real and not perceived pest problems*

- *Step 3. Match pesticides with field site features so that the risk of contaminating water is minimized*

2. Define and give example of:

- Cultural control methods—*"Good farming" practices that break the pest infestation cycle by making the environment less suitable for pest survival.*

  Familiar examples include crop rotation, tillage, altering planting and harvest date, seedbed preparation, and sanitizing practices.

- Biological control methods—*Use of living organisms to suppress populations of other living organisms.*

  Lady bugs to control white flies

- Host-plant resistance—*Plants that tolerate, kill, or repel pest.*

  Hessian fly resistant wheat

3. Discuss from an ecological standpoint the four basic ways that cultural controls can reduce pest problems.

   From an ecological standpoint, cultural methods reduce pest populations in four basic ways: (1) reduce the overall favorableness of the habitat (by destroying pest overwintering sites and other infestation sources both in the crop field and alternate hosts or habitats); (2) alter planting patterns to disrupt or interrupt in time and space the food or other habitat resources required by the pest; (3) divert mobile pests away from the crop; (4) enhance the vigor of the crop so that it can better tolerate pest injury.

4. List three groups of biological control agents

    - *Predators*
    - *Parasitoids*
    - *Pathogens*

5. List the three basic approaches to biological control and differentiate among these basic approaches.

    - *Introduction of biocontrol agents into areas they do not exist; here the goal is to establish new populations that permanently reduce pest infestation levels;*
    - *Augmentation of biocontrol agents already present via mass-releases; here the goal is to supplement the effectiveness of natural populations during the current growing season by adding more natural enemies;*
    - *Conservation of biocontrol agents already present; here the goal is to maintain or enhance the impact of native species on pest infestations.*

    The differences between introduction, augmentation and conservation start to blur in the field; in practice these strategies are not quite so distinctly different as formal definitions here suggest. Of the three, conservation is the most practical approach farmers can adopt in their own fields. In contrast, introduction requires technical and financial resources far beyond those of any individual farmer and so remains within the realm of public or governmental agencies. Augmentation holds great potential for agricultural IPM, but with few exceptions, is not yet widely practiced in commercial agriculture.

6. Which of the three basic approaches to biological control is the most practical for farmers to adapt? Discuss this approach and why it is most practical.

   Conservation of biological control agents. The goal is to maintain or enhance the impact of native species on pest infestations. Diverse communities of predatory and parasitic insects occur in many field and row crops every year where they help to keep damaging insects in check. But with the exception of flashy-colored lady beetles, the role of these bioagents in naturally keeping pest species in check often goes unnoticed. The key to intensifying impact of beneficials already present is to minimize use of broad spectrum insecticides (insecticides that kill broad variety of insects). With few exceptions, the commonly used agricultural insecticides are at least moderately lethal to the common predators and parasitoids. Many are highly toxic to beneficials. Indiscriminate or excessive insecticide application contributes to pest outbreaks by eliminating natural enemies and allowing pests to rebound without checks. This does not mean that conventional chemical insecticides automatically are incompatible with biological controls. Sometimes broad spectrum insecticides can be used in ecologically selective ways that minimize risks to beneficial natural enemies.

7. What steps need to be taken to reduce the impact of pesticides on biological control agents?

   Alter the rate, form, timing and application method to target the control of the specific pest while doing minimal harm to the biological control agents. Leave areas in the field untreated ensure survival of the natural enemies.

8. The developmental threshold for cotton boll weevil is 60°F. Calculate the degree days (DD) accumulated for one day in which the high temperature is 92°F and the low is 65°F.

$$DD = \left(\frac{92° + 65°}{2} \right) - 60° = 18.5°$$

9. Calculate the degree days if the nighttime low is 56°.

$$DD = \left(\frac{92° + 60°}{2} \right) - 60° = 16°$$

10. Discuss the importance of site specific pesticide selection to environmental concerns.

The final component of IPM is selection of pesticides that pose the least risk of leaching through soil or being transported from fields in runoff water and sediment or drifting as spray particles on the wind. The potential for water contamination depends on two primary factors: (1) local environmental features, particularly soil texture, permeability, and organic matter and (2) properties of the pesticide itself.

Student Activity 19

1. Identify the major objective of IPM in controlling pest and the IPM tactics currently most useful to agriculture.

The idea is to identify weak links in the pest life cycle or vulnerable life stages that selectively can be exploited with minimal disturbance to the rest of the system. IPM tactics most useful to agriculture include:

(1) protection and enhancement of naturally occurring insect predators and parasites by controlling pests with physiologically selective insecticides (microbial insecticides) or ecologically selective use of broad spectrum pesticides (altering application time, rate, and placement);

(2) crop management practices that make the environment less favorable for pest colonization, establishment and survival, especially manipulation of crop rotations, planting, and harvest dates, site selection, cultivation, irrigation, and fertility regimes;

(3) pest resistant/tolerant crop varieties.

2. The exact mix of IPM tactics depends on pest status. Describe the three general categories of pest status (non-economic pests, occasional pests and severe) and the appropriate pest control action for each category.

   Non-economic pests—Pests that consistently remain below economic thresholds and never reach levels that require specific IPM action. Their presence in fields causes such insignificant crop damage that the costs of pest control outweigh the benefits of control. The appropriate action is no control. Many pests fall within this category.

   Occasional pests—Pests are those species that normally remain below the ET, but sporadically exceed the threshold. Here an appropriate strategy is early detection and prediction through field scouting with remedial use of pesticides when the threshold is reached.

   Severe pests—Pests including many weeds and plant pathogens whose average densities are extremely high or pests that cause cosmetic damage to high-value fruits and vegetables. Pesticide use against severe pests is not justified except as a short term, stop-gap measure because the frequent applications necessary for control inevitably result in environmental problems and greatly increase the risk of resurgence, replacement and resistance. Instead, long-term management requires combinations of methods that permanently reduce environmental carrying capacity and so dampen pest levels below threshold levels. IPM strategies for severe pests typically require combinations of cultural and biological controls that reduce overall environmental favorableness to the pest.

3. Is there a single recipe for IPM?

   No. There is no single recipe for IPM. The specific mix of control tactics varies with each site-specific situation, each crop, each insect, each disease, each weed or other pest.

Student Activity 20

1. Rank the three most common pesticide classes, both in the U.S. and worldwide, in terms of active ingredient used.

   1. herbicides, 2. insecticides, 3. fungicides

2. What are the two most widely used formulations by commercial applicators?

   Emulsifiable concentrates and wettable powders

3. List three precautions when using emulsifiable concentrate formulations.

   - *Most EC formulations are easily absorbed through the skin.*
   - *EC formulations contain solvents that can cause rubber hoses, gaskets, and pump parts to deteriorate.*
   - *Mixtures of EC formulations may be phytotoxic.*

4. What are adjuvants?

   Chemicals that are added to a pesticide formulation or mixture to improve performance and/or safety.

5. What precautions should be taken when using adjuvants?

   Some labels clearly prohibit adjuvants, or require specific adjuvant types, or instruct when to add the adjuvant to the spray mixture.

6. List an insecticide mode of action that affects both insects and mammals.

   Nerve poison

7. List the three herbicide categories based upon application timing.

   - *Pre-plant*
   - *Pre-emergent*
   - *Post-emergent*

Module 4—The Influence of Climate and Water Management on Nutrient and Pest Management Planning

Overall Learning Objective

Using the concepts in this module and the background data on the climate of the planned area, the participant will be able to explain the importance of weather information and incorporate the factors of climate and water management into a nutrient and pest management plan.

Introduction

The climate of an area influences the timing of nutrient and pest management activities, and their effects on the environment. Temperature, wind speed and direction, and the timing and amount of precipitation, both rain and snow, often dictate when field operations can take place. After nutrients and pesticides are applied, the climate will affect the physical, chemical, and biological fate of these materials. Understanding the relationship between climate and the physical, chemical, and biological processes that affect agricultural inputs will influence the development of the resource management system.

A modifier to climate can be water management. Water management practices and techniques such as irrigation, drainage, water level control, and residue management modify deficits and excesses of soil moisture, all of which have an impact on nutrient and pest management planning.

This module is divided into two major parts: **Part A—Forces and Impacts of Climate** and **Part B—Water Management's Influence on Nutrient and Pest Management.**

Module 4, Part A—Forces and Impacts of Climate

Supporting Objectives

Upon completion of Part A of Module 4 you will be able to:

- List the five climatic forces that influence nutrient and pest management.
- Describe environmental impacts as a result of climate conditions.
- List two sources of near term weather data.
- List two sources of historic climate data.
- Explain the importance of using climate data to plan nutrient and pest management.

Introduction

A number of climatic forces that influence nutrient and pest management. These forces are not independent, but work in combination to produce the weather and climate of an area. They are:

Precipitation

Water is the universal solvent. Water carries nutrients and pesticides either in solution or suspension. Besides irrigation, precipitation in the form of rain or snow is the source of water for plant growth, soil biological activity, heating and cooling, and transport of soil, plant, and other organic materials by gravity flow. Precipitation adds moisture to the soil profile to provide water for plant uptake while it carries dissolved nutrients into the root zone. Excess water on the soil surface can cause runoff and the loss of nutrients attached to soil particles, such as phosphorus. Excess water in the soil profile can carry soluble nutrients, such as nitrate nitrogen, or soluble pesticides, such as atrazine past the root zone and toward ground water supplies.

Wind

Heating of the earth's surface causes differences in air pressure. Movement of air (wind) equalizes these differences from areas of high air pressure to areas of low air pressure. Wind moves material when the threshold velocity for the particle density is exceeded. Gases, liquids, and solids can be moved by wind.

Temperature

Temperature is a measure of the molecular activity of matter. Higher activity is a result of higher temperatures. Temperature creates the atmospheric pressure gradients that produce wind, helps drive the biological activity (a doubling of biological activity for every 18°F rise in temperature) that controls plant growth, nutrient and pesticide uptake, pesticide degradation, and affects the moisture regime of the soil and plant through evaporation and transpiration.

Atmospheric Pressure

Air movement from areas of high atmospheric pressure (a HIGH) to areas of low atmospheric pressure (a LOW) creates wind. Differences in atmospheric pressure create air currents, which affect near-surface air movement. Air movement can affect the amount and rate of surface evaporation, odor and particulate movement, spray and spreading patterns, and temperature changes.

Solar Radiation

The sun's energy drives many biological processes. Radiant energy is essential for photosynthesis, the basic process of green plants for producing growth. The duration and intensity of sunshine can effect the movement and transformation of agrichemicals. Solar radiation increases heat transfer and increases the rate of evaporation and transpiration. The sun's energy can cause nutrient and pesticide losses by volatilization, evaporation, and photolysis (changes caused by light energy).

Student Activity 1

1. List the five climatic forces that influence nutrient and pest management.

Important Impacts of Climate on Nutrients and Pesticides

Climate has many direct impacts on the fate and transport of agrichemicals.

Transport of excess water via runoff and gravity flow

When the amount of water added to the soil surface, either by precipitation or irrigation, exceeds the soil's capacity to retain that water, the excess will move by one of three processes:

- Runoff—This is the portion of the added water that does not enter the soil profile, but leaves the site as overland flow. Runoff can carry dissolved nutrients and pesticides away from the target area. If runoff volume and energy are great enough, it can carry soil particles and organic matter, with adsorbed nutrients and pesticides, from the field.

- Leaching—The soil has a finite capability to hold water within the soil profile against the force of gravity. Once the profile is saturated, the excess water moves downward by gravity flow through the soil. Water will continue to drain freely until the soil reaches field capacity, which is when the macropores are empty.

- Evaporation—Water is lost from the soil surface and near surface by this process. Evaporation occurs when the atmospheric vapor pressure is low compared to the vapor pressure at the plant or soil surface, and there is sufficient solar energy to convert liquid water to water vapor. The rate of evaporation is affected by temperature, wind speed, soil moisture content, radiant energy, and relative humidity.

Volatilization by Wind and Temperature

When the right combination of climatic conditions exist, chemical compounds can pass from the liquid phase to the vapor stage. Heat energy, from solar radiation, is needed to drive this process.

Air movement carries the vapor compound from the soil and plant surface, creating a concentration gradient that allows for additional vaporization to occur. A common example of volatilization is the movement of ammonia (NH_3) from the soil surface. As much as 50 percent of the nitrogen in some fertilizer materials can be lost by ammonia volatilization. Surface-applied pesticides behave much the same way. Label requirements for those chemicals that are subject to volatilization are very specific on the climatic conditions that must exist during application of these products.

For example, some of the label requirements for the liquid fumigant Telone II are:

- "It must be placed at least 12 inches below the final soil surface."
- "Soil temperature at the depth of application must between 40°F and 80°F."
- "It is critical to manage soil moisture properly before fumigation. Plan fumigation for seasons, crop rotations, or irrigation schedules, which leave moisture in the soil."
- "Immediately after chisel application of Telone II the soil must be "sealed" to prevent fumigant loss and insure that an effective concentration of fumigant is maintained within the soil for a period of several days."
- "To maximize sealing, steps should be taken to compact the soil surface to further retard the rate of fumigant loss by following with a ring roller, cultipacker, or roller in combination with tillage equipment."

Wetting and Drying

Excessive rains or irrigation that saturate soils can have an impact on nutrient and pest management. When precipitation occurs or irrigation water is added to the soil profile it begins to fill with water. The smaller pores fill and hold the soil moisture against the forces of gravity. Next the large pores are filled and water begins to drain from the soil. The point at which the small soil pores are filled is called field capacity. When all pores are filled and water begins to drain from the profile, the soil is considered saturated. At this point the soil profile has a low capacity to flex its structure and can be compressed by vehicular traffic. This is called compaction, a distortion of the soil that causes an increase in the soil density, reduces pore space, and can easily restrict root and air movement. Heavy equipment, such as manure applicators or fertilizer spreaders, can cause compaction if operated on saturated soils. Rutting destroys the soil structure, which has a negative impact on infiltration, permeability, water and nutrient availability, and near-surface chemical and biological processes.

Saturated soil profiles have a limited capacity to infiltrate runoff or to hold agrichemicals against the force of gravity. Runoff from fields, especially after an agrichemical application, is a major source of nonpoint pollution. Leaching (gravity flow of water from the soil profile) is another transport mechanism that can carry agrichemicals below the root zone. Depending on the subsurface flow paths in the area, these chemicals will appear in drainage water, in return flow to streams or go into the ground water. Excess moisture in the soil profile adversely affects nutrient uptake and other plant growth processes, and chemical, biological, and physical processes in the soil. Saturated soil conditions can result in nitrogen losses when ammonium nitrogen is converted to nitrogen gas (N_2O) by chemical reduction instead of nitrate nitrogen (NO_3^-). Also, as mentioned in Module 3, anaerobic soil conditions in the presence of an energy source such as soil organic matter can denitrify NO_3^--N to nitrogen gases.

Dry soils do not have trafficability problems like wet soils. They do, however, present special management considerations if large cracks appear on the soil surface. Fertilizers or pesticides applied under these conditions can easily go deeper into the soil than intended. In addition, subsequent rainfall or wind events can move these materials, either directly or attached to soil particles, into the cracks, bypassing the dilution and adsorption processes that would occur if they had moved through the entire soil profile.

Movement of odors by atmospheric pressure and wind

The effects of climatic conditions on air movement and odor dissipation are illustrated in figure 4.1. Odors are compounds that follow the laws of diffusion and gradients. Under conditions of LOW atmospheric pressure the air rises and with it the odor. Wind at higher altitudes often dissipates the odor. As clouds form in LOW pressure areas, the odor is trapped and can once again descend to the ground. Rainfall can dissipate and dilute the odor to a non-offensive level.

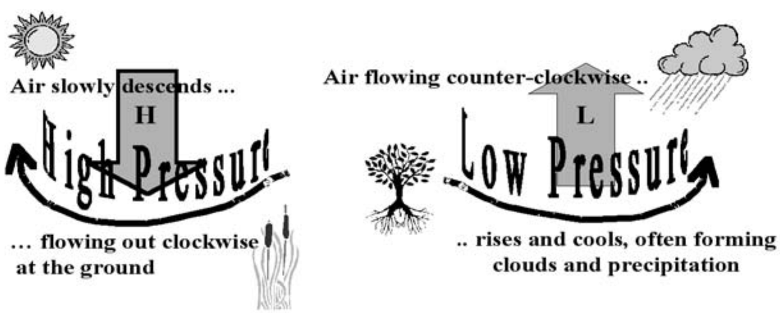


Figure 4.1 Effect of changes in atmospheric pressure on air movement.

HIGH atmospheric pressure usually means clear weather. In HIGH pressure situations the air descends to the ground carrying with it any odors that are in the atmosphere. These odors are pushed toward the ground surface and are dispersed along the ground surface. Odors become strongest at the ground level under HIGH pressure.

Winds that move from areas of high pressure to low pressure carry the odors. If there is a large pressure gradient between the areas of high and low pressure, strong winds are generated that will rapidly carry odors from a location. Because of the turbulence usually associated with high winds, the odors dissipate quickly.

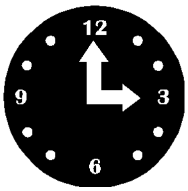
Small gradient differences between pressure centers will create only gentle winds. Even though these small winds will move odorous compounds, the movement may be too slow for dissipation of the smell and only extend the area of odor.

Table 4.1 shows the effects of different wind speeds. A wind speed of less than 7 mph (light breeze) would be considered too weak to dissipate strong odors.

Table 4.1 Wind Force Scale (compiled by U.S. National Weather Service).

Wind Speed (mph)	Wind effects observed on land	Terms used in NWS Forecasts
0-1	Calm; smoke rises vertically.	Calm
1-3	Direction of wind shown by smoke drift, but not by wind vanes.	Light
4-7	Wind felt on face, leaves rustle, ordinary vane moved by wind.	Light
8-12	Leaves and small twigs in constant motion; wind extends light flag.	Gentle
13-18	Raises dust and loose paper; small branches are moved.	Moderate
19-24	Small trees in leaf begin to sway; Fresh crested wavelets form on inland waters	Fresh
25-31	Large branches in motion; whistling heard in telephone wires; umbrellas used with difficulty.	Strong
32-38	Whole trees in motion; inconvenience felt walking against the wind.	Strong
39-46	Breaks twigs off trees; generally impedes progress.	Gale
47-54	Slight structural damage occurs; chimney pots and slates removed.	Gale
55-63	Seldom experienced inland; trees uprooted; considerable structural damage occurs.	Whole gale
64-72	Very rarely experienced inland; accompanied by widespread damage.	Whole gale
73 or more	Very rarely experienced; accompanied by widespread damage.	Hurricane

A weather map can be a practical tool for short-term planning of animal waste application. High barometric pressure is usually associated with fair weather, a time when fieldwork can be done. High pressure also means the air is descending and odors will hang near the ground surface. The neighbors may object to odors from the manure spreading operation, especially if the weather is bright and sunny and everyone is enjoying the outside weather. If the winds increase to greater than a light breeze (>7 mph) the opportunity for odor dissipation also increases. Be aware of the direction of the wind as well as the velocity. In low pressure areas the air is ascending and carrying the odors to a higher altitude. Cloud cover, however, especially low clouds, can trap the ascending air and contain the odors near the ground level.



The time of day manure is spread can make a difference, too. Morning is a good time to spread manure, because air is being heated by the sun and rises. As the warm air rises, it carries the odors with it, and they are dissipated in the upper atmosphere. In the evening, the air is cooling and begins to descend, plus winds usually diminish toward sunset. This time is less appropriate for applying manure, because the odors will tend to stay close to the ground and not be dissipated by winds.

Drift of material from the target site

The purpose of agrichemical application is to deliver the material to the target site, whether it is the plant canopy or the soil surface. Weather conditions (temperature and wind) can cause the material to move from the application area to a location offsite where it can have an adverse resource impact. The classic example is the application of pesticide materials during a wind event with velocity greater than 7 mph. The droplets produced by the applicator are sufficiently small that winds of this speed can deflect the path of the droplets. Some droplets can be carried a long distance (up to 1 mile!).

Other examples of agrichemical drift are poorly managed injection and shut off of anhydrous ammonia, organic waste odor, and wind-blown spreading patterns of fertilizer and irrigation water.

Frozen and snow covered soil surface

Precipitation that falls as snow presents special challenges for nutrient and pest management. When soil water freezes the connected pore spaces in the soil become restrictions to infiltration and percolation. A soil surface cover of snow and ice also restricts infiltration. Agrichemical such as pesticides and fertilizer rarely freeze because of their high ion concentration. However they do remain suspended and unabsorbed above or on the soil surface. There they are susceptible to weather conditions that produce runoff, wind movement, detachment or suspension, and volatilization. Organic material like sludges and manure actually break apart by freezing and thawing, releasing nutrients, metals, or organic materials that could be carried off-site by water or wind. Abrupt climatic changes that affect the surface condition of the soil, such as rapid snow melt or rain on frozen soil, can have severe environmental impacts because of the loss of agrichemicals that are on the soil surface. *

* Applying organic materials to frozen soil may be better than applying them to snow-covered fields. Manure applied to snow is subject to runoff. Snow melts from the top down, and can carry material in runoff, even above the soil surface. High amounts of standing crop residue trap more snow, thus potentially causing more runoff.

Student Activity 2

1. In the table below, enter the letter of the environmental impacts that result from the climatic conditions or impacts.

Environmental Impacts

a. Complaints of odors during sunny afternoons.

b. Tomato plants and garden flowers exhibit herbicide injury, though no herbicide was applied to them.

c. No-till corn shows nitrogen deficiency, even though urea was surface applied at recommended rates.

d. Surface applied chemicals were found deep in the soil profile, even though they were applied to a dry surface and not incorporated.

e. Agrichemicals are detected in off-site drainage ditches and tile lines.

f. High fecal coliform levels are detected in agricultural runoff during February and March.

g. Plant emergence and growth are slow in depressions left by wheel tracks from chemical application equipment.

Climatic Conditions or Effects	Environmental Impacts
Transport by water	
Volatilization	
Wetting and Drying	
Atmospheric pressure and wind movement	
Drift of material	
Frozen and snow covered soil surfaces	

Prediction of Climatic Forces

Weather forecasting is a sophisticated science based on satellite imagery, ground instrumentation, and historic records. At best, prediction is still based on real time tracking of current weather conditions that provide a basis for near future site-specific weather predications. Forecasting the weather more than 3 days in advance is difficult. However, as conservation planners we must use the science available to best predict weather conditions to guide the near-term management of agrichemicals.

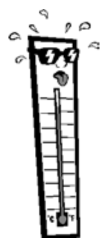
Weather maps developed by meteorologists are a valuable tool in predicting climatic conditions and forecasting events. Current weather maps show direction and intensity of fronts that may influence water needed or being received, temperature, wind, atmospheric pressure, and solar radiation. Weather channels on television that continuously update the front and cloud movement are valuable for making up-to-the-minute decisions of agrichemical management. The most immediate weather forecast can be made on-site by watching cloud movement. Generally, forecasts more than 3 days into the future are not reliable.

These elements of weather are also key factors in managing irrigation applications. Weather drives the evapotranspiration (ET) occurring from the plant and soil. In major irrigated areas, computed ET estimates are frequently reported with weather forecasts to aid in the appropriate scheduling of irrigation

Water

The most sought after information from weather forecasters is, “When will it rain, and how much?” Moisture, or the lack of it, affects almost all aspects of agricultural production. Rain and snow provides water to reservoirs and, along with irrigation, moisture to the soil. Precipitation or irrigation is required to incorporate surface-applied herbicides and fertilizer. Rain can disrupt field operations, preventing them from being performed in a timely manner. Rainfall or irrigation that occur soon after pesticide application can wash off material from the target site. Excess rainfall or irrigation amounts cause runoff and leaching. Precipitation and irrigation water can be measured with a rain gauge.

Temperature



Temperature prediction is important in estimating the potential for evaporation and transpiration or how quickly soil will warm up in the spring. Heat indexes are useful to predict or track the growth of many plants and insects. Temperature is typically measured with a thermometer.

Prediction of temperature is based on atmospheric pressure zones, movement of fronts, and amount of expected solar radiation. Again, near-term forecasting (< 3 days) is somewhat reliable. Historic record averages are good estimates for predicting high and low temperatures.

Wind

Wind is difficult to predict more than 2 days in advance. In the near-term, wind velocity and wind direction can be predicted by measurements of atmospheric pressure and the spatial relationship between the pressure zones. Local wind speed can be obtained from a local official weather station, usually at an airport or radio station, which measures wind speed with an anemometer. But wind speed and direction can vary widely depending on localized conditions. Wind speed and direction should be measured on-site just before application. In doing this the applicator will have some indication of its impact on application. Hand-held equipment is available that can measure wind speed and direction at the application site. This information can be used to determine if conditions are suitable for application.

Atmospheric Pressure

A barometer measures the pressure imparted by the atmosphere. Pressure zones vary constantly as wind and fronts move to equalize the pressure differences. Atmospheric pressure is predicted by continually monitoring a number of strategically placed barometers and compiling the data over a broad area. Weather maps show points of barometric pressure and contain lines that represent equal pressures and potential wind movement. Wind direction can help detect the locations of high and low pressure zones because wind travels from zones of high pressure to zones of low pressure.

Radiation

Presence or absence of clouds directly affects the amount of radiation reaching the earth. Generally high amounts of sunshine mean high radiation. An instrument called the pyranometer measures the quantity and quality (intensity) of the sunlight striking the earth's surface.

Student Activity 3

1. List a tool or instrument for measuring each of the following weather forces:

    a. Water ____

    ____

    b. Temperature ___________________________________

    ____

    c. Wind ____

    ____

    d. Atmospheric pressure ____________________________

    ____

    e. Solar radiation _________________________________

    ____

Sources of Climatic Data

Near-term weather information can be acquired from local weather forecasters on television and radio. Television forecasts have the advantage of spatially displaying the weather map and giving site-specific predictions. Newspaper weather maps at the local scale can also provide the spatial detail, but are not usually current enough to provide weather information for immediate decisions. Televised weather channels and computer on-line weather are the most current sources of information for making short term decisions. For periods more than 3 days into the future, weather forecasts are little better than using average climatological expectations.

Long-term climate information can be gathered from state and national weather services. Most states publish climatological data based on 30-year weather information. The National Atmospheric and Oceanographic Agency (NOAA) summarizes climatic data for each state every ten years. NOAA state data is normalized over the previous 30-years. Historic weather data is valuable to make long-term decisions and can be the basis of many general plans and designs. The duration of snow cover or monthly precipitation is information needed for animal waste storage design or opportunities for land applications. Use of long-term historic data insures that decisions are not clouded by the memory of more recent weather events.

Evapotranspiration data (ET) for irrigation water requirements and average seasonal needs are available from various sources. Most states with extensive irrigated acreage have an automated weather network available for accessing real time and daily evapotranspiration information. Historic or seasonal average irrigation water requirements can generally be located in the appropriate NRCS state irrigation guide or through various Extension Service bulletins.

Student Activity 4

1. List two sources of near term weather data.

2. List two sources of historic climate or evapotranspiration data.

Using Climate Data to Plan Nutrient and Pest Management

With all the complexities of weather patterns, it is difficult to predict the specific effects of climate on the management of agrichemicals in any one location. However, understanding weather patterns and movement can help guide decisions concerning the timing and method of application to avoid adverse impacts to the environment.

As a start, historic climate records can tell us the average duration of weather conditions that can adversely impact agrichemical applications. For example, the historic record of precipitation during the year, or part of the year, can help planners determine the amount of storage required to contain the water falling on a confinement site. Likewise, temperature, wind and radiation data can be used to predict the amount of evaporation that will occur from surface water bodies and soil. This information can be used to design the storage volume needed for animal waste management.

For land application, historic climate data helps the planner select optimum periods or windows of opportunity for application. The duration of manure storage will depend on the periods when fields are free of snow cover, the minimum chance of runoff or leaching events occurring, and periods when crops are growing and able to use the nutrients in the organic material. From a broad planning sense these periods or windows can be marked on a calendar along with an estimate of the quantities of waste material produced and quantities used. Matching the quantity estimates to the potential windows will help determine the amount of storage needed.

Another valuable source of information is a crop growth/ development curve. These curves can show the planner when the crop might best use nutrients or supplemental irrigation. Various models exist for monitoring real time development but average trend information can frequently be located in the NRCS state irrigation guide or various Extension Service bulletins.

Long-term weather data on precipitation and evapotranspiration can give guidance for design of irrigation systems to apply organic waste or treat fields with agrichemicals.

In the near term, weather data will direct the timing and method of applications. Application may be restricted on sites that have high runoff or leaching potential. Some sites may require soil incorporation rather than surface application because of runoff risk. Timing of application may be delayed because of predicted storm events that could produce runoff or leaching. Another management adjustment may be required when irrigated manure disposal could produce saturated soil in pasture areas after heavy rainfall events. Certainly the most common direct impact on application and timing is presence of wind velocities that are above the threshold velocity for drift and or that may distract the application pattern. When the wind is blowing above the threshold, it is easy to stop application operations. Atmospheric pressure and wind direction can be used to determine the best times for surface application of organic material.

Student Activity 5

1. Explain the importance of using climate data to plan nutrient and pest management.

Module 4, Part B—Water Management's Influence on Nutrient and Pest Management

Supporting Objectives

- Describe how contamination of water can occur through availability, detachment, and transport of nutrients and pesticides.
- Determine how much available water a soil holds.
- Calculate nitrogen credits from irrigation water application.
- Explain evapotranspiration (ET) and how the information is used to schedule irrigations.
- Determine how much water an irrigation system is applying.
- Determine the frequency of irrigation to minimize leaching potential.
- List two reasons why drainage is important to crop production.
- Describe how nitrogen, phosphorus, and carbon can be influenced by soil moisture status.

Introduction

The control and management of the water resources for crop production is essential for controlling and managing the environmental effects of water on our natural resources. In areas where rainfall provides the majority of soil moisture for crop production, controlling excess overland flow or the water status of the soil profile is often necessary. In arid areas, where irrigation water supplies the majority of the soil moisture, controlling irrigation rates and timing to the soil to limit runoff and leaching is necessary.

Water management practices have been developed by NRCS for three major areas:

- Irrigation
- Drainage
- Water level management

Current NRCS Planning and Management Guidance

NRCS has developed a number of conservation practices that give guidance for water management. These practice standards are in the Field Office Technical Guide and the National Handbook of Conservation Standards.

Irrigation Practices

Irrigation Canal or Lateral	320
Irrigation Field Ditch	388
Irrigation Land Leveling	464
Irrigation Pit or Regulating Reservoir	552 (A or B)
Irrigation Storage Reservoir	436
Irrigation Trickle System	441
Irrigation Sprinkler System	442
Irrigation Surface and Subsurface	443
Irrigation Tailwater Recover	447
Irrigation Water Conveyance	
Ditch (various materials)	428 (A–C)
Pipeline (various materials)	430 (AA–HH)
Irrigation Water Management	449

Drainage Practices

Mole Drains	482
Precision Land Forming	462
Regulation Water in Drainage Systems	554
Subsurface Drain	606
Surface Field Drain	607
Surface Main or Lateral Drain	608
Vertical Drain	630

Water Level Control Practices

Controlled Drainage	335
Pumping Plant for Water Control	533
Structure for Water Control	587
Water Table Control	641

Pollution Process

The pollution delivery process will be reviewed briefly again to better understand how water management influences nutrient and pest management. This section will discuss certain aspects of surface and ground water contamination. It will describe how an applied pesticide or nutrient, or the soil itself, can become a contaminant. Two of the major plant nutrients, nitrogen, and phosphorus, will be examined in detail to show how they can move from the soil surface and root zone to contaminate surface and ground water. Deep percolation and surface runoff from excess moisture, irrigation, or rainfall are the prime transporters of contaminants.

As discussed previously in Module 2, pollution is the result of a series of processes. These can generally be categorized as availability, detachment, and transport. A water pollution hazard exists only when a pollutant is available in some form at the field site, becomes detached, is transported beyond the edge of the field, leached below the root zone, or a result of wind drift toward a receiving water body. An existing or potential pollution problem from water management activities may be due to the decision-maker using an unsuitable water management system, using poor operation techniques, and making poor water management decisions when applying pesticides and/or nutrients. A potential pollution opportunity exists even if the best water management practices are used, as all chemical compounds are vulnerable to the pollution process.

- Availability—There is a potentially mobile chemical substance in some amount and in some place. The potential pollutant could be sediment from a highly erosive soil because soil is always available. Chemical compounds vary not only in quantity, but also in the degree of their availability for movement. The amount available at the time of runoff or deep percolation is important. Nutrients from fertilizer in or on the soil or from mineralized crop residue, pesticides applied to the field, bacteria carried with an application of animal manure, or some other potentially harmful material all have different forms and timing of availability for movement.

- Detachment—The potential pollutant or its environment is modified so that the substance can be moved from where it is found to where it should not be found. The detachment process will be either physical or chemical. Chemical pollutants can be grouped into three categories based on their adsorption characteristics:

  — strongly adsorbed

  — moderately adsorbed

  — non-adsorbed

  Detachment is dependent on the type of compound and concentration, bonding strength to the soil particles, quality and quantity of irrigation water, the chemical, physical, and biological characteristics of the soil (pH, soil organic matter, porosity, electrical conductivity, and others), climatic conditions (wind, temperature, and water movement), and the properties of the chemical compound. Highly soluble compounds are easily detached by dissolving into both surface runoff and percolating water. Strongly adsorbed compounds are sometimes not detached, but are carried by soil particles that have been separated by water drop splash or erosion. Some compounds, such as 2,4-D, are highly volatile, and can be detached when the heat of solar radiation changes them from a solid of liquid to a gas.

- Transport—Transport is the movement of a material from its natural or applied position. Figure 4.2 presents several transport pathways. A contaminant is transported to a place where it may become harmful to human health or the environment. Agricultural pollutants are typically transported in water as surface runoff or deep percolation, or can be moved through wind drift and volatilization. The particular pathway by which a pollutant leaves the field depends on: soil type, hydrology of the field, type of water management system and its operation techniques, timing and rates of nutrients and pesticides applied, and the interaction of the compounds with the water and soil as affected by management practices.

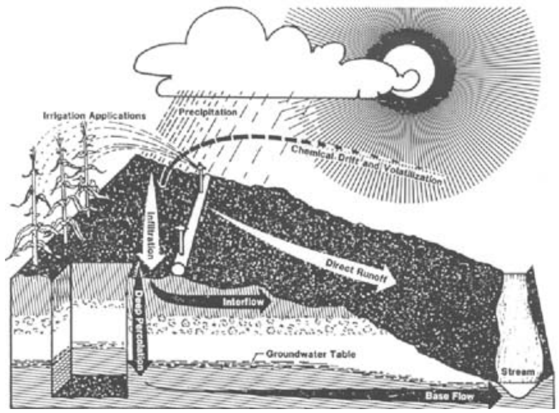


Figure 4.2 Pathways through which substances are transported from agricultural land to become water pollutants.

To summarize, contamination of water occurs through availability, detachment, and transport. For contamination to occur, contaminants must be available at the source of supply. Mechanisms with strong forces separate (detach) contaminants from the source and move (transport) them to where they may degrade a water resource or create an adverse environmental impact.

The potential for pollution can be reduced by:

- Minimizing availability of the pollutant in the environment
- Minimizing the detachment of the contaminant compound
- Minimizing the transport of the contaminant substance

Student Activity 6

1. List three primary ways to reduce the potential for pollution to occur.

Water Management Planning Accounts

Two types of water management planning accounts are used by planners depending on the purpose and need. A water budget is a projected accounting of the water supply in the soil for a general area for a general period. Simply, where does the water come from and where does it go? A water balance is the daily accounting of the water supply for a specific field (soil and crop type) during a specific time.

The difference in the two methods can be compared to a family expense account (figure 4.3). The budget is the money that is known to come in (income) and spent (expenses) each month. A balance is the daily running account that the bank records of what is deposited (precipitation and irrigation) and what is spent (runoff, evapotranspiration, deep percolation). Budgets are estimates based on past habits and historic conditions. The balance is the actual ledger of money (soil moisture) on hand in the account at any one time.

Figure 4.3 Balancing income with expenses.

Water budgets are for water management planning or broad assessment of the field or farm conditions. Examples we will work with are for planning agricultural water storage and application, pesticide application, and nutrient management. Other uses are general irrigation design, seasonal crop water requirements, and farm operation scheduling.

The difference is in the detail used and the accuracy. Water budgets generally are based on average monthly values from historic weather records. They may use averages of rainfall or precipitation over 10 or 15 days. The inputs are precipitation plus irrigation, and the debits are evapotranspiration, runoff, and deep percolation plus changes in the soil water storage. Average monthly values are used to calculate average monthly budgets. Budgets vary according to crop, soil, and location. Budgets can be developed as a general scenario for each climatic zone, county, or watershed, either for 1 year or for the crop rotation. They are more useful when they have been customized to local conditions.

Water budgets are used for determining:

- Monthly seasonal crop water requirements
- Irrigation storage requirements
- Irrigation system design capacity
- Periods of excess precipitation
- Periods of deficit precipitation
- Potential periods suitable for application of:
  - Nutrients
  - Pesticides
  - Agricultutral waste

Water balances are generally considered to be site specific. They use information about the soil water holding capacity, short-term additions of water to the soil, daily climate data, and crop water requirements to track soil water changes on a short, namely, daily, time step.

Water Management-Irrigation (Irrigation Impacts to Water Quality)

Recommended additional training materials that support this subject matter can be accessed through the University of Nebraska Cooperative Extension website at http://citv.unl.edu/waterquality/firsttime.html.

Soils

Soils play a key role in determining various parameters of water management. Irrigation water available to transport pollutants comes from either surface runoff or deep percolation. When water is added to a crop root zone by surface or sprinkler irrigation, a portion leaves the field as surface runoff, a portion moves below the crop root zone as deep percolation and a portion is stored in the crop root zone for use by the crop between irrigations.

In surface irrigation, beween 25 and 35 percent of the applied water generally leaves the field as surface runoff, while surface runoff is minimal for sprinkler irrigation. With surface irrigation, at least 20 to 25 percent surface runoff is necessary for adequate irrigation at the bottom of the field. Surface runoff can be reduced to nearly zero by including improvements like a tailwater recovery with a pumpback system or with a properly designed and managed sprinkler system.

Deep percolation occurs when water is added to a soil profile in excess of water holding capacity. Deep percolation is usually from 20 to 30 percent of applied water for a surface irrigation system. This can be greatly reduced with a surge system or reduced to near zero with a sprinkler system. We generally assume deep percolation is not desirable because it acts as a major transporter of soluble pollutants. However, when salinity problems exist in the soil or with the irrigation water, excess irrigation and deep percolation are necessary to leach excess salts from the crop root zone to avoid crop damage.

To understand the relationship between the soil and irrigation and how they potentially impact surface and ground water quality, one must have a basic understanding of soil infiltration (intake) rates and soil water holding capacities.

Soil Infiltration/Intake Rate

Infiltration rates change during the time that water is being applied to the soil surface, typically becoming slower with elapsed time. In addition, rates typically decrease through the irrigation season. This is especially true if cultivation operations are done at higher soil-water content levels. This can impact preferential flow paths such as cracks and wormholes, which have a direct influence on infiltration and permeability. Water quality, suspended sediment, temperature, sodicity, and Sodium Adsorption Ratio (SAR) also affect infiltration rates.

Soil intake characteristics affect design, operation, and management of surface irrigation systems.

Surface Irrigation

For surface irrigation systems, the water infiltration capability of a soil is referred to as soil intake characteristic or intake family. For surface irrigation systems, intake characteristic is expressed as the cumulative intake for an opportunity time period.

Soil intake characteristics directly influence length of run, required inflow rate, and time of set that provide a uniform and efficient irrigation without excessive deep percolation and runoff. The following table displays a comparison of estimated soil infiltration characteristics for border, furrow and fixed set or periodic move sprinkler irrigation systems based on surface soil texture.

Table 4.2 Soil intake ranges by surface texture.

Soil Texture	Intake characteristics (in/hr)		
Texture	**Sprinkle**	**Furrow**	**Border & basin**
C, SIC	.1 – .2	.1 – .5	.1 – .3
SC, SICL	.1 – .4	.2 – .8	.25 – .75
CL, SCL	.1 – .5	.2 – 1.0	.3 – 1.0
SIL, L	.5 – .7	.3 – 1.2	.5 – 1.5
VFSL, FSL	.3 – 1.0	.4 – 1.9	1.0 – 3.0
SL, LVFS	.3 – 1.25	.5 – 2.4	1.5 – 4.0
LFS, LS	.4 – 1.5	.6 – 3.0	2.0 – 4.0
FS, S	.5 +	1.0 +	3.0 +
CS	1.0 +	4.0 +	4.0 +

1/ These estimates are based on soil texture. They should be used only where local data are not available.

For surface systems, water is considered ponded where it is 2 to 8 inches deep. Water infiltration for borders and basins is vertically downward. For furrows, infiltration is vertically downward, horizontal, and upward into furrow ridges. More field testing has been done for borders than for furrows; therefore, intake estimates for borders are more readily available. These intake characteristics can be converted for use with furrows, but the intake process differences must be accounted for in the conversion.

Sprinkler Irrigation

For sprinkle irrigation, infiltration is referred to as either an intake rate or maximum application rate, expressed as inches per hour (in/hr). Application rates and timing vary according to type of sprinkler or spray head. With impact heads, water on the ground surface is at a single point only with each head rotation. With spray heads, water is on the ground surface continuously, but at shallow depth. Soil surface storage is important where water is applied in short periods; that is, the outer ends of low pressure center pivot laterals.

General sprinkler intake influencing components:

- Fine textured soils generally have slower intake rates than coarse textured soils.
- Single grain or granular structure = most rapid intake
- Blocky or prismatic structure = moderate intake
- Massive or platy structure = slowest intake
- Dense soils have grains tightly packed together. The effect of density on intake can be -50 percent to +30 percent from the typical.

Center pivot systems, because of their configuration, have considerably higher application rates in the outer fourth of the circle. The longer the pivot lateral, the higher the application rates in the outer portion. To maintain their usefulness on medium or fine textured and sloping soils, surface storage is essential to prevent translocation of applied water. Surface storage can be provided by:

- Soil surface roughness or cloddiness developed from tillage equipment
- In-furrow chiseling or ripping
- Crop residue on the soil surface
- Basin tillage
- Permanent vegetation
- Any combination of these

Soil Structure

Soil structure is the arrangement and organization of soil particles into natural units of aggregation. Weakness planes that persist through cycles of wetting and drying and cycles of freezing and thawing separate these units from one another. Structure influences air and water movement, root development, and nutrient supply. Illustrations of different soil structures are given in figures 4.4 through 4.8.

In single-grained soils, such as loose sand, water percolates rapidly. Water moves very slowly through most clay soils. A more favorable water relationship occurs in soils that have prismatic, blocky and granular structure. Platy structure in fine and medium soils impedes the downward movement of water. Structure can be improved with such cultural practices as conservation tillage or residue management, improving internal drainage, liming or adding sulfur to soil, using grasses in crop rotation, incorporating crop residue, and adding organic material or soil amendments. Structure can be destroyed by heavy tillage equipment or excessive tillage operations.

Examples of Soil Structure

Figure 4.4 Platy—the units are flat and plate like. They are generally oriented horizontal.

Figure 4.5 Prismatic—the individual units are bounded by flat to rounded vertical faces, distinctly longer vertically.

Figure 4.6 Columnar—the units are similar to prisms and are bounded by flat or slightly rounded vertical faces, that have tops very distinct and normally rounded.

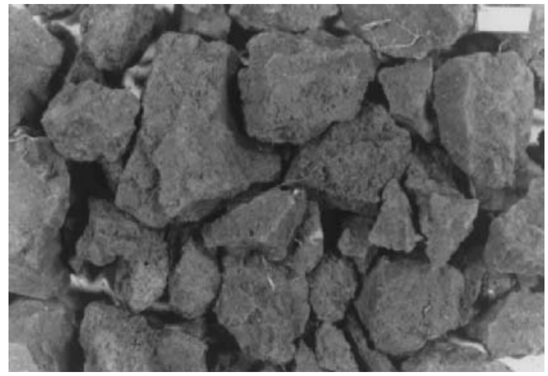


Figure 4.7 Blocky—the units are block like or polyhedral and bounded by flat or slightly rounded surfaces.

Figure 4.8 Granular—The units are approximately spherical or polyhedral and are bounded by curves or irregular faces.

Soil Bulk Density

Refers to the weight of a unit volume of dry soil, which includes the volume of solids and pore space. Units are expressed as the weight at oven-dry and volume at field capacity water content, expressed as grams per cubic centimeter (g/cc) or pounds per cubic foot (lb./ft^3). Soil is composed of soil particles, organic matter, water, and air.

Soil Pore Space

Bulk density is used to convert water measurements from a weight basis to a volume basis that can be used for irrigation related calculations.

Pore space allows the movement of water, air, and roots. Dense soils have low available water capacity because of decreased pore space. Density can make Available Water Capacity (AWC) differences of –50 percent to +30 percent compared to average densities. Sandy soil generally has a bulk density greater than clayey soil. Sandy soil has less total pore space than silt and clay soil. Gravitational water flows through sandy soil much faster because the pores are much larger. Clayey soil holds more water than sandy soil because it has a greater pore space volume, and the greater surface area of clay particles provides for greater adhesion forces that attract and hold water in the pores. Clay soil particles are flat or plate-like in shape providing for higher soil-water tension for a given volume of water. When the percent clay in a soil increases over about 40 percent, AWC is reduced even though total soil-water content may be greater. Permeability and drainability of soil are directly related to the volume, size, and shape of pore space.

Uniform plant root development and water movement in soil occur when soil profile bulk density is uniform, a condition that seldom exists in the field. Generally, soil compaction occurs in all soils where tillage implements and wheel traffic are used. Compaction decreases pore space, decreasing root development, oxygen content, and water movement and availability. Other factors affecting soil bulk density include freeze/thaw process, plant root growth and decay, wormholes, and organic matter.

Soil Water Holding Capacity

The potential for a soil to hold water is an important factor in designing and managing an irrigation system. Total water held by a soil is called water holding capacity. However, not all soil-water is available for extraction by plant roots. The volume of water in a soil that is available to plants is referred to as available water capacity.

Available Water Capacity (AWC) is a traditional term used to express the amount of water held in the soil available for use by most plants. It is dependent on crop rooting depth and several soil characteristics. In fine textured soil and soil affected by salinity, sodicity, or other chemicals, a considerable volume of soil water may not be available for plant use.

Soil-Water Potential

Soil-water potential is a more correct way to define water available to plants. It is the amount of work required per unit quantity of water to transport water in soil. In the soil, water moves continuously in the direction of decreasing potential energy. The concept of soil-water potential replaces arbitrary gravitational, capillary, and hygroscopic terms. Total water potential consists of several components. It is the sum of matric, solute, gravitational, and pressure potential. Units of bars or atmospheres are generally used to express suction, tension, stress, or potential of soil water.

Field capacity is the amount of water a well-drained soil holds after free water has drained because of gravity. For coarse-textured soil, drainage occurs soon after irrigation because of relatively large pores and low soil particle surface tension. In fine textured soil, drainage takes much longer because of smaller pores and their horizontal shape. Major soil properties that affect field capacity are texture, structure, bulk density, and strata within the profile that restrict water movement. Generally, fine-textured soil holds more water than coarse-textured soil. Some soil, such as some volcanic and organic soil, is unique in that it can retain significant volumes of water at tensions less than one-tenth bar, thereby giving it a larger available water capacity.

An approximation of field capacity soil-water content level can be identified in the laboratory. It is the water retained in a soil when subjected to a tension of one-tenth atmosphere (bar) for sandy soil and one-third atmosphere for other finer textured soil.

Field capacity water content can be estimated in the field immediately following a rain or irrigation, after free water has drained through the soil profile. Some judgment is necessary to determine when free water has drained and field capacity has been reached. Free water in coarse-textured soil (sandy) can drain in a few hours. Medium-textured (loamy) soil takes approximately 24 hours, and fine-textured (clayey) soil may take several days.

Permanent wilting point is the soil-water content at which most plants cannot obtain sufficient water to prevent permanent tissue damage. The lower limit to the available water capacity has been reached for a given plant when it has so exhausted the soil moisture around its roots as to have irrecoverable tissue damage, thus yield and biomass are severely and permanently affected. The water content in the soil is then said to be the permanent wilting percentage for the plant concerned. Figure 4.9 presents a graphical display of field capacity and wilting point elements.

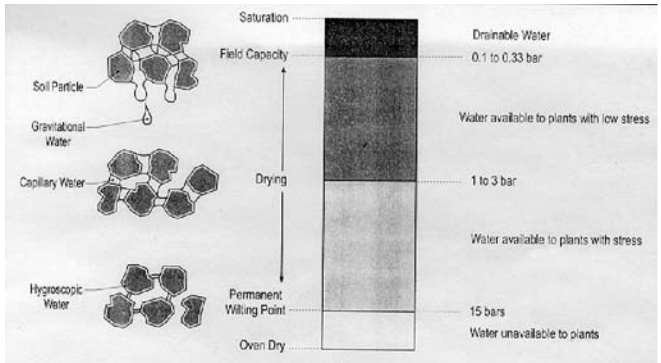


Figure 4.9 Soil water schematic.

Experimental evidence shows that this water content point does not correspond to a unique tension of 15 atmospheres for all plants and soils. The quantity of water a plant can extract at tensions greater than this figure appears to vary considerably with plant species, root distribution, and soil characteristics. Unless plant specific data are known, any water remaining in a soil at greater than 15-atmosphere tension is considered unavailable for plant use.

Major soil characteristics affecting the available water capacity are texture, structure, bulk density, salinity, sodicity, mineralogy, soil chemistry, and organic matter content. Of these, texture is the predominant factor in mineral soils. Because of the particle configuration in certain volcanic ash soils, these soils can contain high water content at field capacity levels. This provides a high available water capacity value. Table 4.3 displays typical available water capacity based on soil texture.

Table 4.3 Available water capacity (AWC) by texture [1/]

Texture Symbol	Texture	AWC Range (in/in)	AWC Range (in/ft)	Typical AWC (in/ft)
COS	Coarse sand	.01 – .03	.1 – .4	.25
S	Sand	.01 – .03	.1 – .4	.25
FS	Fine Sand	.05 – .07	.6 – .8	.75
VFS	Very fine sand	.05 – .07	.6 – .8	.75
LCOS	Loamy coarse sand	.06 – .08	.7 – 1.0	.85
LS	Loamy sand	.06 – .08	.7 – 1.0	.85
LFS	Loamy fine sand	.09 – .11	1.1 – 1.3	1.25
LVFS	Loamy very fine sand	.10 – .12	1.0 – 1.4	1.25
COSL	Coarse sandy loam	.10 – .12	1.2 – 1.4	1.3
SL	Sandy loam	.11 – .13	1.3 – 1.6	1.45
FSL	Fine sandy loam	.13 – .15	1.6 – 1.8	1.7
VFSL	Very fine sandy loam	.15 – .17	1.8 – 2.0	1.9
L	Loam	.16 – .18	1.9 – 2.2	2.0
SIL	Silt loam	.19 – .21	2.3 – 2.5	2.4
SI	Silt	.16 – .18	1.9 – 2.2	2.0
SCL	Sandy clay loam	.14 – .16	1.7 – 1.9	1.8
CL	Clay loam	.19 – .21	2.3 – 2.5	2.4
SICL	Silty clay loam	.19 – .21	2.3 – 2.5	2.4
SC	Sandy clay	.15 – .17	1.8 – 2.0	1.9
SIC	Silty clay	.15 – .17	1.8 – 2.0	1.9
C	Clay	.14 – .16	1.7 – 1.9	1.8

[1/] These estimates are based on soil texture. They should be used only where local data are not available.

It is important to remember that different soils hold water and release it differently. When soil-water content is high, little effort is required by plant roots to extract moisture. As each unit of moisture is extracted, the next unit requires more energy. This relationship is referred to as a soil moisture release characteristic. The tension in the plant root must be greater than that in the soil at any water content to extract the soil water. Typically with most field crops, crop yield is not affected if adequate soil water is available to the plant at less than 5 atmospheres for medium to fine textured soils. At soil-water tensions of more than about 5 atmospheres, plant yield or biomass is reduced in medium to fine textured soils. Figure 4.10 is a graphical presentation of this variation.

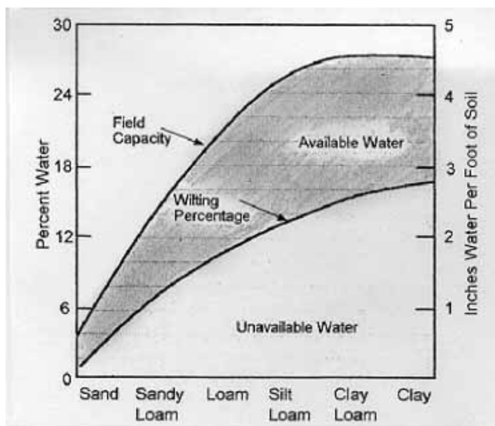


Figure 4.10 Available soil water by texture.

Salts in the soil-water solution decrease the amount of water available for plant uptake. Maintaining a higher soil-water content with more frequent irrigation relieves the effect of salt on plant moisture stress.

AWC is the major soil factor in scheduling irrigations. Only a partial depletion of the AWC should be allowed. For most field crops and loamy soil, 50 percent depletion is considered typical so as not to cause undue plant moisture stress. For most vegetables, 30 percent depletion is desirable.

Allowed soil-water depletion is a management decision based on the type of crop grown, stage of crop growth, total AWC of the soil profile, rainfall patterns, and the availability of the pumped or delivered water. It is referred to as the Management Allowed Depletion, or MAD level. The conventional concepts of total soil volume AWC and MAD do not apply to micro-irrigation, in which root volumes and wetted volumes are restricted. Figure 4.11 presents a relationship of optimum growth to percent soil moisture.

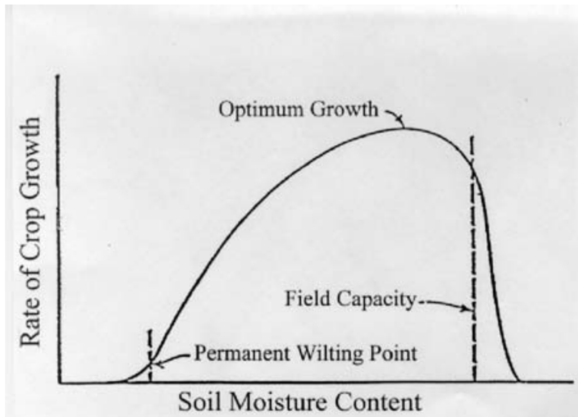


Figure 4.11 Optimum growth versus soil moisture.

Student Activity 7

1. How much water will be held in 4.0 feet of fine sandy loam soil, using the average per foot available water capacity (WHC)?

Nitrogen in Irrigation Water

A consideration frequently overlooked when using irrigation water is that it likely contains some nitrate-nitrogen. This nitrate-nitrogen is available to a growing crop and needs to be considered as another credit in the nitrogen budget. A water test will generally report the nitrate-nitrogen in parts-per-million (ppm). Some tests may report the concentration as milligrams per liter (mg/l), which is the same as ppm. Each ppm is equivalent to 2.72 lb of nitrogen for each 12 inches of water applied. The amount of nitrogen per inch of irrigation application can be calculated as:

(ppm) x (0.23) x (inches of water) = lb of nitrogen/acre in the water

One needs to consider when a crop will use the nitrate-nitrogen being applied by the irrigation or when it might contribute to deep percolation and potential ground water quality problems. Rapid uptake of nitrogen by the crop is a function of plant development. In corn, rapid uptake of N occurs about 4 to 5 weeks prior to pollination and for maybe a week after. Nitrogen applied through the irrigation water after this period is of little value. To reduce potential nitrogen accumulation and leaching problems, one planning component might be to use water high in nitrogen early in the season and during rapid plant development, then switch to a well with less nitrate-nitrogen to finish the season.

Student Activity 8

1. How much nitrogen is supplied if there is 12 ppm N in the irrigation water and 30 inches per acre of water is applied during the growing season?

Irrigation Water Requirement and Management Basics

Crop Evapotranspiration

Plants need water for growth and cooling. Small openings (stomata) on the upper and lower surfaces of the leaves allow for the intake of carbon dioxide required for photosynthesis and plant growth. Water vapor is lost to the atmosphere from the plant leaves by a process called transpiration. Direct water evaporation also occurs from the plant leaves and from the soil surface. The total water used by the specific crop, which includes direct evaporation from plant leaves and the soil surface and transpiration, is called crop evapotranspiration (ET).

Management Allowable Depletion

Determining when to irrigate a specific crop requires the consideration of the Management Allowable Depletion (MAD) of the available soil water. MAD is defined as the percentage of the available soil water that can be depleted between irrigations without serious plant moisture stress. MAD is expressed as:

- a percentage of the total Available Water Content (AWC) the soil will hold in the root zone,
- a soil-water deficit (SWD) in inches, or
- an allowable soil-water tension level.

Different crops tolerate different soil-water depletion levels at different stages of growth without going into moisture stress. Some crops have critical growth periods during only one stage of growth, while others have critical periods during several stages of growth.

MAD should be evaluated according to crop needs, and, if needed, adjusted during the growing season. Values of MAD during the growing season are typically 25 to 40 percent for high value, shallow rooted crops; 50 percent for deep-rooted crops; and 60 to 65 percent for low value deep-rooted crops.

Recommended MAD values by soil texture for deep-rooted crops are:

- Fine texture (clayey) soil—40 percent
- Medium texture (loamy) soil—50 percent
- Coarse texture (sandy) soil—60 percent

Table 4.4 lists recommended MAD levels by crop development stages for a few crops. Caution: Medium to fine textured soil can reduce MAD values given in this table.

Table 4.4 Recommended Management Allowable Depletion (MAD) for crop growth stages (% of AWC) growing in loamy soil [1/,2/]

	Crop Growth Stage			
Crop	**Establishment**	**Vegetative**	**Flowering Yield**	**Ripening Maturity Formation**
Alfalfa hay	50	50	50	50
Alfalfa hay	50	50	50	50
Alfalfa seed	50	60	50	80
Beans, green	40	40	40	40
Beans, dry	40	40	40	40
Citrus	50	50	50	50
Corn, grain	50	50	50	50
Corn, seed	50	50	50	50
Corn, sweet	50	40	40	40
Cotton	50	50	50	50
Cranberries	40	50	40	40
Garlic	30	30	30	30
Grains, small	50	50	40 [3/]	60
Grapes	40	40	40	50

	Crop Growth Stage			
Crop	**Establishment**	**Vegetative**	**Flowering Yield**	**Ripening Maturity Formation**
Grass pasture/hay	40	50	50	50
Grass seed	50	50	50	50
Lettuce	40	50	40	20
Milo	50	50	50	50
Mint	40	40	40	50
Nursery stock	50	50	50	50
Onions	40	30	30	30
Orchard, fruit	50	50	50	50
Peas	50	50	50	50
Peanuts	40	50	50	50
Potatoes	35	35	35	50 [4/]
Safflower	50	50	50	50
Sorghum, grain	50	50	50	50
Spinach	25	25	25	25
Sugar beets	50	50	50	50
Sunflower	50	50	50	50
Tobacco	40	40	40	50
Vegetables				
1 to 2 ft root depth	35	30	30	35
3 to 4 ft root depth	35	40	40	40

For medium to fine textured soils:
[1/] (Most restrictive MAD) Some crops are typically not grown on these soils.
[2/] Check soil moisture for crop stress point approximately one-third of the depth of the crop root zone.
[3/] From boot stage through floering.
[4/] At vine kill.

Irrigation Frequency

How much and how often irrigation water must be applied depends on the soil AWC in the actual plant root zone, the crop grown and stage of growth, the rate of evapotranspiration of the crop, the planned soil Management Allowable Depletion (MAD) level, and effective rainfall. More simply put; it depends on the crop, soil, and climate. Never assume a plant root zone for management purposes. Check actual root development pattern and depth.

Once a MAD is selected, determining when to irrigate simply requires estimation or measurement of when the soil moisture reaches that level. Coarse textured and shallow soil must be irrigated more frequently than fine textured deep soil because fine textured deep soil stores more available water. The moisture use rate varies with the crop and soil. It increases as the crop area canopy increases, as humidity decreases and as the days become longer and warmer.

Frequency can be estimated by dividing the MAD by the estimated or measured evapotranspiration of the crop as follows:

$$\text{Irrigation frequency (days)} = \frac{\text{MAD (inches)}}{\text{Crop ET rate (in/day)}}$$

A much higher quality product is produced if the MAD level is kept less than 35 percent in such crops as potatoes, pecans, vegetables, and melons.

Student Activity 9

1. Explain what evapotranspiration is and how it is used in scheduling irrigations.

Net Versus Gross Application Requirement

Net Irrigation Requirement

The net amount of water to be replaced at each irrigation is the amount the soil can hold between field capacity and the moisture level selected when irrigation is needed (MAD). Maintaining the same soil moisture level throughout the growing season is not practical and probably not desirable. Ideally, an irrigation is started just before the selected MAD level is reached or when the soil will hold the irrigation application plus expected rainfall. The net amount of water required depends on soil AWC in the plant root zone and the ability of a particular crop to tolerate moisture stress. If the MAD level selected is 40 percent of AWC in the root zone (Soil-water deficit = 40%), add that amount of water to bring the root zone up to field capacity. For example if the total soil AWC in the root zone is 8 inches and MAD = 40%:

$$\text{Net irrigation} = 40\% \times 8 \text{ in} = 3.2 \text{ in}$$

In semi-humid and humid areas, good water managers do not bring the soil to field capacity with each irrigation, but leave room for storage of expected rainfall. When rainfall does not occur, the irrigation frequency must be shortened to keep the soil moisture within the MAD limit. It is a management decision to let MAD exceed the ability of an irrigation system to apply water. For example, if a center pivot sprinkler system applies a net of 1 inch per cycle, let MAD be equal to 1 inch plus expected rainfall. MAD for a surface irrigation system will be typically greater as heavier applications are required for best uniformity across the field.

Gross Irrigation Requirement

The gross amount of water to be applied at each irrigation is the amount that must be applied to assure enough water enters the soil and is stored within the plant root zone to meet crop needs.

No irrigation system that fully meets the season crop evapotranspiration needs is 100 percent efficient. Not all water applied during the irrigation enters and is held in the plant root zone. Also, all irrigation systems have a distribution uniformity less than 100 percent. Applying too much water too soon (poor irrigation water management) causes the greatest overuse of water. Irrigation systems and management techniques are available that reduce avoidable losses and resulting water quality problems.

Unavoidable losses are caused by:

- Unequal distribution of water being applied over the field.
- Deep percolation below the plant root zone in parts of the field.
- Translocation or surface runoff in parts of the field.
- Evaporation from the soil surface; flowing and ponded water.
- Evaporation of water intercepted by the plant canopy under sprinkler systems.
- Evaporation and wind drift from sprinklers or spray heads.
- Non-uniform soil.

For a given irrigation method and system, irrigation efficiency varies with the skill used in planning, designing, installing, and operating the system. Local climatic and physical site conditions (soil, topography) must be assessed. To assure that the net amount of soil water is replaced and retained in the root zone during each irrigation, a larger amount of water must be applied to offset the expected losses. The gross amount to be applied is determined by the equation shown at the bottom of this page.

$$\text{Gross irrigation amount} = \frac{\text{Net amount of be replaced (in)}}{\text{Overall irrigation efficiency of system with mgmt (\%)}}$$

$$= \frac{\text{Management Allowable Depletion (MAD)}}{\text{Overall irrigation efficiency}}$$

Student Activity 10

1. What is the gross irrigation requirement in acre-inches (ac-in) when 3 inches needs to be replaced by an irrigation system 60 percent efficient?

Reduced Irrigation Means and Methods

Several opportunities are available to the irrigator in semiarid, subhumid, and humid areas for reduced irrigation water application and minimize potential water quality problems:

- Maximizing effective rainfall.
- Deficit or partial season irrigation.
- Selection of crops with low water requirements during normal high water use periods; that is small grains, (or accept the risk of drought periods).
- Selection of drought resistant crops and varieties that provide yields based on water availability, that is alfalfa hay, grass pasture (accept the reduced yields caused by drought periods).
- Irrigate just before critical growth period(s) of the crop to minimize critical plant moisture stress during those periods.
- Use state-of-art irrigation scheduling techniques that use local area climate and onsite rainfall data, and field-by-field soil moisture status monitoring.
- Use tillage practices that allow maximum surface storage and infiltration of rainfall events, reducing runoff and soil surface evaporation.
- Follow an intensive crop residue management and mulch program and minimize tillage to reduce soil surface evaporation.
- Reduce irrigated acreage to that which can be adequately irrigated with the available water supply.

Risk is less when growing crops on deep, high AWC, loamy soils and in climatic areas that have adequate rainfall for the crop. The risk is greater when growing crops on low AWC soils even in areas that have adequate rainfall during the growing season. When growing high value crops, an irrigation system and adequate water supply are highly desirable for insurance against potential crop loss or yield reduction. A detailed economic analysis should be completed to provide estimates of optimum net benefits. The analysis should include cost of water, pumping costs, reduced yields caused by reduced crop water use, and reduced tillage operation costs. Subsequent management decisions should be based on this analysis.

In some areas, irrigation water delivery systems, including management, limit on-farm water management improvements. Rotational delivery systems have the lowest on-farm water management potential, while on demand delivery systems have the highest.

Improving both management and the irrigation system can reduce the amount of water applied and more effectively use existing water supplies. Improving water management, including irrigation scheduling and adequate water measurement, is always the first recommended increment of change. Improving existing irrigation systems is the next. Unless the existing irrigation system is unsuitable for the site (including unacceptable water quality impacts), crop grown, or water supply, converting to another irrigation method seldom produces benefits equal to improvements in water management.

Student Activity 11

1. List two methods that could be used in semi-humid areas to reduce irrigation needs and reduce potential water quality problems from irrigation application.

   a. ____

   ____

   ____

   ____

   b. ____

   ____

   ____

   ____

Water Management—Drainage

Good soil drainage is essential to successful crop production, both in irrigated and un-irrigated crop production. Plant roots require oxygen to carry on respiration. To ensure that air can get into the upper part of the soil, there must be sufficient internal drainage in the soil profile to allow gravitational water to move downward and out of the root zone. As discussed earlier in Part B of this module, the rate that water moves through the soil is affected by soil texture, soil structure, and the presence (or absence) of impermeable layers. Soil texture and structure affect soil bulk density and pore space, both the number and size of pores. Coarse-textured soils have larger pore spaces, so water will move downward through them quicker than medium or fine-textured soils.

If there are no restrictive layers in a soil, drainage water will move downward through the soil profile and out of the root zone. Depending on the geology of an area, the water may continue downward until it enters the ground water or aquifer. If there is some type of restriction to downward movement, the water will perch on this restrictive layer, and may begin to move laterally. It may eventually return to the surface as spring flow or base flow in streams and rivers.

If there is some restriction to natural gravitational drainage, such as a natural high water table or an impermeable layer of clay or rock occurring close to the surface, water will build up and saturate the root zone. Crop growth will suffer because of low oxygen levels in the soil. In these situations, artificial drainage systems must be installed to allow the excess water to get away.

Managing the water and air status of the soil has a great impact on the fate and transport of agrichemical compounds. The transformation of nutrient and pesticides in the soil are influenced by the drainage status. A well-drained soil allows the plants growing in it to use the maximum potential rooting area. Any agrichemicals applied or incorporated into this rooting area will be used to the greatest extent possible.

In a well-drained soil, aerobic conditions exist. Nitrogen added to the soil as NH_4^+ is oxidized to NO_2^- then to NO_3^- , which is readily available to crops. In a poorly drained soil, the rate of NO_3^- production is much lower. In addition, the NO_3^- that is produced is subject ot denitrification. Anaerobic organisms in the soil get their oxygen from NO_2^- and NO_3^-, releasing N_2 and N_2O (nitrous oxide) which can be lost to the atmsophere. N_2O is considered a greenhouse gas, contributing to the warming of the earth's atmsophere.

The rate of nitrogen mineralization (the conversion of organic N to plant-available forms of N) is also affected by soil drainage. Mineralization occurs through the activity of soil microorganisms. The rate of mineralization is a function of the metabolic rate of these microorganism, which is directly related to soil temperature and soil moisture content. The rate of mineralization slows as the soil moisture content deviates significantly from field capacity.

Proper drainage is important in reducing pesticide carryover in the soil. There are three processes that degrade pesticides in the soil:

- microbial
- chemical
    - — hydrolysis
    - — redox reactions
- metabolism
    - — changes after being absorbed by plants or animals

All of these processes are affected by the drainage status of the soil. A well-drained soil will have a healthy bacterial population that can break down excess pesticides in the soil. Herbicides are taken up better by weeds that are growing vigorously, as they would be in a field with good drainage. The chemical transformations that take place are affected by the moisture and oxygen status of the soil.

Drainage plays a key role in maintaining the productivity of irrigated soil in arid regions, especially if the irrigation water contains signifcant amounts of salts. A good drainage system on irrigated soil permits the removal of excess salts from the soil profile, and prevents salt buildup in the rooting zone if the irrigation water contains excess salts. Irrigation water is applied at a rate that moves the salts down through the profile and below the the root zone. By practicing good irrigation water management, producers can also minimize the amount of salts that are leached out of the soil and reach the ground water or the irrigation return flow.

As water moves through the soil, it carries with it some amount of the soluble materials that are there. Nitrates, potassium, phosphorus, pesticides, and soluble carbon are all carried by drainage water. All of these dissolved materials have the potential to pollute surface or ground water sources (table 4.5). Irrigation tailwater can contain significant amounts of dissolved salts. Special provisions may need to be made to treat this water before it re-enters surface waters. Constructed wetlands can do a good job of removing excess nutrient from drainage water.

Table 4.5 Concentrations (mg/L) and amounts of (lb/ac) of nutrients and pesticides measured in subsurface drain discharges.

Compound		Concentration (mg/L)	Amount (lb/ac)
Total N	(irrigation)	2–20	3–180
	(cropland)	1–25	2–130
Nitrate–nitrogen	(irrigation)	0.4–19	2–120
	(cropland)	0.4–30	2–130
Total P	(cropland)	0.01–1.17	1.25–2.5
	(hayland)	0.16–2.0	0.25–3.0
	(irrigation)	0.1–0.3	3–10
Pesticides		Usually blow the MCL	0–5% of applied

Irrigation drainage water with high salt content presents special concerns. Disposal alternatives include:

- Discharge into salt sinks (ocean, salt basins, underground saline aquifers)
- Discharge into a waste disposal operation
- Reuse on cropland by irrigating high salt-tolerant plants
- Discharge into an on-farm evaporation pond
- Reclaim salt(s) for use in the United States salt market (livestock feed, food processing for human consumption, industrial)

By far the best solution is good onsite water management to minimize the amount of effluent to be disposed, yet maintain proper soil salinity control and soil moisture status in the plant root zone. Drainage effluent can contain naturally occurring soil elements. Drainage effluent from salinity control irrigation management can contain high concentrations of salts and is unsuitable for reuse on most common crops. It has been demonstrated, however, that drainage effluent from fields with intensive salinity control can be used for irrigation of high salt-tolerant plants (agroforestry). Incorporating crop residue containing salt returns the salt to the soil, perhaps with little, if any, net salt removal. Some of these plants are commercially useful and can be grown economically and irrigated with very high salt concentration drainage effluent. When irrigating high salt-tolerant plants, good internal drainage and removal of excess water used for leaching for salinity management are also essential. The final, smaller volume of drainage effluent with a high salt concentration is typically discharged into an on farm evaporation pond. The remaining salts can then be mined.

Student Activity 12

1. List two reasons why drainage is important to crop production.

2. List four alternatives for disposing of drainage effluent.

Water Management—Water Level Control

Water level control is the manipulation of soil moisture to create suitable soil and plant environment for control of vegetative growth, reduction of compounds such as nitrate nitrogen, or promotion of soil micro and mesa fauna. This is accomplished by changing the aeration or water status of the soil pores. Crops like rice respond favorably to water saturated soil conditions and can out compete other vegetation. Plants classified as obligate wetland species grow in these same conditions.

Water level control practices such as subsurface irrigation (figure 4.12), flooding, and water control structures saturate the soil profile and change the reduction-oxidation (redox) status of the soil. This change in redox has an impact on minerals and organic compounds in the soil. A change in redox potential will alter the chemical form of the compound, thereby affecting plant availability and mobility. The conversion of highly adsorbed ferric phosphate to soluble ferrous phosphate occurs when soils become saturated with water. Redox potentials usually only affect iron or manganese phosphates. Calcium phosphates would not be affected by redox since Ca will not be reduced. However, under reducing conditions there is also a tendenacy for the pH to go to neutrality, that is pH about 7. Under these conditions the solubility of calcium phosphate will increase just because of the change in pH. For most calcium phosphate minerals the solubility changes 100 fold with each unit pH change, so even a relativily small pH change has a large affect on solubility.

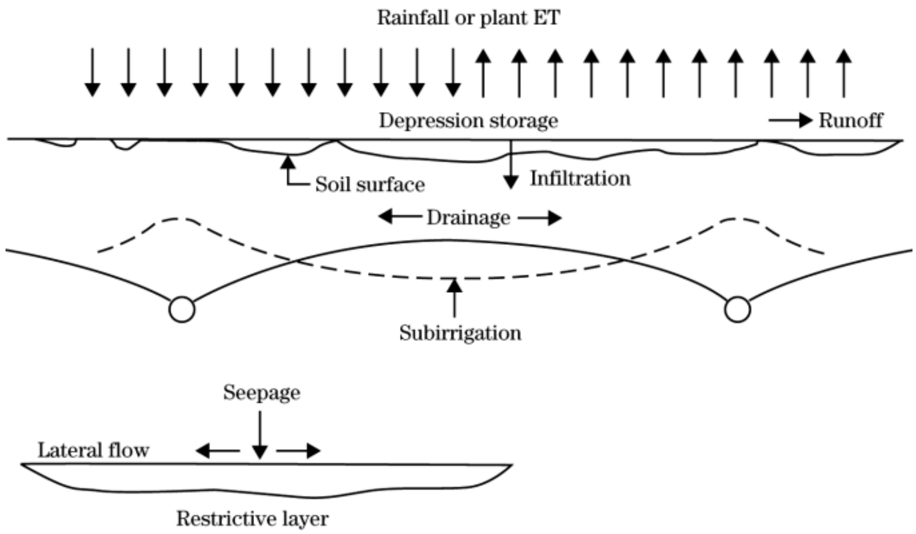


Figure 4.12 Water table control/subsurface irrigation schematic.

The change in the soil moisture status also affects the biology of the soil and plant ecosystem. Different species of soil flora and fauna are present with different soil moisture regimes. Associated soil fauna become transitory to the changing soil conditions. Nitrogen responds to varying soil moisture conditions. When sufficient oxygen is present in the soil, nitrogen will transform to the nitrate nitrogen (NO_3^-) form. If oxygen is limited the soil microbes will use the oxygen contained in the nitrate and convert the compound to atmospheric nitrogen (N_2). Soil carbon also transforms in different pathways depending on the redox potential of the soil. If oxygen is available in the soil, carbon will be released to the atmosphere as carbon dioxide (CO_2), a product of microbial respiration. Limited oxygen in the soil produces methane (CH_4) as a result of microbial by products.

Another consideration with water table control is upward water flow. Upward water flow (up flux) rate is a function of soil properties, primarily texture, and water table depth. Upward flow rate is generally most significant for medium textured soil where the hydraulic gradient and hydraulic conductivity together produce a usable rate of water supply.

Student Activity 13

1. Describe how nitrogen, phosphorus, and carbon can be influenced by soil moisture status.

Activity Answers

Student Activity 1

1. List the five climatic forces that influence nutrient and pest management.

   - *Precipitation*
   - *Wind*
   - *Temperature*
   - *Atmospheric Pressure*
   - *Radiation*

Student Activity 2

1. Match the environmental impacts with the climate condition impacts:

   Environmental Impacts

   a. *Complaints of odors during sunny afternoons.*

   b. *Tomato plants and garden flowers exhibit herbicide injury, though no herbicide was applied to them.*

   c. *No-till corn shows nitrogen deficiency, even though urea was surface applied at recommended rates.*

   d. *Surface applied chemicals were found deep in the soil profile, even though they were applied to a dry surface and not incorporated.*

   e. *Agrichemicals are detected in off-site drainage ditches and tile lines.*

f. *High fecal coliform levels are detected in agricultural runoff during February and March.*

g. *Plant emergence and growth are slow in depressions left by wheel tracks from chemical application equipment.*

Impacts of climatic conditions

1. *Transport by water*
2. *Volatilization*
3. *Wetting and drying*
4. *Atmospheric pressure and wind movement*
5. *Drift of material*
6. *Frozen and snow covered soil surfaces*

Climatic Conditions or Effects	**Environmental Impacts**
Transport by water	*d,e,f,g*
Volatilization	*a, b, c*
Wetting and drying	*d, g*
Atmospheric pressure and wind movement	*a, b*
Drift of material	*a, b*
Frozen and snow covered soil surfaces	*e, f*

Student Activity 3

1. List a tool or instrument for measuring each of the following weather forces:

   - *Water—rain gauge*
   - *Temperature—thermometer*
   - *Wind—anemometer or hand-held wind meter*
   - *Atmospheric pressure—barometer*
   - *Solar radiation—pyranometer*

Student Activity 4

1. List two sources of near term weather data.

   - *Television weather reports*
   - *On-line*
   - *National Weather Service reports*
   - *Newspapers*
   - *Internet*

2. List two sources of historic climate or evapotranspiration data.

   - *NOAA climate data*
   - *State climatologist*
   - *NRCS climate data access facility*
   - *NRCS state irrigation guides*
   - *Extension Service bulletins*

Student Activity 5

1. Explain the importance of using climate data to plan nutrient and pest management.

   Climate data can: a) help determine minimum length of storage time needed for animal waste management systems; b) be used to determine storage volume requirements for animal waste management systems; c) give general windows of opportunity for animal waste application; d) give guidance for design of irrigation systems; e) in the near term, provide information on probability of rainfall events that may cause runoff or leaching of agrichemicals; f) predict conditions that may cause odors from the spreading of animal manure to create a nuisance to neighbors.

Student Activity 6

1. List three primary ways to reduce the potential for pollution to occur.

   - *Minimizing availability of the pollutant in the environment*
   - *Minimizing the detachment of the contaminant compound*
   - *Minimizing the transport of the contaminant substance*

Student Activity 7

1. How much water will be held in 4.0 feet of fine sand loam soil, using the average per foot available water capacity (WHC)?

   The average for a fine sandy loam soil is 1.7 inches per foot of depth.

   Total WHC = 1.7 in/ft x 4.0 feet = 6.8 inches

Student Activity 8

1. How much nitrogen is supplied by the irrigation water knowing there is 12 ppm N and 30 inches per acre of water is applied during the growing season?

   Known: 1 ppm = 0.23 lb/ac of N with each inch of water applied (2.72 lb/ac-ft/12 in/ac-ft)

   Pounds per acre per inch applied = 12 ppm x 0.23 lb/ac/inch/ppm = 2.76 lb/ac/inch

   Nitrogen pounds per acre = 2.76 lb/ac/in x 30 inches = 82.8 lb/ac.

Student Activity 9

1. Explain what evapotranspiration is and how it is used in scheduling irrigations.

   Evapotranspiration consists of two parts, Evaporation (E) and Transpiration (T). Evaporation is loss of water from the soil surface as it changes from liquid to vapor, while transpiration is the process of water vapor loss through microscopic openings on the underside of leaves. The combined ET expression is used in the determination of how much water is depleted from the soil profile and in need of replacement by irrigation.

Student Activity 10

1. What is the gross irrigation requirement in acre-inches (ac-in) when 3 inches needs to be replaced by an irrigation system 60 percent efficient?

   Gross Depth = Net Depth (3 inches) / Efficiency (0.60) = 5 inches

Student Activity 11

1. List two methods that could be used in semi-humid areas to reduce irrigation needs and reduce potential water quality problems from irrigation application

   Any two of the following:

   - *Maximizing effective rainfall.*
   - *Deficit or partial season irrigation.*
   - *Selection of crops with low water requirements during normal high water use periods; that is small grains, (or accept the risk of drought periods).*
   - *Selection of drought resistant crops and varieties that provide yields based on water availability, that is alfalfa hay, grass pasture (accept the reduced yields caused by drought periods).*
   - *Irrigate just before critical growth period(s) of the crop to minimize critical plant moisture stress during those periods.*
   - *Use state-of-art irrigation scheduling techniques that use local area climate and onsite rainfall data, and field-by-field soil moisture status monitoring.*
   - *Use tillage practices that allow maximum surface storage and infiltration of rainfall events, reducing runoff and soil surface evaporation.*

- *Follow an intensive crop residue management and mulch program and minimize tillage to reduce soil surface evaporation.*
- *Reduce irrigated acreage to that which can be adequately irrigated with the available water supply.*

Student Activity 12

1. List two reasons why drainage is important to crop production.
   - *To allow free exchange of air between the pore spaces in the soil root zone and the atmosphere.*
   - *To control excess salinity in the crop root zone.*
   - *To prevent saturated conditions.*

2. List four alternatives for disposing of drainage effluent.
   - *Discharge into salt sinks (ocean, salt basins, underground saline aquifers)*
   - *Discharge into a waste disposal operation*
   - *Reuse on cropland by irrigating high salt-tolerant plants*
   - *Discharge into an on-farm evaporation pond*
   - *Reclaim salt(s) for use in the United States salt market (livestock feed, food processing for human consumption, industrial)*

Student Activity 13

1. Describe how nitrogen, phosphorus, and carbon can be influenced by soil moisture status.

   Soil mositure status determines the reduction-oxidation potential in the soil. A change in redox potential will alter the chemical form of many plant nutrient including nitrogen, phosphorus, and carbon.

   Nitrogen—When sufficient oxygen is present in the soil, nitrogen will transform to the nitrate nitrogen (NO_3) form. If oxygen is limited the soil microbes will use the oxygen contained in the nitrate and convert the compound to atmospheric nitrogen (N_2).

   Phosphorus—The redox potential will determine if phosphorus is in a soluble or insoluble form. Under saturated conditions reduction will occur favoring the conversion of highly adsorbed, insoluble forms of phosphorus to soluble forms of phosphorus (ferric phosphate to ferrous phosphate). Redox potentials usually only affect iron or manganese phosphates. Calcium phosphates would not be affected by redox because Ca will not be reduced. However, under reducing conditions there is also a tendenacy for the pH to go to neutrality, that is pH about 7. Under these conditions the solubility of calcium phosphate will increase just because of the change in pH. For most calcium phosphate minerals the solubility changes 100 fold with each unit pH change, so even a relativily small pH change has a large affect on solubility.

   Carbon—Soil carbon. If oxygen is available in the soil, carbon will be released to the atmosphere as carbon dioxide (CO_2) a product of microbial respiration. Limited oxygen in the soil produces methane (CH_4) as a result of microbial by-products.

Module 5—Natural Resource Planning for Nutrient and Pest Management

Instructions to the Student

You should view the Nutrient Management Planning video at this time. Upon completion of the video, continue your study in the Student Guide.

Overall Learning Objective

Upon completion of this module, participants will be able to identify major resource concerns related to nutrient and pest management to address in a conservation plan.

Introduction

Natural resource planning involves more than simply managing individual resources. Our customer's needs have changed. Producers are faced with the dual challenge of producing an abundance of food and fiber and being good environmental stewards of the land they use.

Resource protection objectives have changed. Ecosystem integrity cannot be assured when the focus is solely on a single resource concern or a single field unit. A broad, integrated, holistic approach to conservation planning is critical, whether it is a basic conservation plan with one or more individuals or an area-wide conservation plan for a watershed or other large geographic area.

Natural resource conservation planning fosters development of conservation plans on a watershed and ecosystem basis and forms a complementary mechanism to apply conservation practices on individual land units. The goal of planning is one comprehensive conservation plan per farm that addresses the producer's objectives, the ecosystem needs, and Federal, State, and local natural resource requirements.

Natural resource planners can use the National Planning Procedures Handbook, Field Office Technical Guide, and an ecosystem approach to identify and assemble conservation practices into various resource management systems. Specific conservation practices will often be identified as essential components. Planning areas under intense agricultural production will require some level of nutrient and pest management. To assure adequate resource protection, an appropriate level of nutrient and pest management must be determined based on the vulnerability of the area and the likeliness of resource impacts. This module will cover planning considerations important for identifying major water quality resource concerns, that should be addressed in a resource management system (RMS) Plan.

This module is separated into four major parts. Parts A through C cover materials common to both nutrient and pest management. Part D, Sections 1 and 2, are specific to nutrient management environmental risk. Part D, Sections 3 through 14 are specific to pest management environmental risk.

Module 5, Part A—Guidance Documents and Planning Approaches

Supporting Objective

- List the sections of the *Field Office Technical Guide (FOTG)* and the planning steps of the *NRCS National Planning Procedures Handbook (NPPH)* that are applicable to nutrient and pest management.
- Describe a resource management system (RMS).
- List the three primary human considerations and explain why they are important in conservation planning.

Introduction

This Part of Module 5 includes an explanation of the planning approaches and reference documents that NRCS uses. It is provided to connect the planning process to the development of nutrient and pest management components of an overall conservation plan. It should be especially valuable for those that may not be familiar with NRCS planning process and reference documents. If you are familiar with the NRCS planning process you should review the materials only as necessary to complete the Student Activities.

The *NRCS National Planning Procedures Handbook (NPPH)* explains in some detail the planning process that NRCS has used and modified over the past 60 plus years of its history. The *Field Office Technical Guide (FOTG)* is the repository of technical information that forms the basis for what NRCS does. Other documents and tools are also available, but will not be discussed here.

NRCS National Planning Procedures Handbook

The NPPH provides guidance and specifications on implementing NRCS planning policy, including relationships to the FOTG. The NPPH is designed to guide the planner in working with clients toward the development, implementation, and evaluation of resource plans; both individual conservation and area-wide plans. The handbook is to be used as a training tool for inexperienced employees and as a reference tool for experienced employees.

As described in the NPPH, nine planning steps are used during the planning process. These planning steps provide guidance on planning conservation assistance. Figure 5.1 illustrates the planning process. Although the nine steps are shown in sequence, the process is dynamic. The process could start with any of the first three steps or even step nine. Cycling back to previous steps is often necessary. For example, step one and two may not be finalized until step four is completed. Also some planning activities may overlap planning steps. The planning steps and their relationship to nutrient and pest management in both individual and area-wide conservation plans are briefly described in table 5.1.

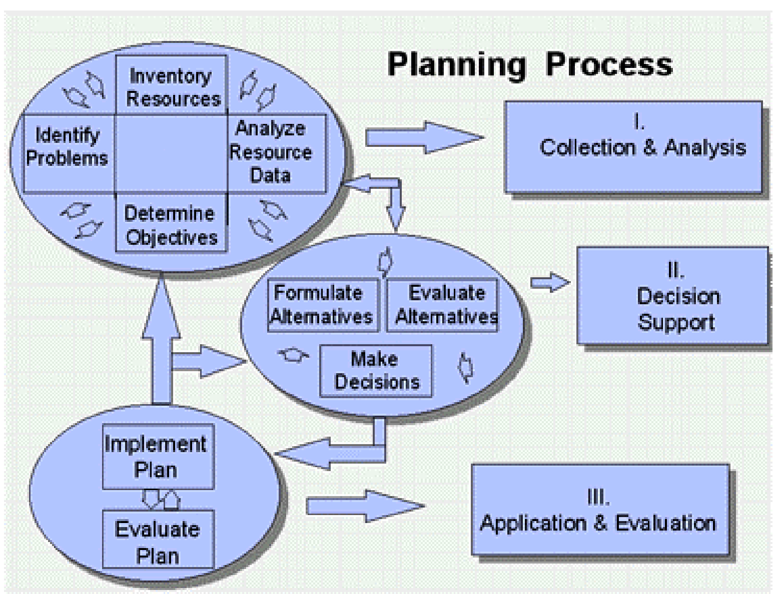


Figure 5.1 NRCS three-phase, nine-step planning process.

Table 5.1 NRCS National Planning Procedures Handbook planning steps and their relationship to nutrient and pest management.

Planning Step	Individual Conservation Plan	Area-wide or Watershed Conservation Plan
Phase I–Collection and Analysis		
Step 1–Identify problems	Nutrient and pest management inputs are not optimized; leaching or runoff of nutrients or pesticides is occurring; economic returns are negatively impacted.	Nutrients and/or pesticides are detected in ground and/or surface water. This is especially important if public water systems are impacted and if concentrations are at or approaching levels of concern established by state water quality standards.
Step 2–Determine objectives	Client wants to improve economic return by optimizing nutrient and pest management to reduce inputs, minimize chemical losses, and protect the environment.	Conservation district or other sponsor wants to develop a watershed plan that addresses specific resource problems and important nutrient and pest management considerations.
Step 3–Inventory resources	Client' s resources are inventoried; problems and opportunities are defined; on and off-site conditions are considered (important records include crop rotation, nutrient and pesticide use, soil test results).	Watershed resources are inventoried; problems and opportunities are defined; off-site and on-site conditions are considered.
Step 4–Analyze resource data	Analyze resource data to clearly define the resource problems, including unacceptable nutrient and pesticide losses.	Analyze resource data to clearly define the resource problems and critical areas where unacceptable nutrient and pesticide losses are occurring.
Phase II–Decision Support		
Step 5–Formulate alternatives	Develop conservation plan alternatives, which include nutrient and pest management components that are compatible with the clients operation.	Develop conservation system and nutrient and pest management alternatives that address watershed resource goals.

Table 5.1 NRCS National Planning Procedures Handbook planning steps and their relationship to nutrient and pest management, continued.

Planning Step	Individual Conservation Plan	Area-wide or Watershed Conservation Plan
Phase II–Decision Support		
Step 6–Evaluate alternatives	Determine the effectiveness of the conservation plan alternatives, which include the nutrient and pest management components for addressing the client' s objectives and identified resource problems.	Quantify the effects of each alternative towards meeting the watershed resource goals; incorporate social and economic considerations; identify implementation and funding opportunities.
Step 7–Make decision	Client selects an alternative and application or follow-up assistance is scheduled.	Sponsor, with public input, selects an alternative
Phase III–Application		
Step 8–Implement plan	Selected alternative is implemented. Technical assistance is provided to help the client implement appropriate levels of nutrient and pest management.	Selected alternative is implemented; an implementation schedule is developed; and individual conservation plans (including nutrient and pest management components) are developed as necessary to help implement appropriate levels of nutrient and pest management within the watershed.
Step 9–Evaluate plan	Meet with client and evaluate the plan; determine if the plan is adequately accomplishing the client' s objectives and adjust as necessary; develop case study if useful and integrate important information into guidance documents to help facilitate future planning efforts with others in similar resource settings. This step is essential for nutrient and pest management components, which are extremely dynamic. Use this step to identify opportunities for improvement.	Evaluate the results of the watershed plan for correcting resource problems and meeting the plan objectives and in reducing nutrient and pesticide losses within the watershed to desired levels necessary to protect identified uses.

Field Office Technical Guide

The FOTG was reorganized with the issuance of GM 450, Part 401, dated February 12, 1990. This did not change the NRCS planning process, but did state more clearly the objectives and new direction of the agency. NRCS is focused on natural resource conservation planning, which will help customers address their resource concerns and those of the public in general.

Reorganization of the FOTG in 1990 did not change the number of sections (5). Some sections are the same as before, others have changed significantly. The FOTG contains Quality Criteria, Standards and Specifications, Guidelines and Guidance Documents, and Effects information that will be used and followed as planners do conservation planning and application.

The five sections of FOTG and their relationship to nutrient and pest management are briefly described in table 5-2.

Table 5.2 NRCS Field Office Technical Guide sections and their relationship to nutrient and pest management.

Section	Purpose	Relationship to Nutrient and Pest Management
Section I 1) Reference list 2) Cost data 3) Maps 4) Erosion prediction 5) Climatic data 6) Cultural resources 7) Threatened and endangered species 8) Laws 9) Water quality	References and other information for use in understanding the field office working area and in making decisions about resource use and management systems.	References to: Fertilizer and Pest Handbooks University Fertilizer Guides Industry Databases IPM Circulars Nonpoint Source Management Plan State Water Quality Standards Ground Water Protection Plan Ag Water Quality Protection Plans
Section II 1) Soil legends 2) Soil descriptions 3) Detailed soil interpretations	Current information on soils and their basic interpretations tailored to individual soil survey areas. The National Soil Information System (NASIS) contains all soil survey data.	Soil and site interpretations on cropland and water quality. Soil-pesticide/ nutrient interaction ratings, which would indicate the potential for percolating water to carry soluble contaminants to ground water or for surface runoff to carry soluble and attached contaminants to a receiving surface water body.

Table 5.2 NRCS Field Office Technical Guide sections and their relationship to nutrient and pest management, continued.

Section	Purpose	Relationship to Nutrient and Pest Management
Section III Quality Criteria for major resources: • Soil • Water • Air • Plants • Animals	Provides guidance for developing Resource Management Systems for field office work areas to prevent or treat problems and take advantage of resource opportunities. Establishes minimum treatment levels necessary to adequately address the resource concerns identified during the planning process.	Quality criteria (targets) for nutrients and pesticides in ground and surface water along with tools (indicators) that can be used to evaluate the quality criteria. These tools only provide estimates of resource conditions. They should always be used with common sense and professional judgment. Indicators of nutrient/pesticide concentrations and target values of water quality standards/criteria are used to express quality criteria for water quality related to nutrients and pesticides.
Guidance documents	Description of the resource setting, problems, and alternatives for Common Resource Areas.	Guidance documents may include nutrient and pest management components in the conservation plan alternatives. Specific nutrient and pest management guidance important within the Common Resource Area should be included.
Section IV Practice standards	Contains official names, definitions, criteria, and guides to specifications for the practices used in resource conservation planning.	Standards for nutrient and pest management are included in this section.
Section V 1) Effects for RMS formulation	Effects of the benchmark and RMS alternatives for each corresponding guidance document.	Quantitative or qualitative effects of nutrient and pest management activities in the benchmark and RMS alternative.
2) Conservation effects for decisionmaking 3) Procedural references	The Conservation Practice Physical Effects (CPPE) matrix is contained in this section. The CPPE provides guidance on the expected effects of conservation practices on the identified problems. It assists in selecting practices that will meet the quality criteria when installed.	At the basic level the CPPE will provide guidance on the expected effects of conservation practices including nutrient and pest management on the identified resource problems. The CPPE should be refined at the field office level as necessary to specify expected effects within the local field office area.

What is a Resource Management System?

A resource management system is a combination of structural, vegetative and management practices that:

- when planned, will at a minimum meet established quality criteria levels for all resources, and;
- when installed, will provide for the conservation, wise use, and protection of the resource base for soil, water, air, plant, and animal resources.

Human Considerations

As planners we need to look at more than just the five natural resources: Soil, Water, Air, Plants, and Animals (SWAPA). We must also address Human considerations (SWAPA+H). These Human considerations have a significant impact on the way land users choose to adopt and apply conservation practices. Decisionmaker perceptions of the resource problem and solutions (i.e. conservation practices/systems) as influenced by cultural values and social and economic limitations must be considered to complete the resource management system (RMS) planning process. Without this consideration the planning process will likely never be complete, and important conservation practices will not be implemented.

Resource management systems (RMS) should not be developed solely on the basis of technical resource criteria. Farmers, ranchers, and other land users decide whether to adopt conservation practices or systems based on a number of reasons. These may include: how they perceive the RMS will meet their needs, fit their operation, maintain their economic viability, and give them expected results; and whether or not they are consistent with local cultural values and meet society's expectations (including those required by law, as well as desired expectations).

The challenge of conservation planning is to formulate an RMS option that:

- The client believes is in their best interest to apply and maintain. This is critical because people only change their behavior if they believe it to be in their best interest. If an RMS cannot be developed such that the landowner believes it is in their best interest, incentives, regulations, laws, etc. will, at best, only result in temporary changes.
- Prevents resource degradation or improves the resource and permits sustainability;
- Meets agricultural related regulatory requirements; and
- Adequately addresses economic, social, and cultural considerations.

Therefore, the Human Consideration must address economic, social and cultural interest.

Integrating the planning process described in the NPPH, the technical information contained in the FOTG and a planning approach that uses additional resource evaluation tools, procedures, and partnerships is essential for the success of any conservation plan.

Resource concerns beyond just water must be considered with the use of nutrient and pesticides. The denitrification of commercial fertilizers and animal manure releases nitrous oxide (N_2O) potentially contributing to ozone related problems. Odors are associated with the storage and use of manure. Chemical drift from pesticide applications can impact non-target species including humans living downwind. Impacts also vary depending on current conditions and form of nutrient or pest management selected.

Effects of nutrient management differ if the land user is beginning with a nutrient deficiency or a surplus. For example, adding nutrients to solve a deficiency problem may have a positive effect on plant growth but increase the potential for ground water contamination if nutrient leaching should occur below the crop root zone. Conversely, if soil nutrients are in surplus, reducing application to meet agronomic needs would reduce potential leaching losses.

Pest management creates similar situations. Controlling weeds via cultivation instead of by herbicide use reduces the risk of chemical contamination but may increase risk of erosion. Some alternatives to reduce either nutrient or pesticide risks require use of expensive equipment that may not be economically feasible for some land users. Conflict at the interface of agriculture and urban lands might make even the applications of environmentally safe applications of chemicals socially unacceptable.

The possible tradeoffs are not limited to natural resource concerns; they can also involve economic, social, and cultural concerns as well. See sidebar Economic, Social and Cultural realities on the Fort Hall Indian Reservation.

Economic, Social and Cultural realities on the Fort Hall Indian Reservation

A Case Study video "Nutrient and Pest Management on the Fort Hall Indian Reservation" will be presented in Module 7. In addition, some further discussion of the Fort Hall Indian Reservation will be provided later in the Pest Management portion of Module 5. The Fort Hall Indian Reservation is home to the Shoshone-Bannock Tribes. Here is an agronomic setting where the intense crop rotation of potatoes every other year has long been recognized as a primary contributor to much of the nutrient and pesticide related ground water quality problems that currently exist on the Reservation. A large part of the technical solution would be to change the current predominant crop rotation and reduce the frequency of potatoes in the rotation, thereby greatly reducing the amount of nutrients and pesticides used. However, the economic, social, and cultural perceptions of the situation on the Reservation currently do not make this sort of change possible. Remember RMS are not judged and chosen solely on the basis of technical resource criteria. The majority of farming on the Reservation is by Non-Tribal members. These farmers lease the farmland from the Tribes, and the highest lease rate is received when potatoes are grown. The economy of the Tribes is highly dependent on this lease income. Because of this, potatoes are grown as frequently as possible.

Further complicating this issue are the social and cultural values facing the Tribes. When the Reservation was established, the United States Department of Interior Bureau of Indian Affairs (BIA) expected the Tribes to become farmers and ranchers, and to use the land accordingly. This was completely contrary to Tribal belief. Today only a handful of Tribal members farm on the Reservation even though approximately 150,000 acres of the 544,000 acres is farmland. Past expectations and direction by the government have resulted in large tracts of cropland in ground water vulnerable areas on the Reservation that follow an intense rotation of potatoes every other year. This still takes place today even though severe ground water contamination exists. Turning it around and correcting it will take time and will require innovative solutions.

Important events and cooperative assistance to the Shoshone-Bannock Tribes:

1991 Fort Hall Indian Reservation Ground Water Quality Preliminary Investigation

1991 Ground Water Contaminant Monitoring Study (NRCS National Headquarters Funding to construct monitoring wells and conduct ground water quality monitoring)

1992 Idaho Cooperative River Basin Study—Fort Hall Ground Water Quality Project

1993 Fort Hall Water Quality Project, Eastern Snake River Plain Aquifer—USDA Water Quality Incentive Project

1993 Fort Hall Water Quality Project, Eastern Snake River Plain Aquifer—EPA Pollution Prevention

1994 Soils Investigation of the Fort Hall Indian Reservation: Zone 1 of the Fort Hall River Basin Study

1994 EPA Region 10 issued Emergency Administrative Order under the Safe Drinking Water Act as a result of the presence of Ethylene Dibromide (EDB) above the MCL of 0.05 ppb in two pubic supply wells on the Reservation. Item "16" of the Order required the development of "...plans and schedules to implement Best Management Practices (BMPs) for agricultural fertilizers and pesticides to ensure that future ground water contamination is prevented." Because of ongoing work, this requirement was immediately satisfied after discussions with EPA.

1997 Fort Hall National Agricultural Pesticide Risk Analysis (NAPRA) identified 1,3-Dichloropropene and Metam-Sodium as potential pesticides of concern

1998 Public Community Pesticide Outreach Project—"A Shoshone-Bannock Project to Achieve Congruency Between Tribal Values and Pesticide Pollution Prevention Strategies" (EPA Tribal Pesticide Special Project funding)

1999 Fate and Transport Study of Telone and Vapam - "Monitoring Movement of 1,3-Dichloropropene (Telone II) and Metam-Sodium (Vapam) Through the Soil Profile, Fort Hall Indian Reservation, Southeastern Idaho" (EPA Tribal Pesticide Special Project funding) 2000 Proposed field project - "Soil Sampling for Identifying Pest Infestations and Treatment Strategies on the Fort Hall Indian Reservation, Southeastern Idaho - An Integrated Pest Management Approach" (Pending funding)

2000 NRCS District Conservationist assigned to the Reservation

As resource planners we should help our clients develop solutions that make full use of technology, however, sometimes the best technology may either not be economically feasible, socially acceptable, or alone will not fully prevent a resource problem. In those instances we must work to help everyone involved better understand how the land is currently being used, the potential consequences of that use, and viable opportunities for improved management, and change if necessary. Certain areas, like the Fort Hall Indian Reservation, may require intense efforts over many years to fully realize Conservation Planning goals.

The planner must be aware of the science and local perceptions of nutrient and pest management technology. The FOTG contains references and the NPPH outlines a process to assist the planner to formulate an RMS option that:

- the client believes is in their best interest to apply and maintain
- prevents resource degradation or improves the resource and permits sustainability
- meets related regulatory requirements
- adequately addresses economic, social, and cultural considerations

Conservation Practice Physical Effects (CPPE)

As previously described in Section V of the FOTG, the Conservation Practices Physical Effects (CPPE) matrix can provide a basic indication of the effect of a conservation practice on resource concerns. The CPPE matrix is designed to be modified and customized at the local level to better reflect expected effects. The following CPPE matrixes for nutrient and pest management are generic, but provide an example of how they are designed to work. Both nutrient and pest management are unique in that they typically encompass a system of practices that are essential for achieving an RMS level of resource protection. Because of this the physical effects presented in the CPPE matrix will differ from one situation to another.

CONSERVATION PRACTICE PHYSICAL EFFECT WORKSHEET

	PRACTICE: **590 Nutrient Management**	PRACTICE: 595 Pest Management
RESOURCE INDICATORS	**PHYSICAL EFFECTS**	**PHYSICAL EFFECTS**
RESOURCE CONCERN: SOIL EROSION		
SHEET AND RILL	slight reduction in sheet and rill erosion	situational concerning sheet and rill erosion
WIND	slight reduction in wind erosion	situational concerning wind erosion
EPHEMERAL GULLY	slight reduction in ephemeral gully erosion	situational concerning ephemeral gullies
CLASSIC GULLY	slight reduction in classic gully erosion	situational concerning classic gullies
STREAMBANK	N/A	N/A
IRRIGATION INDUCED	N/A	situational concerning irrigation induced eros
SOIL MASS MOVEMENT	N/A	N/A
ROADBANK/CONSTRUCTION	moderate decrease in roadbank construction ero	N/A
RESOURCE CONCERN: SOIL CONDITION		
SOIL TILTH	slight improvement in soil tilth	N/A
SOIL COMPACTION	N/A	N/A
SOIL CONTAMINATION		
• SALTS	situational concerning contam. from salts	N/A
• ORGANICS	situational concerning organic contaminates/soil	N/A
• FERTILIZERS	facilitating	N/A
• PESTICIDES	facilitating	significant reduction in pesticide contam./soil
DEPOSITION/DAMAGE		
• ONSITE	facilitating	N/A
• OFFSITE	facilitating	N/A
DEPOSITION/SAFETY		
• ONSITE	facilitating	N/A
• OFFSITE	facilitating	N/A
RESOURCE CONCERN: WATER QUANTITY		
SEEPS	insignificant	N/A
RUNOFF/FLOODING	slight decrease in runoff/flooding	N/A
EXCESS SUBSURFACE WATER	significant reduction in excess subsurface water	N/A
INADEQUATE OUTLETS	N/A	N/A
WATER MGT. IRRIGATION		
• SURFACE	N/A	slight improvement in irrigation efficiency
• SPRINKLER	N/A	slight improvement in irrigation efficiency
WATER MGT. NON-IRRIGATED	slight improvement in moisture use	slight improvement in moisture use
RESTRICTED FLOW CAPACITY (H20 convey.)		
• ONSITE	slight improvement in onsite drainage	N/A
• OFFSITE	slight improvement in offsite drainage	N/A
RESTRICTED STORAGE	slight reduction in sedimentation of H20 storage	N/A
RESOURCE CONCERN: WATER QUALITY		
GROUNDWATER CONTAMINANTS		
• PESTICIDES	slight reduction GWater contam./pesticides	sign. reduction GWater contam/pesticides
• NUTRIENTS AND ORGANICS	sign poten. decrease/GWater contam./nutr,organ	slight reduction GWater contam/nutr,organ
• SALINITY	slight poten.decrease/GWater contam./salinity	N/A
• HEAVY METALS	slight poten. decrease/GWater contam./heavy m	N/A
• PATHOGENS	slight poten. decrease/GWater contam./pathegen	N/A
SURFACE WATER CONTAMINANTS		
• PESTICIDES	facilitating	sign. reduction in SWater contam/pesticides
• NUTRIENTS AND ORGANICS	sign. reduction in SWater contam./nutri.,organic	facilitating
• SUSPENDED SEDIMENTS	facilitating	N/A
• LOW DISSOLVED OXYGEN	sign. reduction in SWater contam./low oxygen	N/A
• SALINITY	slight reduction in SWater contam./salinity	N/A
• HEAVY METALS	slight reduction in SWater contam./heavy metals	N/A
• WATER TEMPERATURE	N/A	N/A
• PATHOGENS	facilitating	N/A
AQUATIC HABITAT SUITABILITY	moderate inprovement in Aqua. Hab. Suit.	moderate inprovement in Aqua. Hab. Suit.
RESOURCE CONCERN: AIR QUALITY		
AIRBORNE SEDIMENT AND SMOKE PARTICLES		
• ONSITE SAFETY	N/A	N/A
• OFFSITE SAFETY	N/A	N/A
• ONSITE STRUCT. PROBLEMS	N/A	N/A
• OFFSITE STRUCT. PROBLEMS	N/A	N/A
• ONSITE HEALTH	N/A	N/A
• OFFSITE HEALTH	N/A	N/A

AIRBORNE SEDIMENT CAUSING CONVEYANCE PROBLEMS	N/A	N/A
AIRBORNE CHEMICAL DRIFT	situational	situational
AIRBORNE ODORS	situational	situational
FUNGI, MOLDS, AND POLLEN	N/A	N/A
RESOURCE CONCERN AIR CONDITION		
AIR TEMPERATURE	N/A	N/A
AIR MOVEMENT (windbreak effect)	N/A	N/A
HUMIDITY	N/A	N/A
RESOURCE CONCERN PLANT SUITABILITY		
SITE ADAPTATION	N/A	N/A
PLANT USE	N/A	N/A
RESOURCE CONCERN PLANT CONDITION		
PRODUCTIVITY	sign. improvement in plant cond./ productivity	sign. improvement in plant cond./ productivit
HEALTH, VIGOR, SURVIVAL	sign. improvement in plant health,vigor, survival	sign. improvement in plant health,vigor, survi
RESOURCE CONCERN PLANT MANAGEMENT		
ESTAB., GROWTH, HARVEST	sign. improvement in plant estab.,growth,harves	sign. improvement in plant estab.,growth,harv
NUTRIENT MANAGEMENT	sign. improvement in plant nutrient management	N/A
PESTS	slight improvement in plant pest management	sign. improvement in plant pest management
THREAT/ENDANGERED PLANTS	slight benefit to threat/endangered plants	slight benefit to threat/endangered plants
RESOURCE CONCERN ANIMAL HABITAT		
FOOD	slight improvement in animal habitat/food suppl	slight improvement in animal habitat/food sup
COVER/SHELTER	slight improvement in animal habitat/cover,shelt	slight improvement in animal habitat/cover,sh
WATER (QUANTITY & QUALITY)	sign. improvement in animal habitat/water\	sign. improvement in animal habitat/water\
RESOURCE CONCERN ANIMAL MANAGEMENT		
POPULATION BALANCE	slight improvement in animal mgt./pop. balance	slight improvement in animal mgt./pop. balan
THREAT/ENDANGERED ANIMALS	slight benefit to threat./endangered animals	slight benefit to threat./endangered animals
HEALTH	slight improvement in animal mgt./health	slight improvement in animal mgt./health
RESOURCE CONCERN ECONOMIC CONSIDERATIONS		
PLAN / COST EFFECTIVENESS	moderately cost effective	moderately cost effective
CLIENT FINANCIAL CONDITION	situational concerning client financial cond.	situational concerning client financial cond.
MARKETS FOR PRODUCTS	slightly improve market potential	slightly improve market potential
AVAILABLE LABOR	slight increase in labor requirement	slight increase in labor requirement
AVAILABLE EQUIPMENT	moderate increase in equip. needed	moderate increase in equip. needed
RESOURCE CONCERN SOCIAL CONSIDERATIONS		
PUBLIC HEALTH AND SAFETY	mod. improvement in public health safety	mod. improvement in public health safety
PRIVATE/PUBLIC VALUES	situational regarding private/public values	situational regarding private/public values
CLIENT CHARACTERISTICS	situational regarding client characteristics	situational regarding client characteristics
RISK TOLERANCE	slight risk involved	moderate risk involved
TENURE	situational regarding tenure	situational regarding tenure
RESOURCE CONCERN CULTURAL CONSIDERATIONS		
ABSENCE/PRESENCE OF CULTURAL RESOURCES	situational regarding cultural resources	situational regarding cultural resources
SIGNIFICANCE OF CULTURAL RESOURCES	situational regarding cultural resources	situational regarding cultural resources
MITIGATION OF NEGATIVE CULTURAL RES. IMPACTS	situational regarding cultural resources	situational regarding cultural resources

Student Activity 1

1. List the three primary human considerations and explain why they are important in conservation planning.

2. Which sections of the Field Office Technical Guide and the National Planning Procedures Handbook are applicable to nutrient and pest management?

3. Describe a resource management system (RMS).

Module 5, Part B—Environmental Concerns Related to Nutrient and Pest Management

Supporting Objective

- State the goal of the Clean Water Act.
- Describe water quality standards as authorized under Section 303(c) of the Clean Water Act.
- Define use as it applies to water quality standards established under the Clean Water Act.
- Define water quality criteria.
- List five common uses identified in State water quality standards.
- List two potential environmental problems associated with excess nutrients and pesticides and their relationship to the uses of the water.
- Explain how water quality standards should be considered when formulating nutrient and pest management components of a conservation plan.

Introduction

One of the primary concerns related to nutrient and pest management is existing or potential water quality effects on human health. Lack of proper nutrient and pest management can degrade water quality as well as other resource concerns. Sometimes what might seem to be proper use of nutrients and pesticides can have unintended results in the environment. This section will focus on State water quality standards and how they relate to nutrient and pest management.

The Clean Water Act (CWA) is a 1977 amendment to the Federal Water Pollution Control Act of 1972, which set the basic structure for regulating discharges of pollutants to waters of the United States. The objective of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters... and it is a national goal that wherever attainable, an interim goal of water quality which provides for the protection and propagation of fish, shellfish and wildlife, and provides for recreation in and on the water be achieved by July 1, 1983..." This is referred to as the "fishable/swimmable" goal of the CWA. Section 303(c) authorizes States to develop and implement water quality standards, which measure the attainment of the "fishable/swimmable" goal. The Act states that waters shall be protected through designated beneficial uses and setting criteria to protect those uses.

Water quality standards are laws or regulations that States and Tribes adopt to enhance water quality and protect human health. Water quality standards consist of three components:

- the designated beneficial use or uses of a waterbody or segment of a waterbody
- the water quality criteria necessary to protect the use or uses of that waterbody
- an antidegradation policy

When establishing water quality standards, each State must designate uses for each waterbody (the goals), and adopt water quality criteria to protect the designated uses. Designated beneficial uses may include such things as Drinking Water Supply, Coldwater Biota, Salmonid Spawning, and Primary Contact Recreation. Criteria to protect these uses may include such things as a narrative sediment standard to protect coldwater biota and salmonid spawning uses, a numeric bacteria standard to protect Primary Contact Recreation (swimming). The use and water quality criteria component of water quality standards will be the primary topic discussed in this section. For a more detailed discussion of water quality standards, refer to Module 7, Water Quality Standards, of the NEDC Introduction to Water Quality training program.

Although the primary focus of the Clean Water Act is intended for surface water, water quality standards often include a ground water section. Many States have also established comprehensive ground water protection plans, which require that wherever attainable, ground water quality of the state shall be protected for beneficial uses.

Water Quality Standards and Nutrient and Pest Management

Uses

Several terms are used to describe the uses of the waters of the nation and individual States. Some of those include designated use, beneficial use, and appropriate beneficial use. Whatever the terminology may be, the uses as it applies to water resources is the formal use or goal for which each waterbody is designated. Uses as they relate to ground water are not included in the requirements under the CWA, however, they are typically referred to in a less specific way in Federal and State ground water quality laws and regulations. Ground water uses most commonly default to domestic water supply or drinking water. These uses require a high level of protection because of public health concerns. Where ground water discharges to surface waters with sensitive uses (aquaculture, fisheries, aesthetics, etc.), it may be extremely important to protect the ground water supply from contamination at levels that are even more protective than what would otherwise be adequate for drinking or domestic purposes. Although ground water uses are typically not treated in the same context as surface water uses, they are nonetheless important to consider, especially when determining appropriate levels of protection for the corresponding ground water resource. Ground water uses, surface water uses and the interconnection between ground water and surface water should be considered when determining Best Management Practices (BMPs), land treatment, and appropriate levels of nutrient and pest management. This is especially important for critical land units that have a greater potential to negatively impact a receiving waterbody. For these reasons, ground water uses are also included in the following discussion.

In addition to the above water quality related approach, uses can also have a unique definition relating to water quantity, specifically beneficial uses associated with water rights. Water quality use designations will often cover a broader range than what may currently be designated through uses associated with water quantity or water rights. For example, water quality uses must often address areas such as aquatic life or recreation (such as swimming or boating), even when the specified water body has no such designated uses associated with water rights.

Water quality related uses of water resources differ somewhat from one state to another, however they typically include, but are not limited to those listed in table 5.3.

Table 5.3 Typical uses for water resources.

Water Supply	Example
Agricultural (ground and surface water)	Irrigation of crops or livestock water
Domestic (ground and surface water)	Human drinking water
Industrial (ground and surface water)	Waters used for industrial purposes
Navigation	Navigable waters
Aquaculture (ground and surface water)	Fish and other aquaculture
Mining (ground and surface water)	Waters used for mining purposes
Aquatic Life	**Example**
Cold water biota	Viable communities of aquatic organisms and populations of significant aquatic species that have optimal growing temperatures below a certain water temperature (~18°C)
Warm water biota	Viable communities of aquatic organisms and populations of significant aquatic species that have optimal growing temperatures above a certain water temperature (~18°C)
Salmonid spawning	Water that provides or could provide a habitat for active self-propagating populations of salmonid fishes (trout and salmon)
Shellfish propagation	Water that provides or could provide a habitat for active self-propagating populations of shellfish (clams, crabs, and other shellfish)
Coral reef preservation	Water that provides or could provide a habitat for coral and associated biota
Recreation	**Example**
Primary contact recreation	Intimate human contact where ingestion of small quantities or water are likely (swimming or water skiing).
Secondary contact recreation	Human contact where ingestion of small quantities of water is not probable (fishing or boating).
Wildlife Habitat	**Example**
	Waters important for wildlife habitat
Aesthetics	**Example**
	Waters important for aesthetics

Agricultural Chemical Pathways

Environmental risk associated with the use of nutrients and pesticides requires a good understanding of how chemicals cycle through the environment. This section points out the complex relationships conservation planners should consider when formulating nutrient and pest management components of a conservation plan. A major focus is placed on water because it is a primary resource responsible for the movement of nutrients and pesticides, and its quality directly influences human health and the environment.

Water quality problems may result from excess nutrients and/or presence of pesticides in the environment. These problems, and their relationship to the designated use of the impacted water resource, are numerous. Some examples follow:

Excess nutrients in surface water may result in nutrient enrichment. Depending on the degree of enrichment, it may impair one or more of the uses.

Examples

- Aquatic life (loss of sensitive species) from low dissolved oxygen.
- Aesthetics from unsightly algae blooms.
- Agricultural water supply from toxins produced by blue-green algae.
- Domestic water supply from algae blooms, oxygen deficiencies, turbidity problems, foul taste, and odor to the water.

Excess nutrients in ground water may result in elevated nutrient concentrations in ground water and, depending on the nutrient and the nature of the resource setting, may impair one or more of the uses.

Examples

- Domestic water supply caused by nitrate nitrogen concentrations above 10 mg/L.
- Aquacultural water supply from elevated phosphorus concentrations.

Nitrate nitrogen concentrations in ground water are often a primary concern, especially when they occur near, at, or above the drinking water standard of 10 mg/L nitrate-nitrogen. Nitrate concentrations may also be a concern if the trend indicates increasing concentrations. In some cases surface water impairments may result from nitrogen and phosphorus concentrations in ground water that discharges to a sensitive surface water body. Note that this impairment could result from nitrate and phosphorus concentrations well below water quality standards associated with drinking water protection. That is, sensitive resources may be affected even though certain water quality standards are not exceeded. Therefore water quality standards are not always the best indicator of potential water quality impacts.

Pesticides in surface water may result in pesticide concentrations in surface water and may impair one or more of the uses.

Examples

- Aquatic life (fisheries and biota) from pesticide concentrations above the acute or chronic toxicity for species of concern.
- Agricultural water supply from pesticide concentrations above the acute or chronic toxicity for species of concern.

- Domestic water supply from pesticide concentrations above the drinking water standard.

When pesticides are detected in surface water there is also obvious concern. This is especially the case for serious health or environmental problems that can occur when pesticide concentrations in surface water exceed the human drinking water standard (Maximum Contaminant Level - MCL) or advisory (Health Advisory - HA). For aquatic life, Levels of Concern (LOC = 1/2 the LC_{50}) are often used to evaluate acute toxicity from the short term exposure of a pesticide, while the Maximum Acceptable Toxicant Concentration (MATC) is often used to evaluate chronic toxicity from the long-term exposure of a pesticide.

Pesticides in ground water, depending on the pesticide and the nature of the resource setting, may impair one or more of the uses.

Examples

- Domestic water supply from pesticide concentrations above the drinking water standard;
- Aquacultural water supply from pesticide concentrations above the acute or chronic toxicity for species of concern; or
- Agricultural water supply from pesticide concentrations above the acute or chronic toxicity for species of concern.

When pesticides are detected in ground water there is obvious concern. This is especially the case for serious health problems that can occur when pesticide concentrations in ground water exceed the human drinking water standard (MCL or HA). Pesticide concentrations may be of even greater concern if the trend indicates increasing concentrations. In some cases surface water impairments may result from pesticide concentrations in ground water that discharges to a sensitive surface waterbody.

Water Quality Criteria

Water quality criteria are limits on a particular pollutant (e.g. nitrogen or phosphorus concentrations) or limits on a condition (water temperature) of a waterbody needed to protect and support a designated use. As previously discussed, Section III of the FOTG includes the quality criteria for the five resources. For water resources, the FOTG quality criteria should relate directly to the State water quality standards criteria. Because the FOTG quality criteria section establishes the minimum treatment level necessary to adequately address the resource concerns identified during the planning process, it will meet the purpose of the State water quality standards criteria, which is to protect the designated use.

Quality criteria used in the FOTG are quantitative or qualitative statements of a treatment level required to achieve an RMS for identified resource considerations for a particular land area. They are established in accordance with local, State, and Federal programs and regulations in consideration of ecological, social, and economic effects. NRCS planning procedures suggest quality criteria be expressed using a target and an indicator. The term target value is used to express a desired future condition of a resource as measured by an indicator. Another way of looking at indicators and target values is to think of a yardstick as the indicator and the target as a point on that yardstick.

In some cases individual field offices may develop more specific quality criteria. Site-specific State water quality criteria may be developed as the need and additional information become available. State water quality standards criteria and FOTG quality criteria will be important as we begin to focus on problem areas to establish a minimum treatment level that is necessary for adequate resource protection. The greatest challenge will be in balancing environmental considerations with social and economic considerations.

The most important aspect of water quality criteria is that they establish qualitative or quantitative limits on a particular pollutant or a condition of a waterbody. These criteria thus provide us with a way of determining whether or not the quality of the water protects and supports its designated use(s).

If we look at the previous examples of water quality problems that may result from excess nutrients and/or pesticides, we can identify specific criteria that need to be met to protect and support the designated uses. Consider the previous example of excess nutrients in ground water and the impairment of the designated use of *Domestic Water Supply* because of nitrate nitrogen concentrations above 10 mg/L. The concentration of 10 mg/L nitrate nitrogen is both a State water quality criterion as it pertains to State water quality standards and a FOTG quality criterion. In the planning process the concentration of nitrate nitrogen is an *indicator* or yardstick and the value of 10 mg/L is the *target value* or point on the yardstick that we use to make judgments about what is measured. Measurements of 10 mg/L nitrate nitrogen or above mean that the designated use of Domestic Water Supply is not being supported.

In addition to the above application of standards in regards to supporting a specified use, many States may set water quality goals that are based on maintaining or improving existing surface or ground water quality, or based on levels that are more protective than the standards used by other States. Under such circumstances, the level of degradation to a waterbody could be considered unacceptable even if it is below a given standard. The standard itself might need to be set to a lower or more protective level if degradation is still considered to be unacceptable.

Special Water Resource Classifications

Occasionally certain surface or ground water resources receive a special designation. These designations are established for specific water resources based on uses and the elevated importance of the water resource. Special water resource classifications may differ from one state to another; however, they typically include, but are not limited to:

High Quality Waters are of high quality and exceed the minimum water quality level necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water. Typically this will be maintained and protected unless appropriate government agencies, based on intergovernmental coordination and public participation, determine that lower quality conditions are necessary to accommodate important economic and social development. In most cases the lower water quality condition will still be adequate to fully protect existing uses.

Outstanding Resource Waters constitute an outstanding national resource, such as waters of national parks and wildlife refuges, and waters of exceptional recreational or ecological significance. Typically these waters are protected from any adverse water quality impacts.

National Wild and Scenic Rivers Systems are river systems that because of their unique contributions to a State and to the nation have received national recognition and have been designated as Wild and Scenic.

Special Resource Waters include specific segments or bodies of water that are recognized as needing intensive protection to preserve outstanding or unique characteristics; or to maintain current uses. Special Resource Waters may include:

- Waters of outstanding high quality
- Waters of unique ecological significance

- Waters that have outstanding recreational or aesthetic qualities

- Waters where intensive protection of the quality is necessary to maintain an existing, but jeopardized designated use

- Waters where the protection of the quality is of paramount interest to the people of the State or Nation

- Waters that are part of the National Wild and Scenic River System

Sole Source Aquifers are protected under a designation established by Section 1424(e) of the Safe Drinking Water Act. This designation is applied by the U.S. Environmental Protection Agency to an aquifer considered to be the sole or principle drinking water source for a geographic area and which, if contaminated, would create significant hazard to public health.

Additional Aquifer Protection Designations are developed by many States based on uniqueness, increased importance, high level of vulnerability of a specific aquifer, and/or ground water that is already impacted.

Implementing Water Quality Standards

Assessing Water Quality and Identifying Water Quality Limited or Impaired Waterbodies

The Clean Water Act requires States to assess the quality of their waters on a regular basis. States must prepare and submit to EPA a 305(b) report once every 2 years. This report describes the quality of the States waters. Another valuable source of information regarding the quality of surface water is the States 303(d) list. Section 303(d) of the Clean Water Act requires states to identify surface waters that do not meet water quality standards, and that require TMDL development, on the same 2-year cycle as the 305(b) report.

TMDL's

A TMDL (total maximum daily load) is a plan that specifies a quantitative pollutant load necessary to bring a waterbody into compliance with water quality standards. States have the primary responsibility for developing TMDLs for all waters on the State's 303(d) list. TMDLs are a tool for implementing State water quality standards and are based on the relationship between pollution sources and in-stream water quality conditions. TMDLs must address all sources of a pollutant in a waterbody, including point sources, nonpoint sources, and background. Although a quantitative load needed to meet water quality standards must be specified in the TMDL, the nature of the load is much more flexible than the name, *daily load* implies. Particularly with nonpoint sources of pollution such as from agriculture, loads may be more appropriately expressed as annual loads. In addition, it may be appropriate to establish additional targets in the TMDL that more closely relate to conservation practices needed, for example, percent stable streambanks, percent shading, or miles of streambank fenced.

TMDLs establish load allocations and targets needed to meet water quality standards, but the linkage between these allocations and practices needed on the ground to meet them is established in the TMDL implementation plan. Currently these plans are not required to be developed as part of the TMDL, and States usually develop them after the TMDL is completed. Typically these plans focus on identifying specific best management practices for non-point sources in specific geographic areas needed to meet load allocations in the TMDL. Point source reductions needed are often implemented directly from the TMDL, by incorporating wasteload allocations in revisions to National Pollution Discharge Elimination System (NPDES) permits.

Source Water Assessment Plan for Public Water Systems

States are currently developing source water protection plans as required under the 1996 amendments to the Safe Drinking Water Act. The 1996 amendments require States to assess surface and ground water sources (called source water) used for public drinking water supply. Each source water assessment includes:

- Source area delineation, which is that part of the watershed or ground water area that may contribute pollution to the water supply
- Contaminant source inventory, which identifies the significant potential sources of drinking water contamination in those areas
- Susceptibility analysis, which determines the likelihood of the water supply to become contaminated

Farming is a major land use within many watersheds and aquifer recharge areas for public water systems. Farming activities have the potential to contribute certain contaminants, such as nutrients, pesticides, and pathogens to drinking water sources through runoff into surface water or percolation through the soil to ground water. Certain critical source water areas may require increased planning and implementation of agricultural best management practices (BMPs) including nutrient and pest management.

NRCS/State Nutrient and Pest Management Practices

NRCS/State Nutrient and Pest Management practices are essential methods for optimizing agrichemical use and minimizing potential adverse impacts on the environment. They are intended to provide the pollution reduction necessary for a waterbody to attain (or maintain) water quality standards, especially when nutrients and/or pesticides are identified as contaminants of concern. TMDLs, source water protection plans, and other water quality protection plans are integral parts of a State's water quality management program. The goal is to achieve compliance with a State's water quality standards; to have "fishable/swimmable waters." States have the primary responsibility for developing TMDLs and Source Water Protection Plans at levels necessary for attaining and maintaining water quality conditions necessary to support the designated uses.

The designated beneficial use of a receiving waterbody, the status of support for those uses, specific State or local delineation's and water quality protection goals will often dictate how nutrient and pest management components of a conservation plan are formulated and additional mitigating practices (BMPs) that may be necessary to provide adequate resource protection. Certain uses like Drinking Water Supply may require special consideration because they are so important to human health. Other uses like Cold Water Biota and Salmonid Spawning may also require special consideration because they are so sensitive to relatively small reductions in water quality conditions. When a beneficial use for a receiving waterbody is not supported because of water quality limiting conditions, it's on the 303(d) list, additional considerations may be necessary. Plans should include additional mitigating practices that may be necessary to provide adequate resource protection, for example specific practices called for in a TMDL implementation plan and Source Water Protection Plans.

TMDL implementation plans and Source Water Protection Plans focus on identifying specific BMPs for non-point sources in specific geographic areas needed to meet load allocations in the TMDL and Source Water Protection Plans. The overall conservation plan or resource management system will identify specific BMP's that will often include nutrient and pest management on cropland. The implementation of these BMPs, together with other important BMPs, will be a critical step towards actually achieving the load reductions targeted in a TMDL or a Source Water Protection Plan, especially when nutrients and/or pesticides are identified as contaminants of concern.

Student Activity 2

1. What is the overall goal of the Clean Water Act?

2. What are Water Quality Standards as authorized under Section 303(c) of the Clean Water Act?

3. Define use as it applies to Water Quality Standards.

4. List five common uses identified in State water quality standards.

5. List two potential environmental problems associated with excess nutrients and pesticides and their relationship to the uses of the water.

6. Describe the Criteria component of water quality standards.

7. How do the designated uses of a receiving waterbody, the status of support for those uses, and specific State or local water quality protection goals relate to NRCS/State Nutrient and Pest Management practices?

Module 5, Part C—Water Resource Vulnerability

Supporting Objectives

- Describe and determine how climatic patterns, topography, soil properties, geologic setting, vegetation, and land use influence the probability of off-site chemical movement.
- Describe resource vulnerability.
- Describe the difference between Site Characteristics (Intrinsic) and Management (Extrinsic) vulnerability factors.
- List and describe four soil properties that can impact the movement of a nutrient or pesticide to surface or ground water.
- List and describe vulnerability factors that can impact the movement of a nutrient or pesticide to surface or ground water.
- Identify an intrinsically and extrinsically vulnerable soil by its vulnerability factors.
- List four major factors that control movement of pesticides and nutrients through soil.
- List three factors that may increase nutrient and pesticide runoff from the soil.
- Describe how water quality vulnerability assessment tools can be used in conservation planning.

Introduction

Management of nutrients and pesticides to reduce environmental risks or undesirable outcomes, rests on understanding the specific locations where they are being applied or are naturally occurring. Planning sites should be evaluated within a watershed or ecosystem context. That is, the actions taken on a particular field within a specific resource setting may influence water resources within a watershed or ecosystem and need to be evaluated for the effect on surface and ground water. To identify potential impacts of agrichemicals on the ecosystem is important.

Vulnerability is defined as the capacity to be injured. It's closely related to sensitivity, which is defined as the capacity to respond to stimuli, including the capacity to be easily hurt. Resource conservation relies on reducing resource vulnerability/sensitivity with appropriate management. Vulnerable resources that are sensitive to injury may require protective conservation alternatives.

Site characteristics and management factors both contribute to resource vulnerability. For simplicity, we refer to site characteristics as intrinsic factors and management characteristics as extrinsic factors. For nutrient and pest management, we will limit our discussion of human agricultural management activities (extrinsic factors) to primarily field management as opposed to farmstead management.

Site Characteristics (Intrinsic) + Management (Extrinsic) = Resource Vulnerability

Some regions and field sites are intrinsically vulnerable. Intrinsic vulnerability includes natural intrinsic characteristics (physical and biological) of the site that allow contaminant movement, either below the root zone or beyond the edge of the field. Site Characteristics (Intrinsic) include climate, soil properties, vadose zone properties, depth to ground water, and slope and distance to waterbodies. Management (Extrinsic) includes agricultural management systems that introduce pollutants including nutrients (commercial fertilizer and organic materials) and pesticides. Resource *Vulnerability* combines natural intrinsic characteristics and extrinsic management factors. As such, vulnerability provides an overall assessment of water pollution potential. Extrinsic management factors are critical to a vulnerability assessment because irrespective of intrinsic site characteristics, water quality contamination usually does not occur without cropping systems (management) that provide contaminant loading. With this concept in mind, it is important to consider all of the factors under our control and how they can be manipulated to reduce the potential for ground and surface water contamination.

Ground water and surface water are hydrogeologically connected, often in complex ways. However, when considering the consequences of water applied to the soil, a simple rule to follow is, *"what does not run in, may run off."* This rule applies to water movement, and therefore nutrient and pesticide movement with water. Nutrient and pesticide movement into the soil is considered first.

Two intrinsic and two extrinsic vulnerability factors that affect nutrient and pesticide movement through the soil include:

- Soil properties (Intrinsic)
- Climate hydraulic loading (Intrinsic)
- Pesticide and nutrient properties and use practices (Extrinsic)
- Irrigation hydraulic loading (Extrinsic)

Consider how this discussion relates to both surface and ground water. Soils whose properties allow rapid transmission of nutrients or pesticides through the root zone, have a high runoff potential, or easily erode, can contribute to resource vulnerability/sensitivity. However, this alone does not determine the risk to surface and ground water. Proper water management, pesticide or nutrient selection, low application rates, proper timing of applications and careful handling can reduce the risk of contamination and minimize resource vulnerability.

Intrinsic Soil Factors for Runoff, Erosion and Leaching

- Permeability
- Water table conditions
- Organic matter content
- Clay content
- Restrictive Layer

Soil leaching potential refers to the risk that soil water will be transmitted to ground water. Soil leaching potential depends on soil permeability, water table conditions, and hydraulic loading. Permeability and water table conditions together control the soil leaching potential. Soil with high leaching potential are more sensitive to ground water contamination than soil that has a low leaching potential.

Organic matter, and to a lesser extent clay content, control soil sorption potential. Soil that is higher in clay and/or organic matter content has a higher soil sorption potential. Most pesticides and some nutrient forms are sorbed to the soil organic matter. As discussed earlier, sorption is a function of both pesticide/nutrient and soil properties. Soil that has a low sorption potential is more sensitive to ground water contamination than soil that has a high sorption potential.

Interactions between leaching potential and sorption potential govern the overall sensitivity of the soil. A soil that has a high leaching and low sorption potential is the most sensitive.

Soil permeability refers to the rate at which water moves through soil. The size and continuity of soil pores control permeability. Factors that influence the size and continuity of soil pores and therefore permeability include:

- Organic matter
- Texture
- Structure
- Root and animal activity
- Density

These factors are not mutually exclusive. For example, organic matter helps create and stabilize aggregates of grains of sand, silt, and clay. These aggregates, or units of soil structure, have relatively large spaces between them, as well as spaces within them, permitting more rapid water movement. Creation of aggregates decreases soil density. Rainfall, tillage, traffic, and freezing and thawing can decrease soil structure and increase soil density.

Course-textured sandy and gravelly soils have large pores and very rapid permeability. Fine-textured clayey soils have fine pores and very slow permeability. Medium-textured loams, silt loams, and clay loams have a mixture of pore sizes and intermediate rates of soil permeability.

In some soils, roots, burrowing insects, and animals create relatively large voids, or macropores, that can transmit water rapidly. Macropores are especially important where they are connected to the soil surface. Soils with high 2:1 clay contents (e.g., vertisols) can have significant shrinking and swelling and crack extensively upon drying to create another type of macropore.

Heavy rainfall or irrigation may temporarily cause free water to pond at the soil surface. When free water enters surface connected macropores, it will preferentially flow past the soil matrix, thereby bypassing any filtration effect provided by the soil. If this preferential water flow occurs soon after agrichemical application, when pesticides or nutrients are concentrated at the soil surface and not yet incorporated into the soil matrix, these contaminants, (either dissolved or suspended) may be rapidly carried deep into the soil profile.

Macropores an associated percolation can be more prevalent with reduced tillage. However, reduced tillage also promotes soil microorganism activity deeper in the soil profile. Therefore although agrichemicals can move faster and deeper into the soil profile with reduced tillage, increased microbial activity at greater depths can help reduce contaminant movement to groundwater.

Where rapid downward movement of nutrients or pesticides from preferential flow through macropores threatens ground water, disruption of the macropores may be more critical than the benefits of reduced tillage on erosion and runoff. North Dakota State University Extension Service advises: *“Although reduced tillage is beneficial with respect to soil erosion and maintaining of organic matter, it may promote movement of pesticides through soil macropores. In cases where preferential flow is demonstrated as a major factor in water movement, the practice of no-till or zero-till should be modified to include some method of surface disruption. Research results indicate that tillage disrupts macropore connections with the surface and often significantly reduces preferential flow. Excessive tillage to reduce preferential flow, however, would probably result in greater soil erosion.”*

If a majority of nutrients and pesticides have already moved into the soil matrix (via non-macropore flow) before heavy rainfall or irrigation, the concentration at the surface available to run into macropores would be small. During heavy rainfall or irrigation, most free surface water would flows into the surface connected macropores and cracks, leaving only a small portion of water available to infiltrate via non-macropore flow. During these preferential flow events, 'clean' water would rapidly move deep into the profile bypassing the contaminant laden soil matrix.

Generally, macropore flow increases ground water vulnerability if preferential flow inducing conditions exist immediately after application, when the chemical is concentrated at the soil surface. If the chemical is infiltrated into the soil matrix with light rainfall or irrigation (or mechanically incorporated), less chemical is available at the soil surface than in the soil matrix, so subsequent rainfall or irrigation will cause "clean" non-contaminated water to bypass chemicals in the soil matrix. Timing agrichemical applications to avoid heavy rainfall or irrigation soon after application and/or mechanically incorporating them into the surface few inches is critical to reduce ground water vulnerability.

Karst landscapes typically have large preferential flow pathways formed by the dissolution of soluble rocks such as limestone and dolomite. Often times these flow pathways occur at or near the surface as sinkholes allowing rapid movement of water and potential contaminants into ground water. Because water does not follow conventional flow through the soil profile, there is little opportunity for pollutants to be removed before they enter ground water. Karst regions typically contain aquifers that are capable of providing large water supplies. Twenty percent of the land surface in the United States is karst and 40 percent of ground water used for drinking water comes from karst aquifers.

Permeability of a soil in its natural setting is highly variable and difficult to measure. Soil permeability can be measured in the laboratory by measuring the rate of flow through a column of soil under a constant head of water. Permeability rates are given in inches per hour. Typical rates are 0.01 inches per hour for compact clay, 0.5 inches per hour for a loam with good structure, and 1.5 inches per hour for a loamy sand. The soil permeability rates published in the county soil survey reports are mostly estimates based upon soil properties, rather than results of actual measurements, but they are useful for comparing leaching potential of different soils.

Infiltration as opposed to permeability is a measure of the movement of water into the soil profile. A soil may have a high permeability, but a low infiltration rate. For example, rainfall that falls on a permeable soil with little or no plant residue at the surface may cause surface sealing. This decreases infiltration and reduces the potential amount of water that could percolate and leach.

Water table conditions refers to the height and duration of water tables in the soil. Shallow water tables that persist for long periods increase the risk of ground water contamination. Water table information can be obtained locally from ground water studies and from soil surveys. Two types of water tables occur in soils: perched and apparent. A perched water table is the top of a zone of saturation that is separated from permanent ground water by a soil layer of very slow permeability. An apparent water table is the top of a zone of saturation in a soil in which there are no dense or confining layers.

Perched water tables do not increase the risk of ground water contamination as much as apparent water tables unless they are used directly for drinking water supply. The soil layer that perches water may act as a barrier to prevent contaminants from moving to the permanent ground water supply by increasing the contaminant retention time, therefore increase breakdown, uptake and sorption. Perched water, however, will move laterally until it can once again move downward, creating a concern for ground water quality; or until it discharges into a surface water source, creating a concern for surface water quality.

Water moving through the intermediate vadose zone (unsaturated zone of unconsolidated soil/rock above the first water table) recharges the underlying unconfined aquifer (figure 5.2). Also ground water can flow from one aquifer to another, depending on the permeability of the boundary and the hydraulic gradient. An *aquitard* is a geologic formation that slows flow from one aquifer to another because of its low permeability, but does not prevent this flow. Shallow aquifers can recharge deeper ones. The extremely low permeability of an *aquiclude* effectively separates aquifers from one another forming confined aquifers. Recharge areas are especially important as they supply large amounts of water to a ground water system. Because of this these areas should be identified and mapped to assure that appropriate conservation measures are in place to prevent ground water contamination.

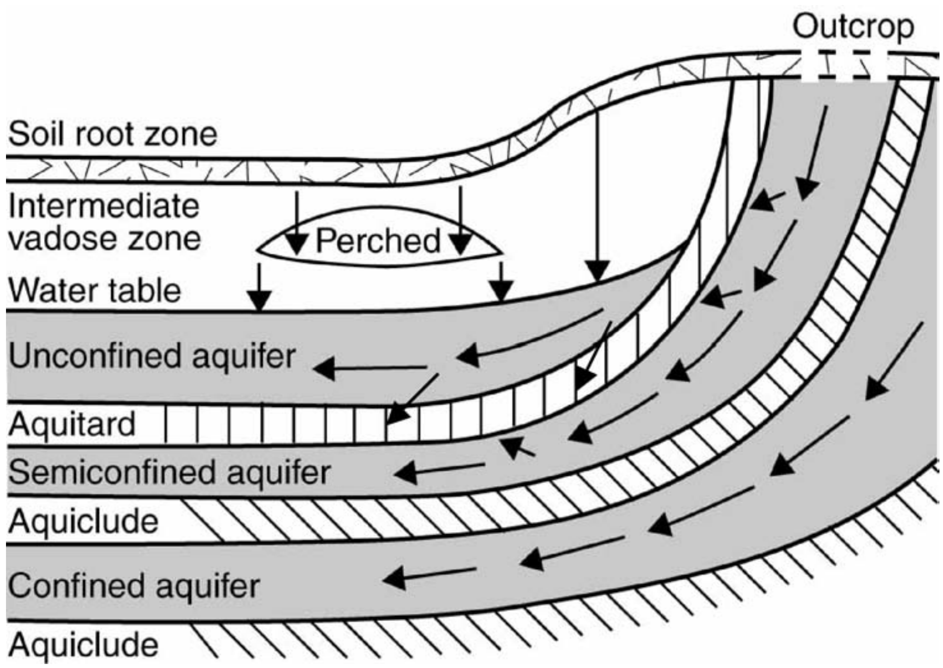


Figure 5.2 Subsurface linkages between soil and ground water.

Soil survey reports contain information on water table conditions in soils. The depth to the water table, the months during which a high water table persists, and whether it is perched or apparent all are given in tabular format. This information is useful in assessing soil sensitivity.

Hydraulic Loading

Hydraulic loading refers to the total amount of water applied to the soil. No matter how permeable the soil, the leaching potential remains low if there is insufficient water to move completely through the soil. Where rainfall or irrigation exceeds both plant consumptive use and the soil's ability to store water, leaching occurs. Water moving below the root zone ultimately reaches ground water, carrying with it soluble soil constituents. In this soil, the leaching potential is highly correlated with permeability. Irrigation compensates for water deficits in dry areas. Irrigation water is taken up by plants, but some usually passes through the soil out of the root zone. Thus irrigation can increase ground water contaminant loading potential just as large amounts of rainfall or precipitation can increase ground water sensitivity. Careful management of the amount and timing of irrigation water applications can be effective in reducing the risk of ground water contamination.

The position of a soil in the landscape also influences its hydraulic loading. Soil near a hilltop often sheds water, either by runoff over the surface or by lateral flow within the soil. Soil lower on the hillside where the slope begins to flatten out, often receives excess water from the higher positions. This soil is more susceptible to leaching from the added hydraulic loading.

Rainfall distribution and amount can affect the potential for leaching or runoff. If a soil is already saturated when a storm occurs, or if rainfall amount or intensity is too great, infiltration will not take place quickly enough. Excess water can then run off the soil surface, even on a soil that has high infiltration rates.

Soil Sorption Potential

Soil sorption refers to the binding of chemicals to particles of organic matter and clay in the soil. Sorption retains chemicals in the soil, where they can either be degraded (pesticides), or more accessible to plants as a nutrient source (nutrients). Thus the higher the sorption potential, the lower the risk of ground water contamination. Sorption potential depends on organic matter content and clay content.

Organic matter content is the most important variable affecting sorption of pesticides. In addition, organic matter stores and supplies such nutrients as nitrogen, phosphorus and sulfur, that are needed for the growth of plants and soil organisms. Organic matter provides a large number of binding sites because it has an extremely large surface area and is reactive chemically.

Organic matter includes both living and non-living biomass. Microbial populations make up the living portion. They help to breakdown pesticides, and transform ($NH_4^+ \rightarrow NO_3^-$) and immobilize nutrients within the soil system. The non-living organic matter can bind pesticides and nutrients, and provide a food source for the soil microbes. Higher organic matter contents usually result in greater soil health.

Organic matter content in soil depends on climate, vegetation, position in the landscape, soil texture, and farming practices. Abundant rainfall, combined with lush natural vegetation, gives rise to soil that has a high organic matter content.

Desert soil has a very low organic matter content. Grassland vegetation generally produces more organic matter deeper in the soil than forest vegetation. Organic matter decomposes more slowly in wet soil. As a result, a poorly drained soil in a low-lying areas tends to have more organic matter than a better-drained soil higher in the landscape. Sandy and gravelly soils tend to be droughty and support less vegetation. Under similar climatic conditions, these coarse-textured soils have less organic matter than medium and fine-textured soils. The difference is particularly marked where rainfall is limiting for plant growth.

Soil organic matter can be lost through runoff and erosion. This process selectively detaches and transports particles on the soil surface that have the highest content of organic matter. Soil organic matter is also used as energy by soil micro-organisms and provides nutrients to support microbial life. Some of the soil carbon is incorporated into the microbes, but most is released as carbon dioxide and water. Some nitrogen is released in gaseous form (denitrified) but some is retained (immobilized), along with most of the phosphorus and sulfur.

When soil is tilled, plant residue is incorporated deeper into the soil profile. Organic matter is decomposed faster because changes in water, aeration, and temperature favor a rapid increase in microbial activity. The amount of organic matter lost after clearing a wooded area or tilling native grassland varies according to the kind of soil, but most organic matter is lost within the first 10 years.

Farming practices that maintain abundant crop residue and other organic amendments at the soil surface help to maintain and even increase surface soil organic matter content. Practices that harvest or incorporate residue into the lower soil profile (excess tillage) tend to reduce soil organic matter.

Clay content refers to the percentage of microscopic plate-shaped grains in the soil. These tiny, flat particles have a tremendous amount of surface area per unit weight of soil, and their surfaces are chemically reactive. The higher the clay content, the greater the number of binding sites for pesticide and some nutrient (positively charged) retention. Clay content is particularly important in the subsoil, where the organic matter content is generally much lower than in the surface soil. Data on clay content are readily available in soil survey reports. For evaluation of sorption potential, it is sufficient to classify soils in generalized groups ranging from low sorption for the coarse-textured sands and gravels to high sorption for the fine-textured silty clays and clays.

Assessment of Soil Sensitivity (Ground Water)—Summary

The combined effects of leaching potential and sorption potential determine a soil's sensitivity with respect to ground water vulnerability. The most sensitive soil is an irrigated sandy soil that has a very low organic matter content. The least sensitive soil is a well-drained clayey soil that has a high organic matter content.

Fine-textured soils—silty clays and clays—generally have low sensitivities because they have slow or very slow permeability and high sorption potentials. Macropore flow in large cracks may be a problem, however.

Medium-textured soils—silt loams, silty clay loams, loams, and clay loams—generally have low to moderate sensitivities, even in humid areas, because they have relatively slow permeability and relatively high sorption potentials.

Coarse-textured soils—sands, loamy soils, and sandy loams—generally have moderate to high sensitivities because they are more permeable and tend to have lower sorption potentials. Small differences in hydraulic loading and organic matter content in these soils impact sensitivity much more than in loamy and clayey soils.

Organic soils—those that consist almost entirely of decomposed plant material. Though these soils have naturally high water tables, cultivated organic soils have been artificially drained, which lowers the water table. Cultivated organic soils typically have low sensitivities to pesticide contamination; however, depending on site-specific condition, huge amounts of phosphorus can be released once these soils are drained and cultivated. Dissolved phosphorus from water draining organic soils is higher than from mineral soils (table 5.4). The mineralization of phosphorus from organic matter is greater and there is less mineral matter (iron, aluminum, calcium, and clays) for adsorption in organic soils than mineral soils.

Table 5.4 Dissolved phosphorus loss in subsurface drainage from mineral and organic soil.

Location	Dissolved P	
	Dissolved P (lb/ac)	**Concentration (ppm)**
Organic Soils		
Florida	0.2 – 0.9	14–150
New York	0.2 – 10.0	1–28
Ontario	0.5 – 18.2	2 –33
Mineral Soils		
Iowa	0.02	0.07
Ontario	0.01	0.03

Factors that Influence Ground Water Quality

Intrinsic Vulnerability/Sensitivity

- Topography and landform—Certain landforms have a high potential to impact ground water (sinkholes/karst) and others have a low potential. Essentially this is determined by the time and distance contaminants must travel and is influenced to a large degree by a combination of other factors.

- Soil permeability class—Soil that has a high potential to transmit water via saturated flow, including the impact of macropores will have high sensitivity.

- Organic matter content—The influence of organic matter varies depending on the contaminant of concern. Soil that has high organic matter content adsorbs nutrients, water, heavy metals, and certain pesticides. Generally speaking, the higher the organic matter content of soil, the lower the sensitivity because of to the high adsorption of potential contaminants, thereby inhibiting their movement into ground water. On the other hand, soil that has high organic matter has the potential for increased nitrogen mineralization and subsequent conversion to nitrate because of more abundant organic nitrogen. This soil also has a greater amount of mobile phosphorus.

- Clay content—Soil that has high clay content near the surface has a high potential for phosphorus and pesticide sorption (though to a lesser extent than organic matter) because of significant mineral surface area. Clay soil would therefore have a low sensitivity. Texture class is typically that of the finest layer greater than 3 inches thick in the upper 60 inches of the soil profile.

- Soil pH—Soil pH influences the amount of phosphorus and pesticide adsorption or precipitation by carbonates and iron and aluminum. Many of the biological and chemical processes in the soil function more efficiently and rapidly when the pH of the soil is between 6 and 7; however, sensitivity varies with pH.

- Soil order—Soil that has amorphous organic-mineral colloids (Spodisols) and allophanic materials (Andisols) has high phosphorus adsorption or fixation and therefore a low sensitivity.

- Depth to apparent water table or perched water table (if it exists)—The deeper a receiving ground water body is from the surface the greater the potential for pollutant attenuation and the lower the sensitivity.

- Vadose zone media or material—The vadose zone is considered to be the unsaturated (or discontinuously unsaturated) material that is above the water table but below the root zone. The type of material in the vadose zone determines the flow path and rate of flow of the water and pollutants percolating through. Flow rate is a function of the hydraulic conductivity of the material. Hydraulic conductivity is greatly increased by joints and fractures in the material. The time available for attenuation processes to occur is inversely related to hydraulic conductivity. The lower the hydraulic conductivity of the vadose zone the lower the sensitivity.

Silt, clay, shale, or claystone usually has low hydraulic conductivities. Limestone, sandstone, and shale sequences have moderate hydraulic conductivities. Clean gravel and sands, basalt, and karst limestone have the highest hydraulic conductivities.

- Aquifer media or material—An aquifer can be defined as saturated geologic material that will yield usable quantities of water. The type of aquifer material controls the flow path and path length that water and pollutants must follow once it reaches the ground water. It also influences its hydraulic conductivity, the aquifer's ability to transmit water. Generally, hydraulic conductivity is lower in fine grained materials such as clays and shales, and in materials lacking interconnecting fractures such as unweathered rocks. The occurrence of joints and fractures greatly increases the paths available for ground water flow and greatly increases the hydraulic conductivity. The greater the hydraulic conductivity of aquifer material, the greater the rate at which a pollutant can be spread through the aquifer once it reaches ground water. Aquifer media or materials that have low hydraulic conductivity's (low transmissivity) will have lower sensitivity ratings.

- Deep percolation—This corresponds to the amount and distribution of precipitation relative to evapotranspiration (ET). Because water is the driving force for contaminant movement, this factor is very important. Areas in which precipitation exceeds ET during the critical period are more likely to have contaminants move out of the crop root zone into ground water. Infiltration rates will ultimately determine whether or not precipitation runs off or contributes to deep percolation. Areas that have a large amount of deep percolation will be highly sensitive.

- Recharge areas—Areas that supply recharge to critical ground water systems have high sensitivity.

Management (Extrinsic)

- Crop grown—Crops that have high nutrient and pesticide requirements, such as corn, onions, potatoes, strawberries and sugarbeets increase the potential for pollutant leaching and therefore have high contaminant loading potential.

- Type of irrigation—Systems that have low efficiencies and excessive irrigation applications distributed during critical period in excess of ET are more likely to move contaminants out of the crop root zone towards ground water. Areas with a large amount of irrigation induced deep percolation will have high contaminant loading potentials.

- Time of nutrient or pesticide application—Agrichemical applications made as close as possible to the time they are required have less opportunity for downward movement. Generally, the greater the time between applications and the time they are required, the higher the contaminant loading potential.

- Application method—Agrichemicals incorporated or injected have a greater potential for leaching into ground water than surface applications. In addition, agrichemicals applied in bands along or over crop rows are more environmentally tolerable because the chemicals are less likely to be off target and lower amounts are used. For certain pesticides foliar applications permit even greater exposure to weather, to the atmosphere, and to sunlight than soil application methods. Consequently, more volatilization and decomposition can occur, and the amount that contacts the ground and becomes available for leaching is reduced. Generally, broadcast applications that are incorporated or injected have higher contaminant loading potentials.

- Tillage—Management practices that maintain residue cover over the soil surface serve to effectively reduce runoff; however, this may likewise shift water from runoff to leaching and deep percolation. Overall though, residue management practices that maximize surface residue help to maintain a more stable soil environment with higher organic matter and better physical, biological, and chemical activity. Generally residue management (conservation tillage) lowers the contaminant loading potential.

Soil Impacts on Surface Water Vulnerability—Summary

Soil properties that affect infiltration will largely determine the potential for runoff. Although slope does not directly impact infiltration, it does impact how long water remains on the surface or is detained for infiltration to occur. Vegetation, residue, or surface roughness can slow the rate of overland flow and increase the opportunity for infiltration.

In addition slope greatly influences erosion. The steeper the slope, the greater the velocity of runoff and the more energy available for erosion to occur. The K factor is an indicator of the inherent erodibility of a site. For soil that has a high infiltration rate, like friable tropical clay high in hydrous oxides of iron and aluminum, or kaolinite, or well-drained sandy soil, K factors are typically low (zero to 0.2). Soil that has moderate structural stability and an intermediate infiltration rate typically has a K factor from 0.2 to 0.3, and soil that has poor structural stability and a low infiltration rate is easily eroded and has a K factor greater than 0.3. Table 5.5 provides some examples of computed K factors for several soils at different locations. The two most significant soil characteristics affecting erosion are infiltration rate and structural stability. Structural stability or the resistance of surface aggregates to raindrop impact and runoff forces protects the soil from erosion. Certain tropical clay soils high in hydrous oxides of iron and aluminum are extremely resistant to erosion from the intense rainstorms they often experience.

For a nutrient or pesticide to move with surface runoff, it must be at the soil surface. For nutrients and pesticides at the surface, availability for movement with runoff will depend on the nutrient or pesticide sorption to the soil. Those that are strongly sorbed to soil are less likely to move with runoff compared to those that are weakly sorbed.

Table 5.5 Computed K values for soil at different locations.

Soil	Location	Computed K
Udalf (Dunkirk silt loam)	Geneva, NY	0.69
Udalt (Keene silt loam)	Zanesville, OH	0.48
Udalt (Lodi loam)	Blacksburg, VA	0.39
Udult (Cecil sandy clay loam)	Watkinsville, GA	0.36
Udoll (Marshall silt loam)	Clarinda, IA	0.33
Udalf (Hagerstown silty clay loam)	State College, PA	0.31
Ustoll (Austin silt)	Temple, TX	0.29
Aqualf (Mexico silt loam)	McCredie, MO	0.28
Udult (Cecil sandy loam)	Clemson, SC	0.28
Udult (Cecil sandy loam)	Watkinsville, GA	0.23
Udult (Tifton loamy sand)	Tifton, GA	0.10
Ochrept (Bath flaggy silt loam)	Arnot, NY	0.05
Alfisols	Indonesia	0.14
Ultisols	Hawaii	0.09
Alfisols	Nigeria	0.06
Oxisols	Brazil	0.02
Andisols	Nigeria	0.02
Inceptisols	Puerto Rico	0.02
Source: Wischmeier and Smith (1978); data for tropical soils cited by Lal (1984).		

Of course, if erosion occurs then nutrients and pesticides sorbed to eroded soil will move with runoff. However, for all but the most severe soil erosion events, most pesticide loss in runoff will be associated with water as opposed to the sediment. Because the nutrient or pesticide must be at the soil surface for loss with runoff to occur, the timing of runoff producing events relative to chemical application is critical in determining loss in runoff.

Rainfall or irrigation events that occur soon after application but do not produce runoff will most likely move the nutrient or pesticide away from the soil surface and greatly reduce the potential for runoff loss with subsequent events.

Other important soil factors that influence runoff potential include structure and structural stability, organic matter content, texture, the kind and amount of swelling clays, soil depth, and tendency to crust. The presence of impervious soil layers or a water table and root and animal activity will also have an impact. All of these factors determine the overall infiltration rate of soil. Because infiltration takes place at the surface, these factors are especially important at the soil surface. As infiltration increases, the potential for runoff decreases.

Other Surface Water Vulnerability Factors (Intrinsic)

- Topography and slope—Steep topography tends to be more erosive and thus more sensitive.
- Depth to impermeable layer—An impermeable layer is any layer that has a slow or very slow permeability class (<0.20 in/hr) and weathered bedrock or unweathered bedrock. Highly fractured bedrock should not be considered an impermeable layer. Impermeable layers will tend to limit infiltration potentially increasing runoff; and may also potentially generate interflow on sloping soil, with infiltrated water and pollutants returning to the surface water as subsurface storm flow. The closer this layer is to the surface the higher the sensitivity rating.
- Annual flooding—The frequency of flooding determines the potential for surface water to pick up contaminants during overbank flow. Areas with frequent flooding will have high sensitivity ratings.
- Runoff class—Runoff will determine the likelihood for pollutants in runoff to enter surface water. Soil that has a very high or high runoff class will have high sensitivity.

- K factor—K factor is an indicator of the potential for sediment-bound contaminants from a site to impact surface water. Soil that has a high K factors has a high sensitivity rating.

- Climate, including rainfall intensity and distribution—Climatic zones that have high amounts and intensities of rainfall that occur at a rate greater than the soil infiltration rate during critical period when nutrients and pesticides are typically applied will have high sensitivity.

- Distance to water bodies or streams—Areas close to a receiving water body will be highly sensitive.

- Residence time in lakes and reservoirs—High residence times retain contaminants for long periods resulting in corresponding periods for adverse impacts as well as accumulation. Areas draining directly to this type of water body would have high sensitivity.

Management (Extrinsic)

- Crop grown—Crops that have high nutrient and pesticide requirements, such as corn, onions, potatoes, strawberries and sugarbeets increase the potential for pollutant runoff losses and therefore have high contaminant loading potential.

- Type of irrigation—Systems with low efficiencies and excessive runoff distributed during critical periods when nutrients and pesticides are typically applied increase the potential for pollutant losses in runoff. Areas that have a large amount of irrigation-induced runoff will have a high contaminant loading potential.

- Time of nutrient or pesticide application—When agrichemicals are applied as close as possible to the time they are required, there will be less opportunity for runoff to occur and resulting pollutant to be lost. Generally, the greater the time between applications and the time they are required, the higher the contaminant loading potential.

- Application method—Agrichemicals that are surface applied and not incorporated have a greater potential for being carried off the field with specific runoff events than incorporated or injected applications. In addition, agrichemicals applied in bands are more environmentally tolerable because the chemicals are less likely to be off target and lower amounts are used. For certain pesticides foliar applications permit even greater exposure to weather, to the atmosphere, and to sunlight than soil application methods. Consequently, more volatilization and decomposition can occur, and the amount that contacts the ground and becomes available for runoff losses will be less. Generally, broadcast applications that are surface applied have a higher contaminant loading potential.

- Tillage—Management practices that maintain residue cover over the soil surface serve to effectively reduce the energy of runoff and resulting soil erosion and pollutant losses. Generally, conventional tillage minimizes surface residue thereby increasing the contaminant loading potential.

Nutrient and pesticide fate in the environment depends on the rate, timing, and method of application, as well as a variety of dynamic and interrelated physical, chemical, and biological processes. These processes are influenced by environmental conditions that are often site-specific. Careful consideration of these fate processes and their interactions is necessary to evaluate the risk to ground water and surface water.

Soil properties and water table conditions that influence leaching and runoff should be carefully evaluated. Site topography and the proximity of water resources should also be considered.

The properties and parameters introduced are most useful as initial risk screening tools and can assist in developing relative vulnerability rankings. They cannot be used to predict the absolute amount of a nutrient or pesticide that may enter ground or surface water.

Water Quality Vulnerability Assessment Tools and Conservation Planning

Water quality assessment tools should be used to provide targeted management for necessary levels of nutrient and pest management. Targeted management identifies those field sites with the most likely potential for contamination to occur and where the greatest intensity of management is required to protect the water resource. In addition, vulnerability assessments help to identify other important areas of less immediate concern and likewise the necessary levels of nutrient and pest management appropriate for those areas.

Users of these tools must understand that these ratings are general and have certain limitations. A low vulnerability/sensitivity rating is not an open ticket for poor management practices. A low rating merely suggests that there is a lower chance of water contamination than in areas of high ratings. Almost any area can contribute to contamination if it is subjected to improper land management. Proper resource protection measures are important under any circumstance.

Many States have developed ground water and/or surface water vulnerability maps to identify regions or areas within the State that may potentially be vulnerable to contamination. These maps will provide a valuable tool for identifying broad areas of concern. Vulnerability assessment tools that meet each State's criteria should be developed and referenced in Section I of the Field Office Technical Guide. NRCS is urged to work with State water quality agencies to develop this information.

Student Activity 3

1. Describe three Site Characteristics (Intrinsic) and how they influence a site's vulnerability to surface or ground water contamination.

2. Indicate (increase or decrease) how the following Site Characteristics (Intrinsic) influence vulnerability.

Site Characteristics (Intrinsic)	**Vulnerability**	
	Surface water	**Ground water**
Intense summer rainfall		
Steep slopes		
Highly permeable soils		
Closed basin		
Short distance to waterbody		
Shallow to ground water		
High runoff class		
Significant deep percolation		
Shallow to impermeable layer		
K factor >0.32		
Long residence time in waterbody		
Slow aquifer hydraulic conductivity		

3. Describe three Management (Extrinsic) factors and how they can influence a site's vulnerability to surface or ground water contamination.

4. Indicate (increase or decrease) how the following Management factors (Extrinsic) influence vulnerability.

Management (Extrinsic)	Vulnerability	
	Surface water	Ground water
Conventional tillage		
Sprinkler irrigation		
Residue management or conservation tillage		
Surface irrigation		
Conversion to CRP		
High input crop		
Fall fertilizer application		
High erosion rate		
Surface applied fertilizer		

5. Describe the difference between Intrinsic vulnerability and Extrinsic vulnerability.

6. Why is Resource Vulnerability important to water quality?

   ____

   ____

   ____

7. Which of the following are Intrinsic vulnerability factors?

   Circle the letter.

   a. Soil texture

   b. Crop rotation

   c. Irrigation

   d. Field slope

   e. Depth to groundwater

8. Field A contains a deep sandy loam soil over fractured bedrock. Field B contains a deep sandy loam soil over karst topography. Field C contains a clay loam over a confined aquifer. Field D contains a loamy sand over a shallow, unconfined aquifer that is used for drinking water supply.

   Rank these fields in descending order of their intrinsic vulnerability to pesticide contamination (the most vulnerable would receive a ranking of 1).

   1. ____

   2. ____

   3. ____

   4. ____

9. The following soil property influence ground water vulnerability. Indicate how vulnerability can be increased and decreased with management.

- Low organic matter content
- Surface connected macropores
- High water table

Decrease: ____

____

____

Increase: ____

____

____

10. List four ways a pesticide may enter surface or ground water.

____

____

____

____

11. What combinations of pesticide and soil properties are most likely to result in pesticide movement to ground water?

Pesticide properties ____

____

Soil properties ____

____

12. Rank the following soils from high to low vulnerability to pesticide movement with infiltrating water (1 is highest and 4 is the lowest):

	Rank
a. loam	____________
b. gravelly sandy loam	____________
c. silt loam	____________
d. silty clay	____________

13. Would a field with a steep slope be more vulnerable to surface water or ground water contamination, all other factors being the same? Explain your answer.

____

____

____

____

____

14. Explain how Site Characteristics (Intrinsic) and Management (Extrinsic) can be used to develop local water quality vulnerability assessment tools and how these tools can be used in conservation planning.

____

____

____

____

____

Module 5, Part D—Environmental Risk Analysis:

Evaluating How Different Conservation Alternatives May Negatively Impact the Ecosystem

Overview

Agriculture often alters an ecosystem to produce food and fiber for human consumption. Resource conservation attempts to minimize agriculture's negative impacts on the ecosystem. Fortunately, resource conservation is often in harmony with agricultural profitability. Cost-effective nutrient management, with a nutrient budget that just meets crop needs, minimizes excess nutrient applications that could harm the environment. Likewise, cost effective pest management that has IPM economic thresholds minimizes pest control measures that could harm the environment.

Efficient nutrient and pest management, however, are not always enough to meet our resource conservation goals. Sensitive resources, such as shallow ground water or a nearby drinking water reservoir, may need special considerations for adequate protection.

Environmental risk analysis looks at specific concerns associated with a given alternative used on a specific site. Matching lower risk alternatives to sensitive sites or recommending appropriate mitigation practices for higher risk alternatives are important parts of the conservation planning process. All risks to all resources should be evaluated and addressed in conservation planning whenever possible. When tools are not available, conservation planners must rely on professional judgement. They should also make their needs known to management to help prioritize new tool development.

In an effort to manage nutrients there are a number of tools used to measure the sufficiency levels of crop nutrients in soil, plants, and water. Soil and plant analyses have been used for over a century to determine the level of nutrients in soil and water. These same tools are now being used to measure the nutrient levels in the environment. The higher the nutrient build up in the environment, it can be assumed, will have a higher potential for negative impacts to the ecosystem. Simple accounting methods that add nutrient inputs into the ecosystem and subtract nutrient outputs are also being used. This nutrient budget helps to show where gross imbalances may be occurring that could lead toward some form of ecosystem imbalance. In the past 10 years process models like EPIC, NLEAP, AGNPS, and GLEAMS are being used to account for nutrient source, fate, and transport through the environment. These models are complex and require extensive data elements. Other risk assessment tools are simple indexes such as the Leaching Index (LI) and the Phosphorus Index (PI). These have been developed recently to determine a field-level risk of nutrient fate and transport. These indexes will be discussed further in *Module 5, Part D, Section 2—Environmental Risk Analysis-Nutrient Management-Nutrient Risk Analysis Tools.*

What is risk?

The Random House College Dictionary defines risk as "exposure to the chance of injury or loss." In business, risk may refer to "exposure to the chance of losing business or money." In fact, risk is an area of study in many academic disciplines where the loss of something positive could occur. Archeologists risk damage to ancient artifacts during digs, physicians risk losing patients due to surgery or misdiagnosis, investors risk capital when they invest in untested companies.

The definition of hazard, unlike risk, does not contain 'chance' or 'probability' of occurrence. A hazard is defined as "that which can cause injury or loss." Therefore, "the exposure to chance of a hazard" is what defines risk.

Because of the complexity involved in pesticide risk analysis, NRCS has developed the Windows Pesticide Screening Tool (WIN-PST). Module 5, Part D, Section 11 illustrates environmental risk analysis and how WIN-PST can be used to evaluate pesticide water quality risks to humans and fish.

Scope

Nutrient and pest management can cause both point and non-point source contamination of water, air, and soil. Contaminants can vary with the type of management used. NRCS's primary concern with nutrient and pest management, is nutrient and pesticide runoff and leaching that impairs water quality for designated uses. The focus of this section is directed towards non-point source contamination of surface and ground water. (Educational training and assessment programs like Farm*A*Syst [Farmstead Assessment System] and regulatory Pesticide Applicator Training [PAT] can help to address point source contamination.)

Module 5, Part D, Section 1—Environmental Risk Analysis: Nutrient Management

Hazards and Risks from Nutrient Management Activities

Supporting Objectives

- Describe NRCS' role in nutrient management.
- Define risks involved in nutrient management.

Introduction

NRCS' role in nutrient management is to:

- ensure that soil and plant nutrient information is available to the producer to provide adequate soil, plant, and water nutrients for optimum grain, fruit, forage, and fiber production;
- assess the environmental risk of using a specific rate, form, timing, and method of nutrient application; and
- provide mitigation strategies to reduce the effects of source, fate, and transport of nutrients in the landscape.

Therefore, one of the conservation planner's jobs is to provide environmental risk information not generally provided by others in the agricultural industry. These risk evaluations are not limited to the amount of fertilizer and organic nutrients, but to their form, source, timing, and method of application and how each can affect the soil-plant-water-air-animal resources. With nutrients, NRCS' charge is to help farmers evaluate the potential environmental risk of recommended nutrient management planning alternatives, and further, to provide mitigation strategies that reduce potentially deleterious offsite losses.

Tools are available both state- and nationwide to help conservation planners analyze environmental risk associated with nutrient management. The NRCS conservation practice standard, Nutrient Management (590), gives the over-all guidance of how nutrients will be managed for all land areas that require NRCS conservation plans or any other lands referenced toward the standard. The State nutrient management policy provides additional information on program requirements and certification. The State Land Grant University provides the guidance for soil and plant sampling, analysis, and interpretation that leads to nutrient recommendations. Although these are used to provide adequate nutrients for crop, forage, and fiber production, analyses can also be used to monitor levels of nutrients and metal in plants and the soil. Soil test analyses have become a vital element in assessing the risk of phosphorus and nitrogen movement in the soil profile. Other risk indices, such as the phosphorus index and the leaching index, give the relative risk of phosphorus or nitrate nitrogen to move in the landscape. These will be discussed in detail in the following section.

Other risk assessment tools such as the Revised Universal Soil Loss Equation (RUSLE), the Wind Erosion Equation (WEQ), Runoff Curve Number (CN), and Hydrologic Soil Groups (HSG) are used to measure the relative risk of erosion, sediment, runoff, and leaching transport in the landscape. When specific tools are not available the environmental risk will rely on the professional judgment of the conservation planner.

Risk Involved in Nutrient Management

Two types of risk are present with nutrient management:

- The risk of applying nutrients to a crop or soil in a way that the proper amount or proportion of essential plant and soil elements are not sufficient for optimizing yields and soil conditions, and
- The risk of applying nutrients is a way that the rate, timing, form, or method of application leads to unacceptable losses of nutrients from the field site and toward sensitive resource areas of air, water, soil, plants, and animals.

A number of risks exist to SWAPA resources involved in nutrient management activities. Not all of them are connected to over-application of a particular element. Applying farm-generated manure as a nutrient source is considered the best alternative for manure use. Misapplying the manure during potential periods of high runoff or erosion, or at inappropriate times when odor or gases can escape the area, can cause serious resource impacts. Growing legumes in the crop rotation has several advantages; one of them being the supply of nitrogen the legume brings to the soil. Not accounting for this additional nitrogen in the nutrient budget will result in an excess supply of nitrogen to the subsequent crop. Surface application of nitrogen material containing urea is hazardous unless the material is somehow incorporated into the soil by tillage or water, either irrigation or precipitation. The urea quickly converts to ammonia gas, which is readily lost to the atmosphere unless converted and stored in the soil. High losses of surface applied nitrogen will require greater quantities of manure to be applied or out-of-the-pocket cost for additional fertilizer N. Gases that are released can cause air quality concerns. Using tillage to incorporate this nitrogen material can increase the risk for soil erosion and sediment transport. Eroded soil sediment along with nitrogen material can leave the Agricultural Management Zone (AMZ) causing siltation of waterbodies. Aquatic life can be negatively impacted by the sediment, covering up bottom feeding and habitat areas, as well as be an over-enrichment of the water column contributing to accelerated eutrophication.

Evaluating the environmental risk of all these nutrient management activities is somewhat complex and confounding. For example, incorporating manure into the soil will decrease the risk of runoff and volatilization of nutrient material, but will increase the risk of leaching and soil erosion. NRCS does have tools that can evaluate certain practices such as tillage and crop rotation. RUSLE and WEQ can be used to estimate erosion. The RCN can estimate runoff and the LI can estimate leaching. Simply meeting the soil loss tolerance (T) level of the soil map unit does not prevent siltation or runoff from occurring. Soil erosion rates lower than the soil loss tolerance may be required to sustain the SWAPA resources. Mitigation practices like conservation buffers and conservation tillage can be planned to minimize the transport of nutrient material once applied to the field landscape.

Module 5, Part D, Section 2— Environmental Risk Analysis: Nutrient Management

Nutrient Risk Analysis Tools

Supporting Objectives

- Using the Phosphorus Index, determine the overall vulnerability of a site and explain the general vulnerability to P loss.
- Using the individual site characteristics for the Phosphorus Index, identify factors of concern and management options that could be used to reduce the site vulnerability.
- List the Leaching Index for a site and indicate whether or not nitrate leaching may be a concern.
- Using the Leaching Index and the Guidelines for Leaching Assessment, indicate what sort of nitrogen management should be considered for a site.

Introduction to the Phosphorus Index

The need for a phosphorus assessment tool came about as a parallel to the nitrogen leaching models (NLEAP and LEACHM) and the water Leaching Index (LI) both developed in 1991. The original Phosphorus Index work group met in San Antonio during the 1990 American Society of Agronomy meetings. From that meeting, the Phosphorus Index Core Team (PICT) was established consisting of members from ARS, land grant universities, and SCS (now NRCS). PICT grew into the Southern Extension and Research Activities Information Exchange Group (SERA-IEG 17) in 1993. At the 1992 ASA meetings in Minneapolis the PI concept was presented in a symposium and later published in the 1993 Journal of Production Agriculture. SCS published the PI as

Technical Note No. 1901 in 1994. It was not until 1999, however, upon the issuance of the new national policy for nutrient management, that the PI became prominent as a risk assessment tool. Now each state is developing a PI for assessing their specific phosphorus movement risk.

The Phosphorus Index (PI) was conceived as a field-based method for determining the relative risk of phosphorus would moving from a site. Originally, the PI was developed as a simple 8 x 5 matrix using a limited number of landform and management characteristics. The input into the matrix is designed to be from easily-obtained field data. From the start the concept of the PI was as an assessment tool, not a process model.

Many States have adopted the PI as the assessment tool for phosphorus movement. Each State has worked with its resource partners to develop a PI that is appropriate for the local conditions. Although the original concepts for the PI has been maintained, many States have developed unique formats and rankings of their site characteristic to match their local needs.

Following is Technical Note No. 1901 that provides the background for understanding and using the Phosphorus Index. An example of the field calculations is given later in the technical note.

The Phosphorus Index
A Phosphorus Assessment Tool

Date: August, 1994

Phosphorus Concerns in the Environment

Eutrophication can be caused by the nutrient enrichment of a water body. Nutrient movement in runoff and erosion from agricultural non-point sources is a resource management concern. The movement of phosphorus in runoff from agricultural land to surface water can accelerate eutrophication. Undesirable aquatic plant growth results from additions of phosphorus to the water. The net result of the eutrophic condition and excess plant growth in water is the depletion of oxygen in the water due to the heavy oxygen demand by microorganisms as they decompose the organic material. Little attention has been given to management strategies to minimize the non-point movement of P in the landscape because of the easier identification and control of point source inputs of P to surface waters and a lack of direct human health risks associated with eutrophication. Phosphorus is generally the limiting nutrient in fresh water systems and any increase in P is usually results in more aquatic vegetation. Society is concerned about maintaining clean drinking water. This concern now includes a cost for removing the color, taste, and odor associated with the high trophic condition and vegetation growth in surface water due to excess nutrients.

Phosphorus Movement Factors

The main factors influencing P movement can be separated into the transport, phosphorus source, and phosphorus management factors. Transport factors include the mechanism by which P moves within the landscape. These are rainfall, irrigation, erosion and runoff. Factors which influence the source and amount of P available to be transported are soil P content and form of P applied. Phosphorus management factors include the method of application, timing, and placement in the landscape as influenced by the management of application equipment and tillage.

Phosphorus Movement in the Landscape

Phosphorus movement in runoff occurs as particulate P and dissolved P. Particulate P is attached to mineral and organic sediment as it moves with the runoff. Dissolved P is in the water solution. In general, particulate P is the major portion (75-90%) of the P transported in runoff from cultivated land. Dissolved P makes up a larger portion of the total P in runoff from non- cultivated lands such as pastures and fields with reduced tillage. In terms of their impact on eutrophication of water bodies, particulate P becomes less available to algae and plant uptake than dissolved P because of the chemical form it has with the mineral (particularly iron, aluminum, and calcium) and organic compounds. The availability of particulate P to plants and algae is variable, ranging from 10 to 90% of the total P. yet can represent a long-term source of P for algae and plant uptake from the water body. Dissolved P is 100% bioavailable to plants. Added together, the bioavailable portion of particulate P and the dissolved P represents the phosphorus that promotes eutrophication of surface waters.

The method by which P in both particulate and dissolved form moves within the landscape are simplified in the following description. Eroding soil material is transported by runoff. During detachment and movement of sediment in runoff, the finer clay-sized fraction of the source material are preferentially eroded. The P content and reactivity of the eroded material to P are usually greater than the source soil from which it was eroded. The suspended sediment in the runoff can rapidly adsorb the dissolved P in the runoff water.

As runoff moves from the landscape and toward the water body there is generally a progressive dilution of P through additions of water and a reduction in the amount of sediment carried because of sediment deposition. Phosphorus may become more bioavailable by the sorption and resorption processes and by the preferential transport of clay-sized material as sediment moves over the landscape.

The movement of dissolved P begins with the Resorption, dissolution, and extraction of P from the soil, plant, and organic material. These processes occur when rain and runoff water interact with the thin layer of surface soil (0.05 to 0.10 inches). Some water infiltrates into the soil and percolates through the profile where desorption of P will result in a low dissolved concentration in subsurface and return flow. High dissolved P concentration can be expected in the water percolating through organic, coarse-textured, and oxygen depleted (reduced), water-logged soils. Soil pH also affects the movement and availability of phosphorus.

The interaction between the particulate and dissolved P in the runoff is very dynamic and the mechanism of transport is complex. Therefore, it is difficult to predict the transformation and ultimate fate of P as it moves through the landscape.

The Concept

The purpose of the Phosphorus Index is to provide field staffs, watershed planners, and land users with a tool to assess the various landforms and management practices for potential risk of phosphorus movement to water bodies. The ranking of Phosphorus Index identifies sites where the risk of phosphorus movement may be relatively higher than that of other sites. When the parameters of the index are analyzed, it will become apparent that an individual parameter or parameters may be influencing the index disproportionately. These identified parameters can be the basis for planning corrective soil and water conservation practices and management techniques. If successful in reducing the movement of phosphorus, the concern of phosphorus enrichment will also be reduced.

For the first version, the Phosphorus Index will be a 8 x 5 matrix using a limited number of landform site and management characteristics. The input to the matrix will be readily accessible field data. This index will be used as a tool for understanding the contribution that individual landform and management parameters have toward risk of phosphorus movement and will provide a method for developing management guidelines for phosphorus at the site to lessen their impact on water quality.

A number of soil, hydrology, and land management site characteristics will describe the landform. The Phosphorus Index (table 1) uses parameters that can have an influence on phosphorus availability, retention, management, and movement. These include the erosion rate in tons per acre per year, runoff, available phosphorus soil test levels given in soil laboratory test units, phosphorus fertilizer application rates in pounds available phosphate per acre, phosphorus fertilizer application methods, organic phosphorus application rates in pounds available phosphates per acre, and organic phosphorus application methods. Field specific data for the eight site characteristics selected for this version (table 1) of the Phosphorus Index are readily available at the field level. Some analytic testing of the soil and organic material is required to determine the rating levels. This soil and material analysis is considered essential as a basis for the assessment.

The P Index is a simple 8 by 5 matrix that relates site characteristics with a range of value categories. This first version (table 1) of the P Index has eight site characteristics. The eight characteristics are:

- soil erosion
- irrigation erosion
- runoff class
- soil P test
- P fertilizer application rate
- P fertilizer application method
- organic P source application rate
- organic P source application method

The five value categories are:

- none

- low
- medium
- high
- very high

There are eight site characteristics used in the P Index to assess a particular site. Each site characteristic is rated NONE, LOW, MEDIUM, HIGH, or VERY HIGH by determining the range for each category. Although ranges have been given in this version of the index, it is imperative that each user establish their own range of values for each characteristic. Each user group should consider the cropping, soil, management conditions in the area designated to use the Phosphorus Index. Consideration need to be made as to base conditions for soil erosion, soil phosphorus test levels, and crop requirements. From these local considerations the ranges of the values category can be made. Any user group should include NRCS, Extension Service, University and ARS researchers, as well as state natural resource agencies and other groups interested in water quality.

The definition of each of the eight site characteristics follows.

Soil Erosion

Soil erosion is defined as the loss of soil along the slope or unsheltered distance caused by the processes of water and wind. Soil erosion is estimated from erosion prediction models currently used (USLE or RUSLE for water erosion and WEQ for wind erosion). Erosion induced by irrigation is calculated by other convenient methods. The value category is given in tons of soil loss per acre per year (ton/acre/year). These soil loss prediction models do not predict sediment transport and delivery to a water body. The prediction models are used in this index to indicate a movement of soil, thus potential for sediment and attached phosphorus movement across the slope or unsheltered distance and toward a water body.

Irrigation Erosion

Potential P loss resulting from furrow irrigation induced erosion is considered by inclusion of a rating system based on soil susceptibility to particle detachment by hydraulic shear and flow rate of water in the furrow. The susceptibility to detachment is given by a relative ranking of soil erodibility classes under furrow irrigation (table 2). These classes are an initial attempt at a relative ranking based on inherent stable and static soil properties (i.e., texture and clay mineralogy). There are temporal variations in the relative erodibility and actual amount of erosion with furrow erosion. These changes in erodibility are a function in the soil properties or a result of management. However, no attempt is made to consider temporal soil properties nor management factors in the rating. The introduced flow rate in the furrow (Q) is given by the irrigation plan and recorded as gallons per minute (gal/min). The furrow slope (S) of the site is given as a percentage (feet per 100 feet). (See USDA-NRCS National Engineering Handbook 15, chapter 5). The product of flow rate (Q) and slope (S) is used to determine the value category.

Runoff Class

The runoff class of the site can be determined from soil survey data. Guidance in determining the runoff class is based on the soil saturated hydraulic conductivity (K_{sat}) and the percent slope of the site. (See USDA-NRCS Soil Survey Manual, Agricultural Handbook 18, 1993.) A more simplified table has been developed using soil permeability classes (table 3). The result of using the matrix relating soil permeability class and slope provides the value categories: NEGLIGIBLE, VERY LOW, LOW, MEDIUM, HIGH, and VERY HIGH.

Another method to determine runoff class is using the NRCS curve number (CN) method. The major factors that determine curve number are the hydrologic soil group, landscape cover type, conservation treatment, hydrologic condition, and antecedent runoff conditions. The NRCS runoff curve number method is described in detail in National Engineering Handbook number 4, 1985. A suggested guidance matrix is given in table 4.

Soil P Test

A soil sample from the site is necessary to assess the level of “available P” in the surface layer of the soil. The available P is the level customarily given in a soil test analysis by the Cooperative Extension Service or commercial soil test laboratories. The user of the P Index must determine the ranges of soil test P in each value category (LOW, MEDIUM, HIGH, and EXCESSIVE). These ranges of soil test P values will vary by soil test method and region. The soil test level for “available P” does not ascertain the total P in the surface soil. It does however, give an indication of the amount of total P that may be present because of the general relationship between the forms of P (organic, adsorbed, and labile P) and the solution P available for crop uptake.

P Fertilizer Application Rate

The P fertilizer application rate is the amount, in pounds per acre (lb/acre), of phosphate fertilizer (P_20_5) that is applied to the soil. This phosphate fertilizer does not include phosphorus from organic sources (recorded in Organic P Sources).

P Fertilizer Application Method

The manner in which P fertilizer is applied to the soil and the amount of time that the fertilizer is exposed on the soil surface until crop utilization effects potential P movement. Incorporation implies that the fertilizer P is buried below the soil surface at a minimum of two inches. The value categories of increasing severity, LOW to VERY HIGH, depict the longer surface exposure time between fertilizer application, incorporation, and crop utilization.

Organic P Source Application Rate

The organic P application rate is the amount, in pounds per acre (lb/acre), of potential phosphate (P_2O_5) that is contained in the manure and applied to the soil. An analysis of the organic material is necessary to determine the potential phosphate content of the manure. The P content by analysis is generally considered to be completely plant available. This organic phosphate source does not include phosphorus from fertilizer sources (recorded in P Fertilizer Application Rate).

Organic P Source Application Method

The manner in which organic P material is applied to the soil and the time that the organic material is exposed on the soil surface until crop utilization can determine potential P movement. Incorporation implies that the organic P material is buried below the soil surface at a minimum of two inches. The value categories of increasing severity, LOW to VERY HIGH, depict the longer surface exposure time between organic P material application, incorporation, and crop utilization.

The Procedures for Making an Assessment

The site characteristics have been assigned a weighting based on the reasoning that particular site characteristics may be more prominent than others in allowing potential phosphorus movement from the site. There is scientific basis for concluding that these relative differences exist; however, the absolute weighting factors given are based currently on professional judgment.

The site characteristic weighting factors are:

- soil erosion (1.5)
- irrigation erosion (1.5)
- runoff class (0.5) * soil P test (1.0)
- P fertilizer application rate (0.75)
- P fertilizer application method (0.5)
- organic P source application rate (1.0)
- organic P source application method (1.0)

The value categories are rated using a log base of 2. The greater ratings, the proportionally higher are the values. The higher the value, the higher potential for significant problems related to phosphorus movement.

The value ratings are:

- none = 0
- low = 1
- medium = 2
- high = 4
- very high = 8

To make an assessment using the P Index, select a rating value for each site characteristic using the categories NONE, LOW, MEDIUM, HIGH, or VERY HIGH. Multiply the site characteristic weight factor by the rating value to get the weighted value for that characteristic. Proceed to rate and factor each characteristic of the index. Sum the weighted values for all eight characteristics, and compare the total with site vulnerability chart.

A description of vulnerability is given to appraise the assessment of the P Index.

Interpretations of Site Vulnerability Ratings for the P Index

LOW—This site has a LOW potential for P movement from the site. If farming practices are maintained at current level, the probability of an adverse impact to surface water resources from P losses from this site would be low.

MEDIUM—This site has a MEDIUM potential for P movement from the site. The probability for an adverse impact to surface water resources is greater than that from a LOW vulnerability rated site. Some remedial action should be taken to lessen the probability of P movement.

HIGH—This site has a HIGH potential for P movement from the site. There is a high probability for an adverse impact to surface water resources unless remedial action is taken. Soil and water conservation as well as phosphorus management practices are necessary to reduce the risk of P movement and probable water quality degradation.

VERY HIGH—This site has a VERY HIGH potential for P movement from the site. The probability for an adverse impact to surface water resources is very high. Remedial action is required to reduce the risk of P movement. All necessary soil and water conservation practices plus a phosphorus management plan must be put in place to reduce the potential of water quality degradation.

Table 1 Phosphorus Index for assessing the vulnerability of a land unit. Summation of the weighted rating value is used to determine the site vulnerability.

	Phosphorus Loss Rating (Value)				
Site Characteristic (weight)	**NONE (0)**	**LOW (1)**	**MEDIUM (2)**	**HIGH (4)**	**VERY HIGH (8)**
SOIL EROSION (1.5)	NOT APPLICABLE	< 5 TONS/AC	5–10 TONS/AC	10–15 TONS/AC	> 15 TONS/AC
IRRIGATION EROSION (1.5)	NOT APPLICABLE	TAILWATER RECOVERY OR QS < 6 FOR VERY ERODIBLE SOILS OR QS < 10 FOR OTHER SOILS	QS > 10 FOR EROSION RESISTANT SOILS	QS > 10 FOR ERODIBLE SOILS	QS > 6 FOR VERY ERODIBLE SOILS
RUNOFF CLASS (0.5)	NEGLIGIBLE	VERY LOW OR LOW	MEDIUM	HIGH	VERY HIGH
SOIL P TEST (1.0)	NOT APPLICABLE	LOW	MEDIUM	HIGH	EXCESSIVE
P FERTILIZER APPLICATION RATE (0.75)	NONE APPLIED	1–30 LB/AC P_2O_5	31–90 LB/AC P_2O_5	91–150 LB/AC P_2O_5	> 150 LB/AC P_2O_5
P FERTILIZER APPLICATION METHOD (0.5)	NONE APPLIED	PLACED WITH PLANTER DEEPER THAN 2 INCHES	INCORPORATE-D IMMEDIATELY BEFORE CROP	INCORPORATED > 3 MONTHS BEFORE CROP, OR SURFACE APPLIED < 3 MONTHS BEFORE CROP	SURFACE APPLIED > 3 MONTHS BEFORE CROP
ORGANIC P SOURCE APPLICATION RATE (1.0)	NONE APPLIED	1 - 30 LB/AC P_2O_5	31 - 60 LB/AC P_2O_5	61 - 90 LB/AC P_2O_5	> 90 LB/AC P_2O_5
ORGANIC P SOURCE APPLICATION METHOD (1.0)	NONE	INJECTED DEEPER THAN 2 INCHES	INCORPORATE-D IMMEDIATELY BEFORE CROP	INCORPORATED > 3 MONTHS BEFORE CROP, OR SURFACE APPLIED < 3 MONTHS BEFORE CROP	SURFACE APPLIED TO PASTURE, OR > 3 MONTHS BEFORE CROP

Total of Weighted Rating Values	Site Vulnerability
< 8	LOW
8–14	MEDIUM
15–32	HIGH
> 32	VERY HIGH

An example in using the Phosphorus Index	
Soil erosion (weight = 1.5) is 7.5 ton/ac/yr (=MEDIUM, value = 2)	1.5 x 2 = 3.0
Irrigation erosion (weight = 1.5) is not applicable (=NONE, value =0)	1.5 x 0 = 0
Runoff class (weight = 0.5) is LOW (value = 1)	0.5 x 1 = 0.5
Soil P test (weight = 1.0) is 82 lb P (=HIGH, value = 4)	1.0 x 4 = 4.0
P fertilizer application rate (weight = 0.75) is 25 lb/ac (=LOW, value = 1)	0.75 x 1 = 0.75
P fertilizer application method (weight = 0.5) is placed with planter(=LOW, value = 1)	0.5 x 1 = 0.5
Organic P source application rate (weight = 1.0) is 95 lb/ac (=VERY HIGH, value = 8)	1.0 x 8 = 8.0
Organic P source application method (weight = 1.0) is surface applied a month before no-till planting (=HIGH, value =4)	1.0 x 4 = 4.0
	Sum Total of all weighted values = 20.75

Site Vulnerability is HIGH.

HIGH—This site has a HIGH potential for P movement from the site. There is a high probability for an adverse impact to surface water resources unless remedial action is taken. Soil and water conservation as well as phosphorus management practices are necessary to reduce the risk of P movement and probable water quality degradation.

Furrow Irrigation Erosion Site Characteristics

QS value

Q = flow rate of water introduced into the furrow (in gallons per minute, GPM).

S = furrow slope (in feet per 100 feet, percent).

Example: For a 5 gpm flow rate and a 2% furrow grade:

QS = 5 gpm * 2% grade = 10

Relative ranking of soil erodibility under furrow irrigation

Use local criteria to determine the relative erodibility of the soil in question. If no local criteria are established, use the following for guidance:

- Very Erodible Soils

  Soils in which the surface layer texture is silt, or silt loam with < 15% nonmontmorillonitic clay, or fine and very fine sandy loam with < 15% nonmontmorillonitic clay, or loamy fine sand, or loamy very fine sand. Contact a soil scientist for clay content and mineralogy.

- Erosion-resistant Soils

  Soils that have the following characteristics in the upper 5 cm of the surface layer: silty clay, clay, or sandy clay texture, weak or massive structure, and mixed or montmorillonitic clay mineralogy.

  Other soils that have medium or coarse blocky structure or coarse granular structure (i.e. natural aggregates > 10 mm) and very firm or firmer rupture resistance class in the moist state (i.e. requires at least strong force between thumb and forefinger to cause failure of a moist soil aggregate).

See the Soil Survey Manual (1993), chapter 3 for description of soil structural aggregates (peds), and table 3-14 for soil rupture-resistance classes.

- Erodible Soils

Soils that have a surface layer not fitting any of the above criteria.

Table 3 The surface RUNOFF CLASS site characteristic determined from the relationship of the soil permeability class and field slope. Adapted from Soil Survey Manual (1993) Table 3-10.

	Soil Permability Class[1]				
Slope (%)	Very Rapid	Moderately Rapid and Rapid	Moderately Slow and Moderate	Slow	Very Slow
	Runoff Class[3]				
Concave 2	N	N	N	N	N
< 1	N	N	N	L	M
1–5	N	LV	V	M	H
5–10	LV	L	M	H	HV
10–20	LV	L	M	H	HV
> 20	L	M	H	HV	HV

[1] Permeability class of the least permeable layer within the upper 39 inches (one meter) of the soil profile. Permeability classes for specific soils can be obtained from a published soil survey or from local USDA-NRCS field offices.

Soil Permeability Classes in inches per hour (in/hr):

very slow (< 0.06 in/hr); slow (0.06 - 0.20 in/hr); moderately slow (0.20 - 0.60 in/hr); moderate (0.60 -2.00 in/hr); moderately rapid (2.00 - 6.00 in/hr); rapid (6.00 - 20.00 in/hr); very rapid (>20.00 in/hr).

[2] Area from which no or very little water escapes by overland flow
[3] RUNOFF CLASS: N = negligible, LV = very low, L = low, M = medium, H = high, HV = very high.

Table 4 The surface RUNOFF CLASS site characteristic determined from the relationship of the NRCS curve number and field slope. Refer to National Engineering Handbook number 4, 1985.

	Runoff curve Number				
	< 50	50 - 60	60 - 70	70 - 80	> 80
Slope (%)	Runoff Class[1]				
< 1	N	N	N	N	M
1–2	N	N	LV	L	M
2–4	N	N	L	M	H
4–8	N	LV	M	H	HV
8 –16	LV	L	M	HV	HV
> 16	LV	L	H	HV	HV

[1] RUNOFF CLASS: N = negligible, LV = very low, L = low, M = medium, H = high, HV = very high.

Precautions in the Use of the Phosphorus Index

The Phosphorus Index is an assessment tool to be used by planners and landusers to assess the risk that exists for phosphorus leaving the landform site and traveling toward a water body. It also can be used to identify the critical parameters of soil, topography, and management that most influence the movement. Using these parameters, the index then can help select in the selection of management alternatives that would significantly address the potential impact and reduce the risk. The index is intended to be part of the planning process that takes place between the landuser and resource planner. It can be used to communicate the concept, process, and results that can be expected if various alternatives are used in the management of the natural resources at the site. THE PHOSPHORUS INDEX IS NOT INTENDED TO BE AN EVALUATION SCALE FOR DETERMINING WHETHER LANDUSERS ARE ABIDING

WITHIN WATER QUALITY OR NUTRIENT MANAGEMENT STANDARDS THAT HAVE BEEN ESTABLISHED BY LOCAL, STATE, OR FEDERAL AGENCIES. Any attempt to use this index as a regulatory scale would be grossly beyond the intent of the assessment tool and the concept and philosophy of the working group that developed it. As discussed in this technical note the Phosphorus Index is proposed to be adapted to local conditions by a process of regional adaptations of the site characteristic parameters. This local development process must involve those local and state agencies and resource groups that are concerned with the management of phosphorus. After the index is adapted to a locality, it must be tested by the development group to assure that the assessments are giving valid and reasonable results for that region. Field testing of the index is one of the most appropriate methods for assessing the value of the index.

Alternative Approaches for Use of the Phosphorus Index

Using the same site characteristics, but a more complex equation, with the assumptions listed below, another approach has been developed to show potential of phosphorus movement. The Phosphorus Index can easily be modified by altering the basic equation, by developing a factoring method.

The basic assumptions used in this modification of the Phosphorus Index is given below:

- If soil erosion and runoff were both nearly zero, then the phosphorus movement vulnerability should be low.
- If application of P has been nearly zero and the soil test P levels are low, then the phosphorus movement vulnerability should be low.

Using these two assumptions and also assuming that the other key parameters are already identified, then the basic equation needs to be modified to produce the expected answer. There are many possible alternates to the basin equation, this is only an example to show one possibility.

One possible formula would be:

Phosphorus Index rating =

((SE)X(C1) + ((RC) x (C2))) x (((P_{org} applic. rate) + (P_{fert} rate) x (AM) x (C3) + ($P_{soil\ test}$) x (C4))

Where:

SE = Soil Erosion

C1 = Coefficient of weighting erosion, that must be increased if irrigation water is used.

RC = Runoff Class (this should reflect the amount or rate of runoff.

C2 = Coefficient of weighting runoff.

P_{org} applic. rate = Organic P application rate.

P_{fert} rate = Commercial fertilizer

P application rate AM = Application method.

C3 = Coefficient of weighting the application method.

P_{soil} test = Phosphorus level in the soil.

C4 = Coefficient of weighting the phosphorus test level.

The values for these parameters would be the same as used in the basic equation. The four coefficients would be dimensionless, and locally adjusted to calibrate the equation.

A test for this alternative algorithm, or any developed for a specific region, would be to perform field validation. After customizing the algorithm it should be tested using data not used in the development. A site known to be effected by P movement problems should obtain a higher Phosphorus Index rating number than a site that is known not to have any P related problems. Some explanation and adjustment of the algorithm may be needed in order to produce a logical rating with the modified algorithms.

Future Development of the Phosphorus Index

The short term objectives in development of a phosphorus assessment tool, like the Phosphorus Index, are:

- To develop a procedure for field staffs involved in resource management to assess the relative potential that exist for phosphorus leaving the landform site and traveling toward a water body
- To develop a method of using the assessment procedure with in the Phosphorus Index in identifying the critical parameters that most strongly influence the index.
- And then, to select management practices that when applied to the landscape would decrease the site's vulnerability to phosphorus loss.

A long term objective in the development of a phosphorus assessment tool, like the Phosphorus Index, is the use with existing watershed designations and/or water quality models that provide information on sensitivity of water bodies to inputs of phosphorus. The water quality and limnology models need to be sensitive to the form of phosphorus (either particulate or soluble) entering the water body and the specific impact these forms of the nutrient have in the short and long term on water quality. There is a need to link the movement of phosphorus in the landscape to the delivery of phosphorus to the water body. An additional site characteristic that addresses potential for transported P to reach water bodies from the edge of the field would be desirable.

Phosphorus Index Core Team (PICT) Development

Assessing the potential for soil P to move in the landscape and play a significant role in eutrophication of surface waters is a prerequisite for an effective, prioritized nutrient management and water quality program. This phosphorus assessment tool, the Phosphorus Index, as described in this technical note has been developed by a national group of scientist with the USDA, universities, extension, private agencies, and industry. This group was titled the Phosphorus Index Core Team (PICT). The objective of the group was to develop a P indexing procedure that would identify soil, landforms, and management practices with varying degrees of potential risk to have unfavorable impacts on water bodies because of the potential for P movement. This group recognized the need for a simple, field-based index using readily available information that could be used to assess site conditions and potential vulnerability. As this index evolves more detailed research and field information can be added to advance the science and methodology of P assessment. The work group has expanded and diversified its effort (now known as the Southern Regional Extension and Research Information Exchange Group) and continues to develop the science of P behavior and management in the soil.

Use of the Phosphorus Index in the Natural Resources Conservation Service

The Phosphorus Index is a planning tool that can be used in resource management plans, for water and soil quality, nutrient management, and ecosystem based planning assistance in watersheds. It is intended to be used by the planner to communicate to the landuser the relative potential for phosphorus movement in the landscape. The NRCS does not condone or promote the use of the index for placing any restrictions on land use or other regulatory purposes that could be construed by manipulating the parameters of the index.

Use of the Phosphorus Index—An Example

Consider the results of the example provided in Technical Note No. 1901.

An example in using the Phosphorus Index	
Soil erosion (weight = 1.5) is 7.5 ton/ac/yr (=MEDIUM, value = 2)	1.5 x 2 = 3.0
Irrigation erosion (weight = 1.5) is not applicable (=NONE, value =0)	1.5 x 0 = 0
Runoff class (weight = 0.5) is LOW (value = 1)	0.5 x 1 = 0.5
Soil P test (weight = 1.0) is 82 lb P (=HIGH, value = 4)	1.0 x 4 = 4.0
P fertilizer application rate (weight = 0.75) is 25 lb/ac (=LOW, value = 1)	0.75 x 1 = 0.75
P fertilizer application method (weight = 0.5) is placed with planter(=LOW, value = 1)	0.5 x 1 = 0.5
Organic P source application rate (weight = 1.0) is 95 lb/ac (=VERY HIGH, value = 8)	1.0 x 8 = 8.0
Organic P source application method (weight = 1.0) is surface applied a month before no-till planting (=HIGH, value =4)	1.0 x 4 = 4.0
	Sum Total of all weighted values = 20.75

The sum total of all weighted values was 20.75. Using table 1 in Technical Note No. 1901, the total fell in the High category between 15 and 32. The overall interpretation of this site vulnerability rating is as follows:

HIGH—This site has a HIGH potential for P movement from the site. There is a high probability for an adverse impact to surface water resources unless remedial action is taken. Soil and water conservation as well as phosphorus management practices are necessary to reduce the risk of P movement and probable water quality degradation.

This particular site has a high probability for an adverse impact to surface water quality if existing management is not adjusted to reduce the site vulnerability. Sites with a vulnerability rating greater that Low, especially those in the High and Very High category, should be targeted as sites with the greatest potential to accelerate eutrophication and adversely impact surface water quality. The P Index can also be used to identify management options available to land users and will allow them flexibility in developing remedial strategies. The first step is to determine the P Index for sites adjacent to sensitive waters and prioritize the efforts needed to reduce P losses. Then, management options appropriate for soils with different P Index ratings can be implemented. General recommendations are given in table 5.6; however, P management is site specific and requires a well-planned, coordinated effort by the farmer, extension agronomist, and soil conservation specialist.

Table 5.6 Management options to minimize nonpoint source pollution of surface waters by soil P (from Agricultural Phosphorus and Eutrophication, Sharpley et.al. 1999), Phosphorus Index.

Phosphorus Index	Management Options
<8 (Low)	Soil testing: Test soils for P at least every 3 years to monitor buildup or decline in soil P. Soil conservation: Follow good soil conservation practices. Consider effects of changes in tillage practices or land use on potential for increased transport of P from site. Nutrient management: Consider effects of any major changes in agricultural practices on P loss before implementing them on the farm. Examples include increasing the number of animal units on a farm or changing to crops with a high demand for fertilizer P.
8 to 14 (Medium)	Soil testing: Test soils for P at least every 3 years to monitor buildup or decline in soil P. Conduct a more comprehensive soil testing program in areas identified by the P index as most sensitive to P loss by surface runoff, subsurface flow, and erosion. Soil conservation: Implement practices to reduce P loss by surface runoff, subsurface flow, and erosion in the most sensitive fields (that is, reduced tillage, field borders. grassed waterways. and improved irrigation and drainage management). Nutrient management: Any changes in agricultural practices may affect P loss; carefully consider the sensitivity of fields to P loss before implementing any activity that will increase soil P. Avoid broadcast applications of P fertilizers and apply manure only to fields with low P index values.

Phosphorus Index	Management Options
15 to 32 (High)	Soil testing: A comprehensive soil testing program should be conducted on the entire farm to determine fields that are most suitable for further additions of P. For fields that are excessive in P, estimates of the time required to deplete soil P to optimum levels should be made for use in long-range planning. Soil conservation: Implement practices to reduce P loss by surface runoff, subsurface flow, and erosion in the most sensitive fields (that is, reduced tillage, field borders, grassed waterways, and improved irrigation and drainage management). Consider using crops with high P removal capacities in fields with high P index values. Nutrient management: In most situations involving fertilizer P, only a small amount used in starter fertilizers is needed. Manure may be in excess on the farm and should only be applied to fields with lower P index values. A long-term P management plan should be considered.
>32 (Very High)	Soil testing: For fields that are excessive in P, estimate the time required to deplete soil P to optimum levels for use in long-range planning. Consider using new soil testing methods that provide more information on environmental impact of soil P. Soil conservation: Implement practices to reduce P loss by surface runoff, subsurface flow, and erosion in the most sensitive fields (that is, reduced tillage. field borders, grassed waterways, and improved irrigation and drainage management). Consider using crops with high P removal capacities in fields with high P index values. Nutrient management: Fertilizer and manure P should not be applied for 3 years or more. A comprehensive, long-term P management plan must be developed and implemented.

Using the individual site characteristics, let's identify some factors of concern and management options that could be used to reduce the site vulnerability.

Soil Erosion—The soil erosion rate was 7.5 tons/ac/yr, falling in the Medium category. Prediction models are used in the index to indicate a movement of soil, thus potential for sediment and attached phosphorus movement across the slope or unsheltered distance and toward a water body. Such conservation measures as residue management or reduced tillage should be considered as a way to reduce erosion. In addition, other conservation measures like field borders, grassed waterways and improved drainage management should be considered as a means to mitigate offsite transport and improve the quality of runoff leaving the field.

Soil P Test—The soil P test was High. Remember that the soil test level for "available P" does not measure the total P in the surface soil. It does however, give an indication of the amount of total P that may be present because of the general relationship between the forms of P and the solution P available for crop uptake. Research has conclusively shown that the higher the soil test P level of a site, the proportionately higher the potential P loss will be from that site. Therefore the long-term goal should be to conduct a comprehensive soil testing program on the entire farm to determine fields with lower soil test P levels that are more suitable for additions of phosphorus. For fields with excessive P levels, estimates should be made to determine the time required to deplete the soil P to optimum levels.

Organic P Source Application Rate—The organic P source application rate was 95 lb/ac, falling in the Very High category. This particular site characteristic is especially important. Here we have a field with a soil test P level that is already high and very high rates of organic P are being applied. Considering the long-term management options discussed under Soil P Test, the organic P application rate should either be reduced to crop P uptake or less, or no organic P should be applied to this field until the soil P is depleted back to an optimum level. The organic P material should be applied to fields with lower soil P test and index values.

Organic P Source Application Method—The organic P source application method was surface applied a month before no-till planting, falling in the High category. Remember that the manner in which organic P material is applied to the soil and the time that the organic material is exposed on the soil surface until crop use can determine potential P movement. Because the organic P was surface applied a month before the crop was planted, and the crop to be planted was a no-till crop, the organic P would not be incorporated and would have a substantial surface exposure time between application and crop uptake. Mechanical incorporation by reducing the amount of nutrients in the thin mixing zone at the soil surface and/or on crop residue or foliage, reduces the interaction with and transfer of nutrients to runoff water and thereby reduces runoff loss. Incorporated material is more subject to downward movement. With incorporation, other environmental losses may also be reduced, and nutrient management may be improved. However, mechanical incorporation with tillage may reduce soil protecting crop residue and increase erosion. Leaching losses may—but are not likely to—be increased, and the relative importance of the different loss pathways needs to be considered. The organic P material should be injected or incorporated if possible, and applied immediately before the crop is planted.

Introduction to the Leaching Index

The amount of water that percolates through the soil and below the crop's root zone is important in determining the amount of nitrate nitrogen leached. Various crop, soil, and climate factors interact to affect the amount of deep percolation. A Leaching Index (LI) for each soil hydrologic group has been developed for various regions of the country. The Leaching Index uses soil hydrologic groups (A, B, C, and D), annual precipitation, and seasonal rainfall when no crops are growing to estimate plant transpiration. The Leaching Index for local areas can be found in the Field Office Technical Guide, Section II or may be calculated using the following equations.

Leaching Index (LI) = Percolation Index (PI) x Seasonal Index (SI), where:

$$PI = \frac{(P - 0.4s)^2}{P + 0.6\ s}$$

P = average annual precipitation (inches)

s = (1000/ CN) - 10

CN = SCS curve number

PI = average annual percolation (inches)

An alternate calculation for the Percolation Index is:

For Hydrologic Soil Group A, PI = $(P - 10.28)^2 / (P + 15.43)$
For Hydrologic Soil Group B, PI = $(P - 15.05)^2 / (P + 22.57)$
For Hydrologic Soil Group C, PI = $(P - 19.53)^2 / (P + 29.29)$
For Hydrologic Soil Group D, PI = $(P - 22.67)^2 / (P + 34.00)$

$SI = (2\ PW / P)^{1/3}$

PW = Fall and winter precipitation when crop growth is minimal, usually the sum of precipitation during the months of October, November, December, January, February, and March.

P = annual precipitation (inches)

Guidelines for leaching assessment

- A LI less than 2 inches would probably not contribute to soluble nitrogen leaching below the root zone.
- A LI between 2 and 10 inches may contribute to soluble nitrogen leaching below the root zone. Nutrient management practices and techniques such as split nitrogen application rates, pre-sidedress nitrate nitrogen testing or other locally recommended nitrogen testing, and use of a nitrification inhibitor should be considered.

- A LI larger that 10 inches will contribute to soluble nitrogen leaching below the root zone. Intense nitrogen management must be employed to minimize nitrate nitrogen movement. This would include careful management of applied nitrogen, precise timing to match crop use, conservation practices that restrict water percolation and leaching, and cover crops that capture and retain nutrients in the upper soil profile.

Use of the Leaching Index in the Natural Resources Conservation Service

The Leaching Index is a planning tool that can be used in resource management planning to protect ground water quality. It is to be used by the planner to communicate to the land user the relative potential for nitrogen leaching. The NRCS does not condone or promote the use of the index for placing any restrictions on land use or other regulatory purposes that could be construed by manipulating the parameters of the index.

Use of the Leaching Index—An Example

Consider the results of the following example:

Annual precipitation	50 inches
Seasonal precipitation from October to March	25 inches
Soil Hydrologic Group	C
Percolation Index, PI = $(50 - 19.53)^2 / (50 + 29.29)$ =	11.71 inches
Seasonal Index, SI = $[2(25) / 50]^{1/3}$ =	1.0
Leaching Index, LI = 11.71/1 =	11.71 inches

The Leaching Index for this example is 11.71. Because the LI is greater than 10, the Guidelines for Leaching Assessment indicate this site will contribute to soluble nitrogen leaching below the root zone. A nitrogen budget should be developed to account for all significant nitrogen sources and to match the application rate to the remaining amount needed to achieve a realistic yield goal. Intrusive nitrogen management must be employed to minimize nitrate nitrogen movement. This would include careful management of applied nitrogen, precise timing to match crop use, conservation practices that restrict water percolation and leaching, and cover crops that capture and retain nutrients in the upper soil profile. It would also include nutrient management practices and techniques such as split nitrogen application rates, pre-sidedress nitrate nitrogen testing or other locally recommended nitrogen testing, and use of a nitrification inhibitor.

Student Activity 4

Phosphorus Index Calculation

Hypothetical Field

Soil erosion (weight = 1.5) is 1.5 ton/ac/yr	1.5 x ? = ?
Irrigation erosion (weight = 1.5) is 20 tons/ac/yr	1.5 x ? = ?
Runoff class (weight = 0.5) is LOW	0.5 x ? = ?
Soil P test (weight = 1.0) is High	1.0 x ? = ?
P fertilizer application rate (weight = 0.75) is 25 lb/ac	0.75 x ? = ?
P fertilizer application method (weight = 0.5) is placed with planter	0.5 x ? = ?
Organic P source application rate (weight = 1.0) is 95 lb/ac	1.0 x ? = ?
Organic P source application method (weight = 1.0) is surface applied in the Fall prior to a Spring crop	1.0 x ? = ?
Sum Total of all weighted values = ?	

Use the hypothetical example above and table 1 in Technical Note No. 1901 to answer the following questions:

1. List the overall vulnerability of this site and explain the general vulnerability to P loss.

2. Using the individual site characteristics, identify the primary factors of concern that are contributing to the site vulnerability rating.

3. Using the primary factors identified in question 2, list some management options that could be used to reduce the site vulnerability.

____

____

____

____

____

____

____

____

Leaching Index Calculation

Hypothetical Field 2

Soil erosion (weight = 1.5) is 1.5 ton/ac/yr	1.5 x ? = ?
Irrigation erosion (weight = 1.5) is 20 tons/ac/yr	1.5 x ? = ?
Annual precipitation	25 inches
Seasonal precipitation from October to March	12 inches
Soil Hydrologic Group	C
Percolation Index, PI	? inches
Seasonal Index, SI	?
Leaching Index, LI	? inches

Use the hypothetical example above for Field 2 and the Guidelines for Leaching Assessment to answer the following questions:

4. List the Leaching Index for this site and indicate whether or not nitrate leaching may be a concern.

____

____

____

____

____

____

5. Would nitrogen management be important on this field?

____

____

____

____

____

____

Hypothetical Field 3

Soil erosion (weight = 1.5) is 1.5 ton/ac/yr	1.5 x ? = ?
Irrigation erosion (weight = 1.5) is 20 tons/ac/yr	1.5 x ? = ?
Annual precipitation	45 inches
Seasonal precipitation from October to March	30 inches
Soil Hydrologic Group	B
Percolation Index, PI	? inches
Seasonal Index, SI	?
Leaching Index, LI	? inches

Use the hypothetical example above for Field 3 and the Guidelines for Leaching Assessment to answer the following questions:

6. List the Leaching Index for this site and indicate whether or not nitrate leaching may be a concern.

   ____

   ____

   ____

   ____

7. Would nitrogen management be important on this field?

   ____

   ____

   ____

   ____

8. What sort of nitrogen management should be considered for this field?

Module 5, Part D, Section 3—Environmental Risk Analysis: Pest Management

Hazards and Risks from Pest Management Activities

Supporting Objectives

- Describe NRCS' role in Pest Management.

According to NRCS' Pest Management Policy, NRCS' first two roles in pest management are:

- Evaluating environmental risks associated with probable pest management recommendations, and
- Developing appropriate mitigation alternatives to minimize environmental risks.

NRCS is uniquely qualified to carry out these roles because we can provide environmental risk information not generally provided by Extension agents or crop advisors. NRCS can additionally integrate mitigation for identified risks into the overall conservation plan. NRCS has a proven track record of providing analysis of soil loss and planning conservation techniques that conserve soil resources. Many of the techniques used to prevent soil movement and subsequent loss can be used to reduce the risks of pesticide movement as well. Filter strips, for example, can be used to trap soil and trap pesticides.

The 'probable' in "Evaluating environmental risks associated with probable pest management recommendations", refers to those pest management recommendations that are most likely to be used by the producer for that particular field/crop rotation sequence. It is the list of pest management techniques from which the producer has agreed to choose from. It does not need to include the entire range of possible recommendations that are available, but only those that the producer would most likely use. The word ‘probable’ was used because a single, specific, pest management alternative cannot always be chosen in advance.

In fact, IPM discourages using ‘preventive’ suppression techniques, such as applying a herbicide before the pest pressure can be determined. IPM would encourage using a more ‘wait and see’ approach. That is, suppression would only occur when a pest pressure reaches an economic threshold. Some years the threshold would not be met and chemical suppression would not be needed. Other years, the threshold may be reached several times, and several different suppression techniques must be used to prevent resistance.

Many crop consultants will complain that they cannot always predict, in advance, what specific chemicals they will recommend. They do however, agree that they have a list of chemicals that they have good luck with under specific conditions. This list is further culled down to the chemicals that the producer, in question, would most likely choose. Typically, producers will choose pesticides that are the least expensive and have worked for them in the past. If the occurrence of potential pests can be predicted, a list of probable pest management can be developed. These predictions are not necessarily ‘out-of-thin-air’. Past pest pressures on that field, typical pest pressures for that crop and region, potential pest pressures based on rotation sequence, can all be used to develop a ‘probable’ pest management list. This list, barring any unusual circumstances, becomes the list from which the producer agrees to choose.

Mitigation strategies can then be planned to address the environmental risks associated with all of the probable pest management alternatives. Some producers may want to choose alternatives that typically have the same loss pathway. For example, all herbicides chosen in advance (making them 'probable') by a producer may have a high potential to runoff (both in solution and adsorbed to sediment). Mitigation can then be planned that encourages infiltration and discourages sediment transport. The mitigation planned should be designed to adequately reduce the risk of the most hazardous probable alternative. Even if the producer does not actually use the most hazardous alternative that year, the mitigation should be designed to deal with it. The important thing is there would be adequate resource protection if the producer were to choose that alternative. If the producer agrees to use only low hazard alternatives, then the mitigation does not need to be substantial. If however, one alternative has a high risk, then the mitigation must be planned to address that risk. As long as there is a relatively good probability that the hazardous alternative could be used, it should be mitigated. By making a good faith effort to evaluate potential alternatives that may be used, frequent 'emergency' updates of the plan are not needed.

Periodically, an unforeseen situation may occur that will result in abandoning the planned alternatives for a different, unplanned alternative or set of alternatives. In this case, the unplanned alternative should be applied as timely as possible to manage the pest. The plan and probable pest management list should be updated to minimize this situation in the future. Unless the alternative was completely unforeseen, the unplanned alternative should be added to the producers 'agreed to' choice list. If the alternative was less risky than other choices on the agreed list, no further mitigation needs to be planned. If however, the alternative used was more hazardous than those already planned, new mitigation might need to be added to the plan.

The probability of using that more hazardous alternative again should be the guide as to whether a more resource protective set of mitigation is needed. Consultation with the producer's pest management advisor might be needed to assess the probability of using that alternative in the future.

These risk evaluations are not just limited to pesticides. They can also include environmental risks associated with cultivation or certain cultural techniques like burning or removing crop residue. As an example, cultivation may lead to soil loss, thereby degrading the soil resource, and, if eroded soil enters a stream or pond, sediment contamination of waterbodies may occur. Concerning pesticides, NRCS' charge is to help farmers evaluate the potential environmental risks (especially to water quality) of recommended pesticide management alternatives, and further, to provide mitigation strategies that reduce potentially hazardous offsite pesticide losses.

Tools are available nationwide to help conservationists analyze environmental risks associated with pest management. The Windows Pesticide Screening Tool (WIN-PST) is a new NRCS field-office-level pesticide risk-screening tool that will be presented later in this module. Other more detailed pesticide environmental risk evaluation tools like NAPRA (National Agricultural Pesticide Risk Analysis), also discussed later in this module, will be available in some areas. RUSLE (Revised Universal Soil Loss Equation) can be used to evaluate erosion losses associated with cultivation practices for weed control. Impacts of other pest management practices will often be more difficult to evaluate. Air quality impacts of residue burning may be obvious, but the long-term negative environmental impacts associated with the release of a new predator species, for example, may not be immediately known. When tools are not readily available, environmental risk analysis will be left up to the professional discretion of the conservation planner.

Environmental risks of pest management include both point and non-point source pesticide risks. Point source pesticide risks include pesticide spills from transportation accidents, improper storage, improper mixing/loading and misapplication. Non-point source pesticide risks are generally from pesticide residue that move away from the site of application in water, air, or attached to eroded sediment. Both point and non-point source pesticide contamination may contribute to impaired water quality, but in this course we will focus on non-point source pest management risks. Point source pesticide contamination is addressed with traditional Pesticide Applicator Training (PAT), which should be taken by all conservation planners. Although there are exceptions, high concentrations of pesticides in ground water are generally caused by point source contamination, but high concentrations of pesticides in surface waterbodies may be caused by either point or non-point source contamination, or both.

Module 5, Part D, Section 4— Environmental Risk Analysis: Pest Management

Hazards and Risks from Non-Chemical Pest Management Activities

Supporting Objectives

- List several non-chemical pest control techniques
- Give an example of how a non-chemical pest control technique could pose a risk to the environment
- Give an example of a tool that can be used to evaluate the risk of cultivation

Not all pest management activities center on using pesticides. There are many techniques available that can be used to manage pests. These include: using weed-free seed; using disease and insect resistant varieties (both genetically modified organisms (GMO) and traditionally bred varieties); mechanical controls such as cultivation, mowing, and vacuuming; burning; use of predator species; planting earlier or later; and crop rotation. The list of potential strategies used to manage pests is quite extensive. The list of pest management strategies available for commercial agriculture, however, is often limited to those that are cost effective while providing adequate pest control.

There may be environmental hazards and risks to SWAPA resources from non-chemical pest management practices. Cultivation for example, can be used to disturb weeds by covering them with soil or up-rooting them. Cultivation, even when done carefully and correctly, can lead to excess erosion that degrades the soil resource. Additionally, eroded sediment can leave the field, causing siltation of nearby streams, rivers, ponds, or lakes. Aquatic life can be negatively impacted in streams that have high loads of fine silts and clays. Suspended silt and clay interferes with proper gill function in fish, and can also decrease dissolved oxygen. Additionally, fine sediment particles that settle at the bottom of streams and lakes can destroy aquatic habitat for many species.

Releasing new predator species or augmenting an existing predator population can help to manage pest populations. Many pests in agriculture are not indigenous. That is, they are not native. They have been introduced: by accident; to solve another problem (such as autumn olive and multiflora rose); as an ornamental (such as purple loosestrife); or have migrated with the spread of cropping practices (such as Colorado potato beetle) Because these pests are relatively new to an area, they usually have no indigenous predators or diseases to keep there population under control.

Some “bio-intensive” techniques in IPM use the release of predators or diseases that have evolved with the pest. The idea behind this technique is that through co-evolution, pest/predator and pest/disease populations have come into balance and therefore drastic pest population explosions will not occur. By introducing the co-evolved predator or disease, population balances will be restored to a level where the pest no longer causes significant economic damage. However, release of non-indigenous predators or diseases can be an environmental risk if these predators move beyond the target species and affect other potentially beneficial or neutral species. They may also significantly impact habitat for other species simply because of their uncontrolled population bursts or spread. Because these new “introduced” predator species may have no indigenous controls, their populations can quickly skyrocket.

Genetically modified plants have the potential to 'escape' into the natural environment and crossbreed with non-genetically modified plants. Making the genetically modified plants infertile usually minimizes this risk. Microbial pest control agents' may also be hazardous to non-target species, and thus have the potential to escape, uncontrolled, into the environment.

Evaluating the environmental risks of many of these non-chemical pest management techniques is beyond the ability of NRCS. We do, however, have tools that can evaluate effects of certain practices such as cultivation or crop rotation. RUSLE and WEQ can be used to estimate erosion losses. Erosion predictions can then be used to estimate off-site sediment movement. Mitigations such as filter strips, cross wind traps, and vegetative barriers, can then be planned to minimize movement of sediment past the edge of the field.

Note: Meeting soil loss tolerance (T) values does not necessarily prevent siltation of ponds or streams. Soil loss at or below "T" may sustain the soil resource within the field, but additional conservation measures may be needed to protect neighboring water resources.

Module 5, Part D, Section 5— Environmental Risk Analysis: Pest Management

Hazards and Risks from Pesticides

Supporting Objectives

- List the two components needed to create a pesticide hazard.
- Describe what makes a “hazard” a “risk”.
- Explain “relative” vs. “absolute” risk evaluation.
- Describe how “normalization” for toxicity allows pesticide hazards to be compared.
- Explain uncertainly factors in toxicity thresholds.

When we define “pesticide risk we talk about the chance of exposure to a pesticide that will cause injury or loss. The “pesticide that will cause injury or loss” is the hazard and the “chance” is the probability that it will occur.

Risk = Probability of hazard

To have a pesticide hazard you need two components:

- Toxicity—which is a property of a chemical to cause deleterious effects on a living organism, and
- Exposure—which is contact between the living organism and the chemical.

Hazard = Toxicity x Exposure

If toxicity is held constant, exposure determines the magnitude of the hazard, so risk becomes the probability of exposure to a given hazard. That is, the hazard of a chemical with a specific toxicity, is equal to the exposure. Therefore, risk becomes the probability of exposure to a chemical.

To characterize toxicity we use thresholds. Thresholds provide a measure of whether an exposure is at the concentration that causes a specific deleterious effect. Thresholds for water quality are usually based on a length of exposure to a given concentration. For example, a 96 hour LC_{50}, is the concentration that kills 50 percent of the test population after 96 hours of exposure. At or above this threshold, certain deleterious effects are expected, in this case "death of 50 percent of the population." Below the threshold, the deleterious effect is not expected, "50 percent of the population is not killed." For more information on toxicity and thresholds, see *Module 2, Part B, Section 3—Pesticide Toxicity and Module 5, Part D, Section 10— Toxicity thresholds used in WIN-PST and NAPRA.*

The magnitude and length of exposure above a given toxicity threshold can be used to measure hazard. The number of times the organism is exposed to concentrations above the threshold can be used to measure risk. For long-term exposure through drinking water, certain thresholds have been developed, including EPA's *MCL* (Maximum Contaminant Level) and *HA* (Health Advisory), (See Module 2, Part B, Sections 3 and 4). The *Lifetime HA* is defined by the EPA as: *"The concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic effects over a lifetime of exposure, with a margin of safety."* The *MCL* is defined as the *"maximum permissible level of a contaminant in water, which is delivered to a any user of a public water system."*

These thresholds are used to characterize the hazards associated with a lifetime of exposure to a chemical in drinking water. In theory, exposure to levels above the threshold would have some deleterious effect on certain individuals who drink the water. In other words, chronic exposure to pesticide levels above the established HA would constitute risk. Conversely, exposure to levels under the HA or MCL, would not pose any significant risk. An analogous long-term threshold for fish is the *MATC* (Maximum Acceptable Toxicant Concentration). This is the threshold, above which there would be some negative impact on the fish population, from long-term exposure to that chemical.

Figure 5.3 is a graph of the potential hazard from pesticide runoff, estimated by the NAPRA (National Agricultural Pesticide Risk Analysis) model. Average annual pesticide concentrations in runoff, at the edge of the field (shown), and leaching at the bottom of the root zone, are estimated using 49 years of daily historic climate data. The loss concentrations are then compared with a pesticide's long-term toxicity threshold, in this case 3 ppb, to create a relative measure of risk. *See sidebar Relative vs. Absolute.* Yearly concentrations above the HA are considered 'hazardous'. The number of years the threshold was exceeded is a measure of the 'risk'. Concentrations that do not reach the threshold represent 'no significant hazard'. Because NAPRA estimates not only toxicity and exposure, but also the frequency of the hazard, it can be used to estimate relative 'risks' of off-site pesticide movement.

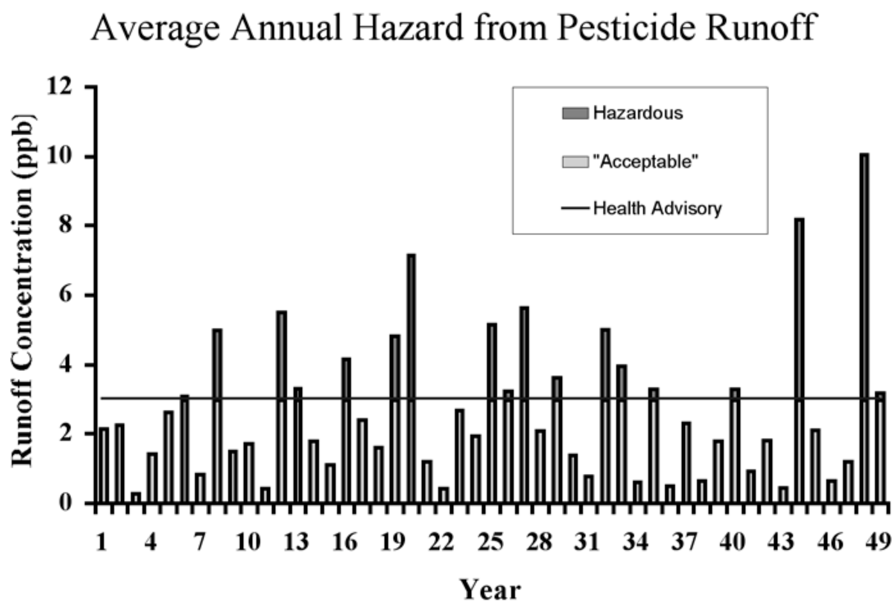


Figure 5.3 Average annual pesticide concentration in runoff.

Relative vs. Absolute

Through computer modeling, we can estimate relative pesticide concentrations in either runoff or leachate with some degree of accuracy. That is, modeling does well at comparing two or more chemicals, application techniques, crop rotations, tillage systems, soil conditions or any combination of these. It is less accurate at determining absolute concentrations of any one chemical. For instance, the GLEAMS model, on which the NAPRA model is based, usually estimates losses within a factor-of-two of measured data. In other words, the confidence interval is between 50 percent and 200 percent of the actual concentration. A modeled loss of 300 ppb for a baseline condition would be 'within the 2x criteria' if the measured concentration ranged from 150 ppb to 600 ppb. The relative nature of modeling would permit a comparison of the 300 ppb modeled loss, without pesticide incorporation (the baseline condition), with a modeled loss of 100 ppb with incorporation. It would then be realistic to assume that incorporation would reduce pesticide loss by approximately threefold.

To compare management techniques that can influence off-site pesticide movement, the hazard shown in figure 5.3 can be 'normalized' for toxicity by dividing the edge-of-field/bottom-of-root-zone pesticide concentration by its appropriate toxicity threshold (figure 5.4). Normalizing for toxicity allows chemicals with different thresholds to be directly compared to each other. A pesticide with a runoff concentration of 15 ppb and a threshold of 3 ppb would have the same hazard potential as a pesticide with a 1500 ppb runoff concentration and a 300 ppb threshold.

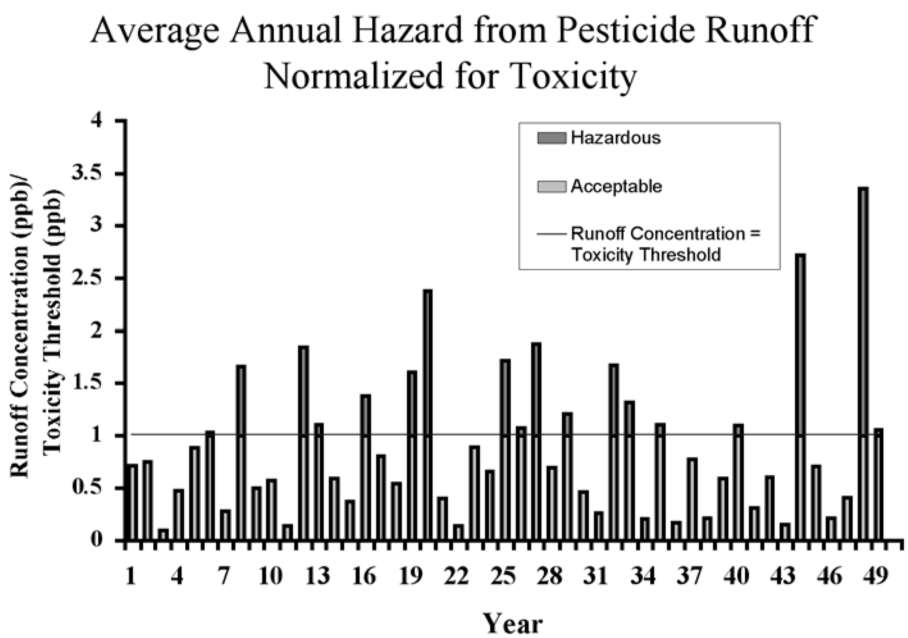


Figure 5.4 Average annual pesticide concentration in runoff divided by the pesticide toxicity threshold (Health Advisory).

Comparison of the many management techniques that can influence off-site pesticide movement, is the power of NAPRA and WIN-PST. The following bar chart, developed from NAPRA analysis, illustrates how the relative risk of different pesticides, pesticide application methods, and tillage methods can be used to develop the pest management component of a conservation plan. Figure 5.5 shows the effect of different tillage and pesticide application methods on potential risks from runoff of several herbicides.

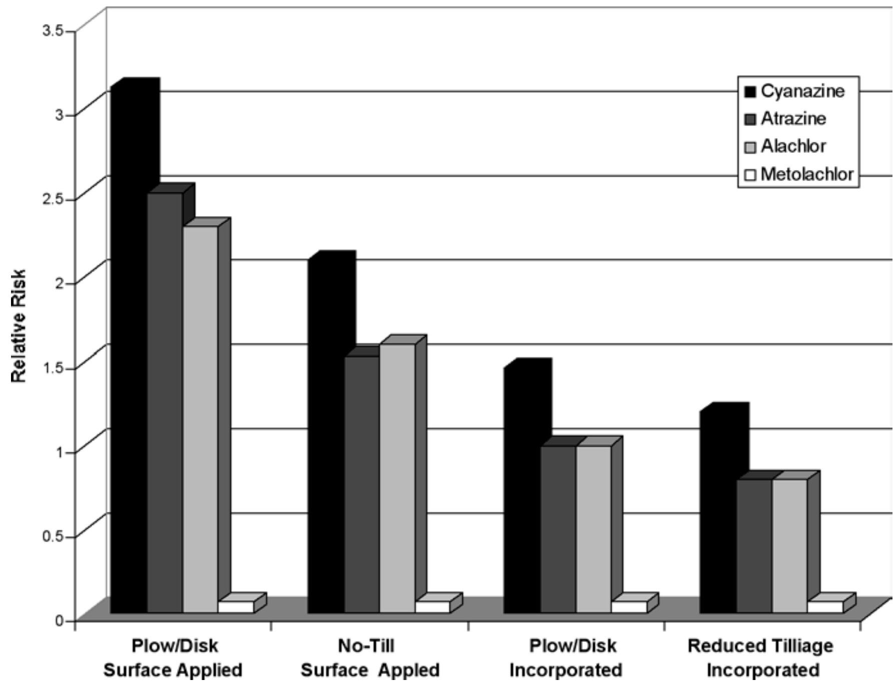


Figure 5.5 NAPRA relative pesticide runoff risk by application method and tillage type (at relative risk = 1, runoff concentration equals the toxicity threshold).

Figure 5.5 was developed by normalizing loss concentrations for toxicity for each year in the simulation, summing the normalized data, and then dividing by the number of years in the simulation. To understand how figure 5.5 was created, refer back to figure 5.4. The part of the bars labeled ‘Hazardous’ is added together (summed) and then divided by the number of years in the simulation (in figure 5.4, this equals 49 years). The result is a measure of relative hazard, independent of the number of years in the simulation. Higher numbers denote higher relative hazard-risk potential. A value of one denotes where runoff concentration equals the toxicity threshold. Above one, estimated concentrations were above the toxicity threshold, and would therefore be potentially hazardous.

This bar chart, however, does not represent the frequency of potentially hazardous concentrations, or the magnitude of individual losses. For that, data presentations such as figure 5.4

are necessary. Figure 5.5 does provide an easily understandable, relative comparison between tillage and pesticide incorporation methods. It is clear in this NAPRA example that residue management and pesticide incorporation could reduce hazardous pesticide runoff for three of the four pesticides modeled. Metolachlor's hazard potential was not influenced by tillage or application method, because of its relatively low long-term human toxicity (higher threshold). Below a value of one, risks are considered acceptable because they, on average, have not exceeded their respective threshold.

Because there may be some risks associated with exposures below any given threshold value, EPA has added a safety factor when estimating their drinking water standards. Any potential risk is taken care of by adding uncertainty factors in calculating each toxicity threshold value. For instance, the first step in calculating the lifetime HA for a pesticide with a 'D' (inadequate or no human data and animal evidence of carcinogenicity) or 'E' cancer class (no evidence of human carcinogenicity), is to divide the NOAEL (No Observable Adverse Effect Level) by an uncertainty factor based on the reliability of available toxicity data. Because of EPA's method of using uncertainty factors, we assume that risk is 'acceptable' at concentrations below the HA or MCL. See sidebar Guidelines Used in Selecting Uncertainty Factors for HAs.

Guidelines Used in Selecting Uncertainty Factors for HAs

An uncertainty factor of 10 is generally used when good chronic or subchronic human exposure data identifying a NOAEL (No Observable Adverse Effect Level) are available, and are supported by chronic or subchronic toxicity data in other species.

An uncertainty factor of 100 is generally used when good chronic toxicity data identifying a NOAEL are available for one or more animal species (and human data are not available), or when good chronic or subchronic toxicity data identifying a LOAEL (Lowest Observable Adverse Effect Level) in humans are available.

An uncertainty factor of 1,000 is generally used when limited or incomplete chronic or subchronic toxicity data are available, or when good chronic data that identify a LOAEL but not a NOAEL for one or more animal species are available.

An uncertainty factor of 10,000 may be used when a subchronic study identifying a LOAEL but not a NOAEL is used.

[a]Source: NAS (1977, 1980) as modified by the USEPA Office of Drinking Water.

Module 5, Part D, Section 6— Environmental Risk Analysis: Pest Management

NRCS' Role in Pesticide Risk Analysis

Supporting Objectives

- Explain NRCS' role in making pesticide recommendations.
- Explain how environmental risk assessment differs from environmental risk analysis.
- Explain how environmental risk screening differs from and environmental risk analysis.

Introduction

NRCS' conservation planning process must address multiple resource concerns. Concerning pest management, NRCS' charge is to help farmers evaluate the potential environmental risks of all pest management activities impacting SWAPA resources, including recommended pesticide management alternatives. Further, NRCS provides mitigation strategies that reduce potentially hazardous off-site pesticide losses to water resources of concern. NRCS strongly encourages the use of Integrated Pest Management and should provide environmental risk analysis not only for existing alternatives, but also during the process of developing new IPM alternatives with pest management consultants.

"*Recommended*" in "recommended pesticide management alternatives" deserves special attention. *NRCS' role is not to recommend any specific pesticide, group of pesticides, or a specific spray program*. This is the exclusive domain of those responsible and licensed for making pesticide recommendations, such as crop consultants, Certified Crop Advisors (CCAs) or Extension personnel.

Pesticide recommendations are usually based on the *efficacy* of a certain product on a certain pest and economics. The term efficacy means *the effectiveness of the pesticide to control the pest*. Other factors may come into play when pesticide recommendations are being made, including, but not limited to: toxicity of the pesticide to the current crop; toxicity to other crops in the rotation; whether the specific crop and/or pest is listed on the label; cost of the product; and available application equipment.

Our responsibility is to evaluate the potential environmental risks of recommended pest management alternatives and provide mitigation measures to reduce the potential for hazardous pesticide losses. To better understand NRCS' role in pest management, two helpful analogies have been created, using two common professions. Please refer to the sidebar: Helpful Analogies: NRCS' role in Pest Management

Helpful Analogies: NRCS' Role in Pest Management

Pharmacist/Prescription Analogy

Perhaps the best way to describe the role of NRCS conservationists in making pesticide recommendations is to use an analogy of physicians, pharmacists, and prescriptions. Cooperative Extension (CE) agents and Certified Crop Advisors (CCA) are much like physicians. Like physicians, who can legally write prescriptions for drugs, CE agents and CCAs, with proper licensure, can legally "prescribe" or recommend pesticides. Their recommendation is based on maximizing efficacy (effectiveness of the pesticide to control the pest is the primary concern), and minimizing costs (least cost per acre), and is derived from extensive knowledge of the pest and crop. The Extension agent or crop advisor will also take into account the toxicity of the chemical to the crop or future crops in the rotation. The professional making the recommendation should also consider other aspects of pest control such as the development of pest resistance to the pesticide(s) being used.

NRCS' job as a "pharmacist" is not to prescribe (recommend) pesticides, but to evaluate Extension's or crop advisor's pesticide recommendations for environmental risk. When filling a prescription, the pharmacist may ask you what other drugs you are taking and advise you of any potential interactions. The pharmacist will additionally provide information like "to be taken after meals" or "avoid exposure to sunlight." Your pharmacist might refer you back to your physician if the drug prescribed could interact with another drug you are taking (over-the-counter medication) that the doctor was not aware of or did not take into account.

The pharmacist has several jobs including: 1) warning customers of potential drug interactions and, 2) protecting customers from risk posed by certain drugs and drug interactions. As with any profession that deals with risk, customer education is always a powerful tool. So pharmacists don't just warn they also educate.

Similarly, conservationists need to warn our customers about pesticide losses caused from 'interactions' of soils and pesticides, and, if any resources can be negatively impacted. Impacted resources could be ground water recharge areas, shallow ground water, karst topography, and nearby streams and ponds. We can protect resources by planning mitigation strategies that help prevent hazardous off-site pesticide movement. It is also acceptable to work with the producer's pest management specialist to see if other 'lower risk' alternatives are available. Further, we can educate our customers about what causes hazardous pesticide losses, and, how such losses can be prevented.

Just as pharmacists can suggest non-prescription items, such as knee supports or vaporizers, conservationists may suggest a non-chemical pest control such cultivation or planting pest resistant varieties.

General Contractor Analogy

Much like the pharmacist/physician analogy, the conservationist's job is analogous to another profession: a general contractor. When building a house, the general contractor acts as the project's coordinator. The conservationist acts as the conservation plan coordinator. The general contractor needs to make sure that the carpenters, plumbers, and electricians do their job properly. A task like building an entire house can seem overwhelming. The task of developing a conservation plan, which now must include pest management, may seem as daunting.

When developing the pest management portion of a conservation plan, the conservationist is not required to do all jobs needed. The general contractor does not need to be a plumber, architect, electrician, roofer, or framer. They just need to see that each job is done correctly (according to the plans). It is helpful though, that the general contractor knows something about each of the trades being used in construction. However, they don't need to be an expert on every subject. The general contractor can do some of the construction work also. As a conservationist, you are not expected to be an expert on pest management. That is what we leave to the Extension agent or CCA. You should be familiar enough with pest management to understand the basics, and in step with our policy, understand IPM principles. Again, making pesticide recommendations is not our role. We need to work with the producer and pest management specialist to determine the best possible solution to lessen the negative impacts of pest management on the ecosystem.

Unlike a general contractor, who works only for the person who is building the home (customer), as conservationists we represent the interest of both the community and the landowner. Both are our customers. Perhaps our jobs are somewhat like a general contractor and a building inspector, though we have no regulatory role like the inspector's. We must make sure that where pest management is applied, both the interests of the community and the interests of the producer are satisfied.

When producers or their advisors provide us with pest management alternatives that are potentially risky to the environment, we must work with them to develop risk reduction alternatives that meet FOTG quality criteria.

Take-Home Message

One of the conservationist's jobs is to provide environmental risk information not generally provided by Extension or crop advisors. These risk evaluations are not limited to pesticides. They can also include environmental risks associated with cultivation or certain cultural techniques (burning or removing crop residue). For example, cultivation may lead to soil loss that degrades soil resources and sediment that degrades water resources.

NRCS can provide mitigation alternatives for high-risk situations. NRCS' strength lies in our ability to plan mitigation techniques and integrate them into an overall conservation plan. Mitigation practices can include filter strips, grassed waterways, tile drains, terraces, constructed wetlands, residue management, and other conservation practices. We can also work with producers and their consultants to help them consider the environmental benefits of alternative management techniques such as choosing less toxic pesticides, using lower rates, banding, spot treatment, and incorporation.

NRCS can also suggest non-chemical techniques such as cultivation or IPM methods such as scouting and planting resistant varieties.

We must partner with those who are qualified to develop and implement IPM and make pesticide recommendations, including crop advisors and Extension. We are not alone. Our job is not to do everything in pest management but to orchestrate the implementation of an environmentally friendly pest management component of an overall RMS conservation plan.

Landowners are the single most important link in reducing off-site impacts of pest management. If landowners understand and believe that reducing negative environmental impacts is critical, we can more easily work with them to develop the pest management component of a conservation plan. We also need to educate Extension and crop advisors as to how their recommendations could be better tailored to minimize risks to natural resources. Just as the pharmacist hopes that the physician takes into account drug incompatibility or other aggravating conditions, we need to train pest management consultants to be aware of potentially hazardous environmental impacts of their prescribed pest management.

We refer to the process of evaluating the potential environmental risks as *risk analysis*. This is to be differentiated from a *risk assessment*. We separate these two terms because risk assessment infers a more in depth, comprehensive examination of the ecosystem. An assessment would include a detailed inventory of biological species and the potential effects of the hazard on each organism and the interactions of those organisms with each other and their environment.

Perhaps the easiest and quickest form of risk analysis is *risk screening*. For most field office situations, risk screening will be the most common form of risk analysis. What is risk screening and how does it differ from risk analysis? Risk screening is the first step or '*tier*' of risk analysis. Risk screening generally requires less data than a full-blown risk analysis. We generally refer to risk screening as '*Tier 1*'. A more in depth risk analysis would continue to Tier 2 or Tier 3. As mentioned earlier, for most field office situations, Tier 1 would be sufficient to satisfy the criteria for a risk analysis. See Module 5, Part D, Section 7.

At a much higher level, NRCS may be called on to assist Extension in developing pest management techniques that reduce off-site pesticide impacts. Again, NRCS would not be recommending any pesticide management technique at the field level.

Note: The role of field offices is not to act in a regulatory manner. NRCS tools are not designed to assess the absolute impacts of pesticide use. That is, we are not in the position of banning or preventing any chemical from being used. We can however, provide information about mitigation strategies that can reduce offsite pesticide movement.

Module 5, Part D, Section 7—Environmental Risk Analysis: Pest Management

NRCS' Pesticide Risk Screening/ Analysis Tools

Supporting Objectives

- Describe the tiered process for environmental risk screening
- Explain what an alpha and beta error are
- Explain which type of error errs on the side of the resource
- Explain how erring on the side of the resource is in the best interest of the producer
- Provide an example of how NRCS provides incentives to producers for erring on the side of the resource

Introduction

NRCS' unique position in pest management, including the provision of risk analysis and risk mitigation for pesticide usage, creates the need for simple, easy to use, pesticide-screening tools. NRCS has several tools that are available for use by field offices, state offices and their partners. Although they are not meant to replace in-depth environmental risk analysis, they do use up-to-date technologies and can be easily used in a field office setting.

NRCS pesticide screening tools can be used to:

- identify potential water quality resource concern areas, and
- identify which management alternatives need mitigation to meet FOTG water quality criteria.

The NRCS Windows Pesticide Screening Tool (WIN-PST) can be used to:

- identify potential water quality resource concern areas, and
- identify which basic management alternatives need mitigation to meet FOTG water quality criteria.

The NRCS National Agricultural Pesticide Risk Analysis (NAPRA) can be used to refine basic WIN-PST results with more detailed analysis of management alternatives on a site-specific basis.

Tiered Screening Tools: The Theory

The ultimate goal of NRCS pesticide risk analysis tools is to help:

- identify potential environmental risks, and
- efficiently apply mitigation strategies.

These tools are designed to help planners deal with the risks of offsite pesticide movement. In many respects, they act as learning tools for both planners and landowners.

There are several major factors used in pesticide risk analysis. These include soil characteristics (organic matter, water holding capacity, layer depth), pesticide properties (toxicity, solubility, affinity for organic matter), management factors (pesticide timing, application rate, tillage type) and climate (rainfall, irrigation, temperature).

To understand the limitations and strengths of each pesticide risk analysis tool, we have classified them into to “Tiers”. The tier system at its first step is designed to provide easy-to-use, base level screening tools that meet most field office needs. As problems and solutions become more complex, higher tiers can be used to give answers that are more detailed. As answers get more detailed, tool inputs become more complex and costly to develop.

As stated earlier, each tier relates to the tool’s complexity and ability to take into account multiple variables. Tier 1 tools take into account a small set of important variables. Tier 3 tools can take into account a complex array of multiple variables. Tier 2 tools are intermediate in complexity. The result is that tier 1 tools can give basic answers that can be easily applied over large regions. Because of the grossness of tier 1 estimates, these tools can only “qualify” potential risk. That is, they can state whether a risk is “high”, “moderate” or “low”. Another limitation of tier 1 tools is that they are usually better at determining when risk is minimal, and less accurate when the potential for losses increases.

In practice, the “tiers” are more like guides than they are actual “steps”. They are a generalization of the complexity of the tool and the flexibility of their results. The skill level and time needed to complete a risk analysis increases with each tier.

Much like the “fuzzy logic” used by soil scientists, we have hybridized our tools. Our newest tier 1 tool, the Windows Pesticide Screening Tool (WIN-PST), has been designed to incorporate pesticide toxicity, management and local climate adjustments previously available in tier 2 tools. The resulting hybrid we sometimes refer to as a tier “1.5” tool. The addition of toxicity, management, and climate allows conservationists to better differentiate the hazards created by pesticide losses. In most cases, WIN-PST can be used by field offices to plan mitigation strategies that can reduce hazardous pesticide losses, without the need to further evaluate with a tier 2 tool.

How "Accurate" Are Our Risk Analysis Tools

Risk analysis always contains some error. We try to minimize error, but with limited tools, time, abilities, and budgets, error is a fact-of-life. Our greatest error occurs when we fail to correctly characterize what's really occurring. We commonly refer to these as Type 1 and Type 2 errors. These errors refer to either accepting something that isn't true (Type 1 [alpha]) or rejecting something that is true (Type 2 [beta]). Put in the context of pesticide risk analysis, this becomes clearer.

If we begin with a null hypothesis that pesticide is not likely to move offsite at potentially toxic levels:

- A Type 1 error would be rejection of the null hypothesis when the null hypothesis should be accepted. That is, saying it is likely that pesticide is moving offsite at potentially toxic levels, when in reality, no such loss is occurring.
- A Type 2 error would be accepting of the null hypothesis when the null hypothesis should be rejected. That is, saying it is not likely that pesticide is moving offsite at potentially toxic levels, when in reality, loss is occurring.

As resource conservationists, we would probably pick a Type 1 error if we had a choice. We would want to err on the side of protecting the resource. As mentioned earlier, we would like to have no error at all, but this is unachievable. At first glance, you would suspect that a landowner or farmer would select Type 2 error as the preferred error. Not having to change current farming practices, or 'staying the course' by getting a 'clean bill of health', would minimize short-term negative economic impacts to the farmer. In the longer term however, (and often in the short term as well) preventing potential problems before they occur, benefits the resources, the community and the producer/ landowner. Preventing fish kills, keeping pesticides out of ground and surface drinking waters, and overall lessening of pesticide impacts to all resources, is positive. If we accept this premise, then Type 1 errors are much more palatable than Type 2 errors.

To lessen the burden of 'erring' toward the resource, we provide 'economic buffers' to farmers through incentive programs. These programs provide monetary support for practices that we think will decrease agricultural impacts to SWAPA resources. We must remember, however, that erring toward the resource is not a call to regulate. NRCS is not a regulatory agency. As with all conservation planning, we must balance natural resource risks with economic risks of the landowner and the risk to maintaining a safe and plentiful supply of food and fiber.

Module 5, Part D, Section 8—Environmental Risk Analysis: Pest Management

Environmental Hazards and BMPs Listed on Pesticide Labels

Supporting Objectives

- Describe the minimum requirement for pesticide usage to meet RMS criteria.
- Be able to:
  - — read and understand pesticide labels.
  - — list all active ingredients.
  - — list the class of pests that the product controls.
  - — describe selective vs. non-selective.
  - — list specific pests that the pesticide controls.
  - — list the rates, methods, or timings of application for specific crop/pest/soil conditions.
  - — list the conditions under which the product can or cannot be used.
  - — find the sections of the label that deal with environmental hazards.
  - — list the species to which the product is toxic.
  - — list setbacks.
  - — list any specific restrictions for use.

Pesticide labels attempt to address general risk with label restrictions. At a minimum, all RMS plans must meet all label restrictions for site-specific conditions. Restrictions may include application setbacks from streams or ponds, application rates based on soil organic matter content, and prohibitions of use on certain soil textures or drainage classes. Two example labels, one for BASIS GOLD® and one for BANVEL®, are at the end of this section. Labels may additionally contain specific Best Management Practices for ground and surface water protection and spray drift management.

As part of our normal technical assistance, NRCS needs to provide certain information to producers concerning site conditions that could effect the environmental risks of the pesticides. Our role in environmental risk analysis is alluded to in the environmental hazard section of certain pesticide labels. The label for BASIS GOLD specifically states that "Users are advised not to apply BASIS GOLD where the water table (ground water) is close to the surface and where the soils are very permeable (i.e. well drained soils such as loamy sands). Local agricultural agencies can provide further information on the type of soil in your area and the location of ground water." Additionally, There is an explicit reference to SCS on AAtrex® labels concerning maximum application rates on Highly Erodible Soils.

You do not need to memorize this information, nor should you ever recommend a specific rate of application. You must be familiar with the kind of information available on the label. The following activity is designed to help familiarize you with the label so you can understand what kind of information is available to the producer, the pesticide applicator or the crop consultant. We are responsible for assisting the producer to comply with the environmental impacts portion of the pesticide label.

Student Activity 5

Carefully read the BASIS GOLD® and BANVEL® labels provided. For more information on reading a pesticide label refer to Module 6. Pay special attention to the Environmental Hazards section of the BASIS GOLD® label and note the BANVEL Best Stewardship Practices and Ground and Surface Waters Protection sections. Environmental implications may also be included in other sections of the label. Note that each label is set up differently (e.g., section headers), but the same information is covered. For those chemicals that have minimal environmental hazards, the Environmental Hazards section may be short and only address direct application to surface water or disposal of washwater. The Environmental Hazard statement for ROUNDUP ULTRA® simply states:

Environmental Hazards—ROUNDUP ULTRA®

"Do not apply directly to water, to areas where surface water is present, or to intertidal area below the mean high water mark. Do not contaminate water when disposing of equipment washwaters."

1. What are the active ingredients in BASIS GOLD®?

   ____

   ____

2. What is the generic class of pests that it controls?

   Circle one:

   a. diseases

   b. insects

   c. weeds

   d. mollusks

   e. rodents

3. BASIS GOLD® is 'selective'. What does selective mean?

____

____

____

4. What pests does BASIS GOLD® control? Give three examples.

____

____

____

5. What BASIS GOLD® active ingredient has been found in ground water?

____

____

6. Name two site/soil conditions under which BASIS GOLD® should not be used.

____

____

____

7. What is the setback for a:

   a. Perennial or intermittent stream? ____________________

____

   b. Natural or impounded lake or reservoir? _____________

____

8. What is the active ingredient in BANVEL®?

____

____

9. What is the generic class of pests that it controls?

Circle one:

a. diseases

b. insects

c. weeds

d. mollusks

e. rodents

10. What is the EPA Reg. No. (EPA registration Number) of BANVEL®?

____

____

11. What specific type of pests does BANVEL® control?

____

____

12. What BANVEL® active ingredient has been found in ground water?

____

____

13. Under what conditions should BANVEL® not be used? List three.

____

____

____

14. What is the rate of application for Preplant/Preemergence in No-tillage Corn on an 'Alpha' SIL at 1.5 percent organic matter?

____

____

____

Module 5, Part D, Section 9— Environmental Risk Analysis: Pest Management

Targeting Pesticide Risk Analysis: Determining What Areas May Need the Most Assistance

Supporting Objectives

- Describe when a pesticide risk analysis is needed.
- Describe how to determine which areas are the highest priority for pesticide risk analysis.
- List one pesticide risk screening/analysis tool for each Tier of the three-tiered risk analysis process.
- Describe how soil maps of pesticide leaching and runoff can be used.

Introduction

In theory, every instance where a pesticide is being applied should be analyzed for potential risk. The NRCS Pest Management practice standard requires a pesticide risk screening to be conducted when pesticides are used and a water resource concern has been identified. In other words, for a plan to meet the requirements of an RMS, pesticide environmental risk screening must be conducted when pesticides are being applied, and, a water resource of concern has been identified.

The next step is to consider special resource impairments or site sensitivities. Pesticide labels are not designed to cover every conceivable issue. Conservation planners are in the unique situation of understanding the topography, soils, and resource issues directly related to specific sites.

Where more complex risk analysis is needed, priorities must be set to:

- maximize the impact of field office staff time and effort, and
- benefit the identified resources.

The highest priority areas should be addressed first. These are areas where a resource of concern has been degraded or is at risk for degradation. Areas where pesticide contamination might be a perceived concern should also be included in these high priority areas. Public perception is an important issue especially where urbanization has encroached on farmland. Secondary targets for risk analysis would then include areas that might possibly be at risk, but no data is available to show impairment. The last areas to receive risk analysis would be those where a resource is not currently impaired and might only be impacted in extremely rare cases. This latter case may be addressed by simply following label recommendations.

Pesticide Environmental Risk Analysis Tools

These tools can help to identify:

- high-risk areas within a watershed or other area that should be targeted for field-level assistance;
- high priority monitoring needs; and
- low risk pest management alternatives and/or appropriate mitigation practices on a field by field basis.

Tier 1 tools are designed to quickly evaluate the potential for off-site movement of pesticides through dissolved runoff, erosion, or leaching. Tier 1 tools are the primary tools used at the NRCS field office. Tier 1 tools will be sufficient to address most typical pesticide problems. Analysis beyond Tier 1 requires state level specialist support.

Tier 1 tools have several main functions:

- to educate conservationists, crop advisors, producers and others about the hazards created by pesticide movement;
- to identify sensitive areas that have significant potential for off-site agrichemical movement; and
- to justify appropriate mitigation in vulnerable areas (conservation planning).

Examples of Tier 1 tools:

- Soil/Pesticide Interaction Screening Procedure Version 2 (SPISP 2)
- Windows® Pesticide Screening Tool (WIN-PST)
- Pesticide Decision Tool (PDT)
- NPURG
- Oregon Water Quality Decision Aid, (OWQDA))
- Chemical Movement in Layered Soils (CMLS)

SPISP 2's relative loss potentials are based on generalized pesticide interaction with soil component properties. As with most Tier 1 tools, SPISP 2 is based on generalized relationships, and does not consider local climate, crops grown, management conditions, pesticide efficacy, crop nutrient use, crop productivity, or economic impacts. WIN-PST improves on SPISP 2's basic loss potentials by adding in some basic management conditions, basic climate considerations, and chronic pesticide toxicity to humans and aquatic organisms.

Tier 2 tools provide more detailed evaluation of management practices including tillage and chemical application rate, method and timing, coupled with intrinsic site characteristics such as soil component, slope, water table depth, and detailed climate characteristics. NAPRA (National Agricultural Pesticide Risk Analysis) is an example of a Tier 2 tool. Tier 2 tools can be used to refine WIN-PST and other Tier 1 tool ratings for specific climates, site conditions, and management practices. Tier 2 tools may also be used to determine the effectiveness of different mitigation strategies. In areas that have a pesticide TMDL, Tier 2 tools may be necessary to better characterize pesticide losses and the effectiveness of different mitigation strategies, and help develop new BMPs for water quality.

At the Tier 2 level, generic analysis is focused on how typical farm management systems can effect agrichemical losses under local climatic conditions. Although the probability of loss varies greatly from year to year, the goal is to identify practices that reduce the overall risk of offsite pesticide movement. The effectiveness of mitigation practices varies with the severity and distribution of climatic events. Modeling helps to predict practice effectiveness for local climatic conditions. Tier 2 results are specifically designed to help quantify the relative environmental benefits of management alternatives. This is done by estimating how often agrichemical losses at the edge of the field or the bottom of the root zone may exceed environmental standards for drinking water or aquatic organisms.

In practice, Tier 2 analysis will be conducted by trained specialists on a region by region basis, depending on the severity of water quality impairment and the level of concern. These specialists will conduct Tier 2 analysis and interpret results for field office use.

Tier 3 analysis tools use site-specific inputs. At the Tier 3 level, field measured soils data and individual producer records replace generic inputs. Acquisition of detailed Tier 3 data will be expensive and time-consuming. This kind of analysis may require a year or more of highly specialized work. Tier 3 analysis may be warranted in situations where there is a high level of environmental concern and Tier 2 generic scenario analysis indicates a high level of risk for all viable alternatives. Tier 3 analysis may also entail field sampling for pesticides in runoff and leachate. Environmental monitoring can help to validate (ground truth) modeling results and fine tune model input parameters.

Examples of Tier 3 tools include GLEAMS, EPIC, PRZM, and NAPRA.

Perhaps the most obvious determiner for needed field risk analysis is environmental monitoring. A pesticide detection in ground or surface water at a concentration that exceed the drinking water HA or MCL for a significant portion of the year, is a call to do some field-level risk analysis. In such cases, following label rates and other restrictions may not be sufficient to protect ground or surface water.

In places where monitoring data is not available, *risk screening* may be done on a watershed or multi-watershed level. These activities would not typically be the responsibility of the field office. Such large-scale risk screening would be done at the State level, usually in partnership with state agencies. The resulting analysis could be used to target field-level risk analysis or to assist in targeting program dollars for environmentally sensitive pest management.

Maps can be developed to visualize an area's *site vulnerability/ sensitivity* to pesticide loss. The soil WIN-PST or SPISP 2 (Soil Pesticide Interaction Screening Procedure, Version 2) leaching, runoff, and adsorbed to sediment, loss potentials, can be attached to GIS soils maps, as data layers. The resulting loss potential maps can highlight soils that are at risk for offsite pesticide movement. An example SPISP 2 map for runoff potential is shown in figure 5.6.

Figure 5.6 Soil pesticide interaction screening potential 2 (SPISP 2) soil solution runoff potential.

Data layers that show proximity to surface water, ground water, wells, vadose zone characteristics, and slope can also be used to aid in watershed level targeting for risk analysis. In this map, a 50 ft buffer is drawn around streams to accentuate fields that border streams. Fields that rate either a 'High' or an

'Intermediate' runoff potential, should be targeted for pest management conservation assistance.

Vulnerability is a function of both inherent site characteristics (intrinsic factors) and how fields are managed (extrinsic factors). Often, the most important extrinsic management factors are the pesticides that are used (different physical properties and toxicities) and how they are used (different rates, application methods and timing). Frequently though, pesticide application data is not available at the watershed level. This often requires assumptions about pesticide use based on cropping data and local Extension recommendations.

Module 5, Part D, Section 10— Environmental Risk Analysis: Pest Management

Pesticide Toxicity Thresholds Used in WIN-PST and NAPRA

Supporting Objectives

- Describe common thresholds used in pesticide risk evaluation.
- Describe acute vs. chronic and how each threshold can be used in a risk evaluation.
- Explain why LD_{50} is an improper measure of drinking water hazard for humans.
- Describe the differences and similarities between an MCL and an HA.
- Explain what an MATC is and it's relationship to NOAEL (NOEL) and LOAEL (LOEL).
- Describe what a CHCL is and when it is used.
- Describe what an STV is and when it is used.

Toxicity thresholds used for environmental risk analysis are chosen based on the species of concern (fish, humans, and birds), the duration and magnitude of exposure, and a chosen end-point. 'End-point' refers to the potential result if a threshold is met or exceeded. For some acute thresholds, like LD_{50} and LC_{50}, the end-point is "death of 50 percent of exposed (test) population." Other less lethal long-term end points are sometimes more applicable to conservation efforts, especially when dealing with maintaining health in an undisturbed state, whether it be humans, fish, birds or other non-target organisms.

Acute exposure for humans is important to know, for example, for pesticide applicators who might be exposed to potentially lethal doses during mixing or spraying. These situations are life threatening and can cause death within hours or even minutes of exposure. At lower doses, pesticides may produce physical effects such as shortness of breath, heart arrhythmia, salivating, and cramping. *See Module 2, Part B, Section 3—Toxicity, Acute Toxicity: Effects of Exposure to Cholinesterase-Inhibiting Pesticides (page 117)* for symptoms of acute pesticide poisoning. Exposure to lower doses can also cause death in some cases if the exposure period is long enough. LD_{50}s are useful for representing acute poisonings such as applicator exposure, children mistakenly drinking the poisonous chemical, or birds, eating pesticide granules. Sub lethal acute exposures (high dose-short exposure) can be inferred from the LD_{50}.

To characterize acute environmental risk to fish, EPA commonly uses a threshold called the 96-hour Level of Concern (LOC). It's calculated by dividing the 96-hour LC_{50} in half. Although the LOC is half the LC_{50}, it still may be lethal to sensitive individuals in the exposed population (refer to Module 2, figure 2.19 Dose response curve).

We would not use an LD_{50} for a human drinking water standard because killing off half the population in a water district is an unacceptable end-point. EPA's Health Advisory (HA) and Maximum Contaminant Level (MCL) thresholds provide a measure of safety to a population who consumes certain chemicals over a lifetime. Lifetime consumption of chemicals in drinking water at their HA or MCL is not expected to cause adverse health effects. Similarly, long term toxicity thresholds have been developed for fish. Most commonly used is the Maximum Acceptable Toxicant Concentration (MATC). The MATC represents a long-term concentration that has only a slight chance of causing adverse effects on the fish population exposed. It is not a concentration where there is no effect (NOEC–No Observable Effect Concentration). In theory, it falls between the NOEC and the LOEC (Lowest Observable Effect Concentration). When both the

NOEC and LOEC are available, MATC can be calculated by taking the geometric (logarithmic) mean of those two values. In the absence of experimentally derived values for NOEC, LOEC, or MATC, the MATC may be approximated by extrapolation from the 96-hour LC_{50} acute toxicity threshold.

Chronic Human Carcinogen Level (CHCL*)

*denotes that the value is calculated

Threshold created by NAPRA team for WIN-PST and NAPRA. The concentration at which there is a 1 in 100,000 probability of contracting cancer over a lifetime exposure. It is calculated using an EPA algorithm and is based on the cancer slope from animal studies. CHCL provides a concentration comparable to an MCL.

Health Advisory (HA)

Health Advisory is determined by EPA's Office of Water (OW). It is the concentration of a chemical in drinking water that is not expected to cause any adverse non-carcinogenic effects over a lifetime exposure with a margin of safety. In accordance with OW policy, Health Advisories are not calculated for chemicals that are known or probable human carcinogens (EPA Cancer Class A and B).

Health Advisory (HA*)

*denotes that the value is calculated

HA* is derived using the EPA method for calculating HA based on Reference Dose (RFD). RFD values are from the EPA Office of Pesticide Programs (OPP), EPA, or World Health Organization (WHO). In accordance with OW policy, Health Advisories are not calculated for chemicals that are known or probable human carcinogens (EPA Cancer Class A and B).

Level of Concern (LOC)

This acute fish toxicity threshold is defined as half of the 96-hour LC_{50}. Its endpoint is based on the lethal dosage. At this concentration, there is significant disruption of the aquatic species of concern, but it does not kill 50 percent of the test population. This concentration may still kill a significant proportion of the population. LOC is used by EPA for aquatic risk assessment.

Maximum Acceptable Toxicant Concentration (MATC*)

*denotes that the value is calculated

MATC is the long-term toxicity value for fish that represents a life cycle (chronic) concentration between a long-term No Observable Effect Concentration (NOEC) and Lowest Observed Effect Concentration (LOEC). At this concentration, a very small percentage of a population may be adversely affected. MATC can be determined empirically by performing long-term or early life-stage toxicity tests. MATC* can be calculated two ways: 1) by determining the geometric mean of the NOEC and LOEC when NOEC and LOEC are available and, 2) if NOEC and LOEC are not available, MATC* can be extrapolated from the 96-hour LC_{50}.

Maximum Contaminant Level (MCL)

Set by EPA, it is the maximum permissible long-term pesticide concentration allowed in a public water source. MCL is always used as a drinking water standard for any pesticide for which EPA has an assigned MCL value. In the absence of an MCL, the HA, HA* or CHCL* are used, in that order.

Sediment Toxicity Value (STV*)

*denotes that the value is calculated

STV* is a threshold created by NAPRA team for WIN-PST and NAPRA. STV* provides a toxicity threshold of pesticides sorbed to detached soil leaving the field. The STV estimates the pesticide concentration in sediment pore water. STV* = Fish MATC x Koc.

Fish MATC is used because toxicity data for sediment dwelling animals are limited. The STV* is derived from a method by Di Torro et al., (1991) that estimated short-term toxicity of nonionic pesticides. It was modified to estimate long-term toxicity by using the MATC instead of the 96-hour LC_{50}. STV* is also used to evaluate ionic pesticides by using estimated K_{oc} for ionic species.

Module 5, Part D, Section 11— Environmental Risk Analysis: Pest Management

Using Field Level Risk Analysis Tools

Supporting Objectives

- Name the pesticide hazard/risk screening tool that will be most often used by field offices
- Explain what screening algorithms WIN-PST is based on
- Explain the primary goal of SPISP
- Explain each of the WIN-PST hazard ratings and what actions should be taken for each rating
- Explain why WIN-PST and NAPRA do not reflect the direct risk to surface and ground water
- Explain why concentrations estimated by NAPRA are frequently orders of magnitude higher than typically found in surface or ground water

Introduction

For the most part, doing a pesticide risk analysis is not much different from typical resource planning. That is, the same steps are valid, including conducting a resource inventory. However, some extra information must be collected, including probable pesticide uses and application details required by the pesticide environmental risk analysis tool that will be used. This information can come from the producer or their crop consultant, but it should include all likely pesticide uses for a particular land unit. Final decisions about specific pesticide uses are often based on field conditions that vary from year to year, but the pest management component of the conservation plan should account for this expected variability whenever possible to avoid the need for continuous updates. Occasionally, unexpected conditions may call for previously unplanned pesticide uses. As soon as practical, new pesticide uses should be included in an updated pest management component of the conservation plan.

Resource inventories should also identify existing mitigation techniques (management techniques and/or conservation practices) that will help reduce pesticide losses. Typical resource inventory data such as distance to surface and/or ground water, soil types (by component or map unit) and field slopes will also be used in the pesticide environmental risk analysis process. The National Pest Management job sheet is provided in Module 6.

Field office pesticide environmental risk analysis will usually entail using NRCS' Windows Pesticide Screening Tool (WIN-PST). Other similar tools may be approved for use in some States. This discussion will be limited to using WIN-PST, because it is available nationwide. Risk screening completed with other tools can be done similarly to screening done with WIN-PST.

Using WIN-PST

WIN-PST is a Tier 1, Windows® based tool, that uses the Soil/Pesticide Interaction Screening Procedure, Version 2 (SPISP 2) developed by Goss and Wauchope (1990). *See WIN-PST—NRCS' Pesticide Environmental Risk Screening Tool.*

WIN-PST—NRCS' Pesticide Environmental Risk Screening Tool

The Windows Pesticide Screening Tool (WIN-PST) is designed to evaluate the potential for off-site movement of pesticides through runoff, leaching, and erosion. Both soil properties and pesticide properties are considered in this screening tool. In addition, basic management techniques and pesticide toxicity are also included in WIN-PST pesticide hazard evaluations.

WIN-PST uses:

- to target vulnerable areas of a watershed or other area for detailed planning
- to screen high versus low risks on a field by field basis
- to apply appropriate mitigation on a field by field basis

WIN-PST is based on SPISP 2 (Soil Pesticide Interaction Screening Procedure; Goss and Wauchope, 1990), and is designed to replace SPISP 1, which has been available to field offices in the Field Office Technical Guide (FOTG) since 1988.

Background on SPISP

Both SPISP 1 and SPISP 2 were developed by creating a population of hypothetical soils and pesticides that cover almost all possible combinations of parameters that are potentially sensitive to pesticide movement by water. Over 40,000 parameter combinations were run through the GLEAMS agrichemical fate model.

Meteorological components used to develop SPISP included an extremely high artificial rainfall regimen that maximized pesticide movement potential. *The primary goal was to determine the capacity of a soil to retain a pesticide at the point of application, regardless of management or climatic inputs.*

The artificial rainfall data used in SPISP consisted of five 3.5 inch rainfall events every other day starting the second day after pesticide application, followed by 1.0 inch rainfall events every other day for at least four times the half-life of the chemical being evaluated.

The most sensitive soil and pesticide parameters were determined through statistical analysis of the completed GLEAMS runs. Further analysis created mathematical relationships and breakpoints within and between parameters. Algorithms were created using these relationships and breakpoints. Real pesticides and soils were then ranked by applying these algorithms to their respective soil and pesticide parameters. Overall ratings, representing the interactions between soils and pesticides, were created by developing a matrix of individual soil and pesticide rankings

Benchmark conditions (what the producer is currently doing) should be evaluated first to determine if there are potential hazards from either runoff or leaching. Alternatives and/or mitigation practices can then be developed for those benchmark practices that pose significant risk (WIN-PST hazard rating of 'Intermediate' or greater) to identified resource concerns.

We need to remember that NRCS is not in the business of making pesticide recommendations. We are in the business of analyzing 'recommended pesticides', within the framework of an IPM program, for their potential environmental impacts. Additionally, we can provide environmental risk analysis on alternatives to pesticides such as tillage for weed control. Hazard mitigation practices (buffer strips, riparian areas, crop rotation), whether dealing with pesticides, tillage, burning, can be recommended by NRCS to reduce the potential environmental hazards of benchmark or planned alternatives.

WIN-PST pesticide/soil combinations that have a 'Low' or 'Very Low' hazard rating, would meet RMS criteria and not need mitigation. In some cases, where alternative IPM methodologies are available, the use of a pesticide with even a 'Low' or 'Very Low' hazard rating may be inappropriate. See *Module 5, Part D, Part 11—Environmental Risk Analysis: Pest Management: IPM.*

Those soil/pesticide combinations that rate 'High' or 'Intermediate' are prime candidates for mitigation practices. See Interpreting the WIN-PST hazard ratings.

Once pesticide risk screening is done, the next step is to provide mitigation strategies. A list of mitigation practices and their effects on leaching and runoff are found in the next section of *Module 6, Part C, tables 6.2 and 6.4.*

Those combinations rating 'Extra High' are considered potentially very hazardous. Using pesticides that have an 'Extra High' rating, indicates the potential to do great harm to the identified resource concern, mostly because of their extreme toxicity to non-target organisms. Mitigation practices for these pesticides may not be sufficient to prevent potentially severe damage to the resource. The potential for mitigation failure is high. These pesticides should only be used with extreme caution and as infrequently as possible. Although these chemicals are applied according to the label, reliance on chemicals that receive an 'Extra High' rating may prevent a plan from reaching RMS status, even with mitigation.

Interpreting the WIN-PST hazard ratings

WIN-PST classifies the potential hazards into five classes:

- X-EXTRA HIGH
- H-HIGH
- I-INTERMEDIATE

- L-LOW
- V-VERY LOW

Only leaching hazard uses the very low class.

Action (mitigation) should be taken when a hazard for the resource concern is listed 'EXTRA HIGH', 'HIGH', or 'INTERMEDIATE'. The use of mitigation measures included in Module 6 can be used as guidance for developing a strategy. Hazard ratings of HIGH and INTERMEDIATE can usually be made acceptable by implementing appropriate mitigation measures.

In general, HIGH hazard ratings warrant more extensive mitigation than INTERMEDIATE hazard ratings. How extensive mitigation needs to be is also dependent on other factors such as the existing level of impairment of the resource, resource sensitivity, and desired level of resource protection. For soil/pesticide combinations that are rated as an 'EXTRA HIGH' hazard potential, mitigation may not be effective. For resources that are highly sensitive or for which a high degree of resource protection is desired, substitution of another less hazardous chemical may be the only remedy. In these cases, the conservationist needs to work with the producer, and crop consultants or extension specialist to find efficacious, economically acceptable, and lower risk alternatives.

For soil/pesticide interactions classified as 'LOW' or 'VERY LOW' hazards, no further action or mitigation is needed. As long as these chemicals are used according to the label, they meet the pesticide quality criteria for RMS planning.

Ground and surface water vulnerability is not measured directly by WIN-PST or NAPRA. Instead, WIN-PST and NAPRA give risk estimates at the edge of the field or bottom of the root zone.

Estimates of ground or surface water vulnerability would require information not easily obtained, such as ground water depth, vadose zone characteristics, travel time between edge of field and surface water.

Significant attenuation of chemical contaminants may occur between the edge-of-field/bottom-of-root-zone and surface or ground water. In fact, many mitigation strategies NRCS uses to reduce surface water contamination, attempt to maximize attenuation of sediments and chemicals through lengthening the distance between the contamination source and the surface water resource. Other mitigation strategies attempt to either decrease the speed of runoff water (decreasing erosivity and sediment carrying capacity) or impound the runoff water (increasing infiltration and decreasing sediment carrying capacity). If, through mitigation practices, we can reduce hazardous pesticide losses from the edge-of-field/bottom-of-root-zone, or prevent pesticides from entering surface or ground water, we can protect identified resources of concern.

Module 5, Part D, Section 12— Environmental Risk Analysis: Pest Management

Example: Using WIN-PST Reports

Supporting Objectives

- List the three WIN-PST reports.
- Explain the difference between a pesticide product and an active ingredient.
- Explain how the EPA registration number can be used to verify that two or more products with different names are the same.
- Explain how one product can be more toxic than another product to non-target species even though they contain the same active ingredient.
- Describe how you rate a: product with more than one active ingredient; map unit with more than one component.
- List the five exposure adjusted toxicity classes.
- Explain why toxicities are 'exposure adjusted'.

Using the WIN-PST Reports for Planning

WIN-PST creates three reports that can be used by the field office conservationist:

- the interaction report (shown immediately below),
- the soils report, and

- the pesticide report (see the *WIN-PST Soils report* and *WIN-PST Pesticide report* at the end of Module 5, Part D). The interaction report contains modified SPISP 2 ratings and hazard ratings for humans and fish. This report should be the starting point of any conservation assistance on the pest management portion of the conservation plan. The soil and pesticide reports back up the interaction report and can be very helpful in choosing alternatives or mitigation strategies. An example interaction report is shown below for a producer who is growing grain corn.

The field contains Rozetta silt loam (SIL) and is within 10 feet of a perennial stream with a 2 to 3 percent slope towards the stream. The producer plants corn to within 10 feet of the stream. As required on the label, the producer has been maintaining a setback for BASIS GOLD of 66 feet. The producer uses cultivation for weed escapes throughout the field and also cultivates the 66 foot setback zone where BASIS GOLD is not applied. He continues to apply PHORATE to the entire field because there is no set back requirement for PHORATE. A WIN-PST risk screening returns the results on the following page:

```
WINPST SOIL / PESTICIDE INTERACTION LOSS POTENTIAL and HAZARD RATINGS REPORT
================================================================================

Soils Data Table: SOIL_IL  Sort Order: MUSYM
Pesticide Data Table Sort Order: NAME

                                           SOILS

                                    279A:  Rozetta SIL 100%
                                    HYDRO: B
PESTICIDES                                 ADAMS COUNTY,
                                           ILLINOIS: IL1
==============================================================
BASIS GOLD HERBICIDE  REG_NO: 00035200585
     _________________________________________________________
     82.44% Atrazine (ANSI)
                              Loss           Human  Fish   |
                              Potential      Hazard Hazard|
                              ---------------------------|
           Leaching  (ILP):   I (f)            H      I    |
    Solution Runoff (ISRP):   I (f)            H      I    |
    Adsorbed Runoff (IARP):   L (f)                   L    |
     _________________________________________________________
     1.34% Nicosulfuron (ANSI)
                              Loss           Human  Fish   |
                              Potential      Hazard Hazard|
             pH 7             ---------------------------|
           Leaching  (ILP):   L (f<ul>)        V      V    |
    Solution Runoff (ISRP):   L (f<ul>)        V      V    |
    Adsorbed Runoff (IARP):   L (f<ul>)               V    |
     _________________________________________________________
     1.34% Rimsulfuron (ANSI)
                              Loss           Human  Fish   |
                              Potential      Hazard Hazard|
                              ---------------------------|
           Leaching  (ILP):   V (f<ul>)        V      V    |
    Solution Runoff (ISRP):   L (f<ul>)        V      V    |
    Adsorbed Runoff (IARP):   L (f<ul>)               V    |




==============================================================
PHORATE 20-G  REG_NO: 00977900293
     _________________________________________________________
     20.00% Phorate (ANSI)
                              Loss           Human  Fish   |
                              Potential      Hazard Hazard|
                              ---------------------------|
           Leaching  (ILP):   I (i)            H      X    |
    Solution Runoff (ISRP):   I (i)            H      X    |
    Adsorbed Runoff (IARP):   I (i)                   I    |
==============================================================
================================================================================

Ratings Legend:
       Ratings:
           X -- EXTRA HIGH
           H -- HIGH
           I -- INTERMEDIATE
           L -- LOW
           V -- VERY LOW
```

Interpreting the Results

In the WIN-PST SOIL / PESTICIDE INTERACTION LOSS POTENTIAL and HAZARD RATINGS REPORT, soil information includes the map unit symbol, the component name, surface layer texture, and component percentage of that map unit. In addition, the soil hydrologic group and soil survey area is included. WIN-PST allows soils to be chosen and reported by component name, in addition to map unit symbol.

Pesticides are listed by product. Additionally, WIN-PST includes the EPA product registration number. Active ingredients are rated under each product that they are contained in. WIN-PST also allows selection and reporting by active ingredient. Field office conservationists will most likely use the 'products report' because the producer is most familiar with products as opposed to active ingredients. Extension recommendations will usually be by-products.

Products vs. Active Ingredients

A 'product' is a commercially available formulation of an active ingredient (A.I.) or combination of several active ingredients, plus other chemicals, such as adjuvants, and inert ingredients. Products are available for sale to the general public or licensed applicator. When any pesticide product is sold to the public, it must have an EPA registration number and that number must appear on the label. A product may have several names depending on the wholesaler or retailer. The EPA registration database, which WIN-PST uses, may not always include the same name as the marketed label. However, products with different names, but identical EPA registration numbers, are identical in all ways. EPA allows manufactures or dealers to change the name of the product as long as the formulation remains identical. If the formulation changes, then the product would receive a new EPA registration number. When in doubt, make sure the EPA registration numbers match.

Active ingredients are the actual chemical compounds that have pesticidal activity. They may be used alone or formulated with other active ingredients to create a product, which can be purchased by the consumer. Active ingredients cannot be sold alone without being part of a product, although a product may have only one active ingredient. Products are rated in WIN-PST by their active ingredients, since the active ingredient part of the product formulation that usually has the most environmental impact.

Some products though, have adjuvants that can be more toxic to non-target species than the active ingredients. ROUNDUP ULTRA® for example, is not labeled for aquatic weed control because of its toxicity to fish. The active ingredient, glyphosate isopropylamine has a relatively low toxicity to fish, but the surfactant included in ROUNDUP ULTRA® is significantly more toxic to fish. Additionally, some studies have shown that the surfactant and glyphosate isopropylamine active ingredient combined are more toxic than either chemical alone. Another glyphosate isopropylamine product, RODEO®, can be used for aquatic weed control because it does not contain the surfactant in ROUNDUP ULTRA®.

The environmental fate and toxicity of many adjuvants is largely unknown. Many adjuvants are considered trade secrets, so chemical manufacturers are reluctant to release data on them. Because of this, WIN-PST has very limited data on those chemicals not expressly considered ‘active ingredients’. When dealing with any pesticide product that has more than one active ingredient, you must rate the entire product by the most hazardous active ingredient. Similarly, you must rate the entire soil map unit by the most sensitive component.

In the case of BASIS GOLD, the ingredient with the ‘HIGH’ hazard rating for humans and an ‘INTERMEDIATE’ hazard rating for fish, is atrazine. Therefore, any mitigation developed must deal with the atrazine hazard potential. See *Interpreting the WIN-PST* *hazard ratings (Module 5, Part D, Section 11).* Depending on the resource concern, one hazard may take precedence over another. That is, if drinking water were the primary resource, the human hazard would be most important. In this example, the stream is linked to both drinking water and fish habitat. Both resource concerns must be addressed. Impact to ground water from leaching, however, is not a major concern at this site.

Behind the WIN-PST Hazard Ratings

Once we know the WIN-PST estimates of the relative potential for a pesticide to move offsite, we must then be concerned with the potential hazard that these losses pose. Because WIN-PST is qualitative in nature (it doesn't produce an actual concentration or mass loading), we need to take the potential for exposure (modified SPISP 2 ratings) and combine it with toxicity to determine the hazard that the chemical poses when it leaches or runs off. That is, a chemical that has a high potential to runoff (in solution) and is not very toxic is less hazardous than a chemical that has a high potential to runoff and has a high toxicity.

The WIN-PST hazard classes were developed to determine the potential hazard of an offsite pesticide movement. These ratings are created by combining the WIN-PST interaction ratings with exposure adjusted toxicity ratings. The result is, for any WIN-PST interaction rating and exposure-adjusted toxicity rating, a single hazard (potential hazard) rating for each resource concern (human and fish).

The exposure adjusted toxicity rating is a rating scheme devised by the NAPRA team to estimate the probability for a pesticide to exceed a concentration in the environment. It is broken down into 5 classes based on the long-term toxicity. This value is not based on the pesticide physical properties used in WIN-PST loss potentials, but instead is based on best guess likelihood of a given pesticide applied at typical application rates (about 0.5 kg/ha- 5.0 kg/ha) to exceed it's long-term toxicity standard (EPA's Health Advisory, MCL, or MATC) For example, if it's extremely probable that a pesticide will exceed it's toxicity threshold in the environment, it will be rated 'EXTRA HIGH'. This toxicity adjustment helps to determine the relative hazard of a chemical that moves offsite.

Each pesticide is classified into an exposure adjusted toxicity class:

For humans:

EXTRA HIGH	X <1 ppb
HIGH	1 ppb > X <= 10 ppb
INTERMEDIATE	10 ppb > X <= 50 ppb
LOW	50 ppb > X <= 100 ppb
VERY LOW	X >= 100 ppb

For Fish:

EXTRA HIGH	X < 1 ppb
HIGH	1 ppb > X <= 10 ppb
INTERMEDIATE	10 ppb > X <= 100 ppb
LOW	100 ppb > X <= 500 ppb
VERY LOW	X >= 500 ppb

An extremely toxic pesticide (< 1.0 ppb for it's long-term threshold) is likely to exceed its toxicity threshold. As the toxicity threshold concentration increases (becomes less toxic), the probability that the threshold will be exceeded decreases.

The other two chemicals in BASIS GOLD are not as toxic as atrazine (see pesticide report below) and are applied at ultra-low rates (< 112 grams/ha or 0.1 lb/ acre) noted by '<ul>' on the report. *See sidebar: Conditions that effect ratings*. These active ingredients on this soil receive a 'Very Low' rating. If these active ingredients were applied alone, they would not need further mitigation. Since they are applied as a mixture with atrazine, the atrazine hazard of this product must be mitigated.

The product PHORATE has only one active ingredient by the same name. Its hazard rating for both leaching and runoff is 'HIGH' for human hazard and 'EXTRA HIGH' fish hazard. For this example we are only concerned with surface water. We need to address ways to prevent phorate runoff from impacting the adjacent stream.

Although no setback is listed on the label for PHORATE, at a minimum, a setback similar to the one imposed on BASIS GOLD should be followed. Even better, a buffer could be constructed between the stream and field. The buffer should be designed and maintained to promote infiltration and discourage concentrated flow. Sediment trapping, although not as high a priority as infiltration in this case, would also be advantageous because the adsorbed sediment hazard to fish is rated as INTERMEDIATE.

Integrated Pest Management (IPM) should always be used when developing the pest management component of a conservation plan. Most states have specific IPM guidance by crop. IPM includes scouting, economic thresholds, non-chemical controls including crop rotation and cultivation for weeds, and judicious pesticide applications. Substitution of pesticides should be done only through consultation with producers, Extension or crop advisors.

Conditions that affect rating:		Effect on ratings:		
Broadcast	- - Default application area. Pesticide applied to more than 50% of the field.			
B	- - Banded Application - - Pesticide applied to less than 50% of the field	-1 PLP,	-1 PSRP,	-1 PARP
Surface Applied	- - Default application method.			
I	- - Soil Incorporated.	+1 PLP,	-1 PSRP,	-1 PARP
F	- - Foliar Application.	-1 PLP,	-1 PSRP,	-1 PARP
Standard	- - Default application Rate. Greater than 0.25 lb/acre.			
1	- - Low Rate of Application. 1 / 4 – 1 / 10 lb/acre (280 – 112 g/ha)	-1 PLP,	-1 PSRP,	-1 PARP
	- - Ultra Low Rate of Application 1 / 10 lb/acre (112 g/ha) or less.	-2 PLP,	-2 PSRP,	-2 PARP
M	- - There are macropores or cracks in the surface horizon deeper than 24".	+1 SLP		
W	- - The high water table comes within 24" of the surface during the growing season.	SLP = HIGH		
S	- - The slope is greater than 15%			+1 SARP
R	- - Residue Management.		-1 ISRP,	-1 IARP
<hl>	- - High probability of rain, Low efficiency irrigation.	+1 ILP,	+1 ISRP	+1 IARP
<ln>	- - Low probability of rain, No irrigation.	-1 ILP,	-1 ISRP,	-1 IARP
<lh>	- - Low probability of rain, High efficiency irrigation.	-1 ILP,	-1 ISRP,	-1 IARP

Note:
+1 – Increase rating by 1 class (ex. INTERMEDIATE goes to HIGH)
-1 – Decrease rating by 1 class (ex. HIGH goes to INTERMEDIATE)

Where:
ILP – Interaction Leaching Potential
ISRP – Interaction Solution Runoff Potential
IARP – Interaction Adsorbed Runoff Potential

PLP – Pesticide Leaching Potential
PSRP – Pesticide Solution Runoff Potential
PARP – Pesticide Adsorbed Runoff Potential

SLP – Soil Leaching Potential
SSRP – Soil Solution Runoff Potential
SARP – Soil Adsorbed Runoff Potential

WIN-PST is available through the Internet on the NRCS National Water and Climate Center web site: http://www.wcc.nrcs.usda.gov/water/quality/wst.html.

A copy of the program can be downloaded free of charge to anyone. It is also CCE certified and available for installation on the Field Office Windows NT systems.

Module 5, Part D, Section 13—Environmental Risk Analysis: Pest Management

Supporting IPM in the Development of the Pest Management Component of a Conservation Plan

Supporting Objectives

- Explain how design of pest management alternatives relates to IPM.
- Describe where IPM information can be found.
- Explain what single factor makes IPM systems less likely to lead to pest resistance.
- Explain why chemical control alternatives should be used only as a last resort in IPM.
- Explain why pesticides that have hazard ratings of *low* or *very low* may be inappropriate alternatives.

NRCS policy is to develop conservation alternatives in the framework of Integrated Pest Management (IPM). USDA strongly encourages the use of IPM principles and programs where they are available. NRCS' Pest Management Standard (595) mandates the use of IPM programs where they are available. Extension provides the specific requirements of each IPM program. Crop consultants are also an excellent source of IPM information and direct technical assistance on IPM implementation.

Simply providing a pesticide environmental risk analysis is not sufficient to complete the pest management component of a conservation plan. If a pest management plan does not include IPM, we should work to convince the producer that IPM is in his/her best interest and provide appropriate IPM technical contact information. Additionally, we need to offer our conservation planning expertise, to both producers and their crop consultants. Our strengths, which includes inventorying resources, providing risk analysis and design of conservation strategies that can lessen the environmental impacts of pest management practices, are frequently the weakness of crop consultants. The crop consultant's strengths, including efficacy, economics, and IPM, are often our weaknesses. We must partner together to fully meet producer needs.

IPM strives to maintain pest levels below economically damaging levels and looks first to non-chemical measures that help prevent problems from developing in the first place. With IPM, the role for chemical pesticides is a last resort when other alternatives fail to correct the problem. Pesticides end up in the 'last resort' category because of chronic use of pesticides can quickly lead to development of pesticide resistance by the target organism. Pesticides can also damage populations of natural or introduced 'pest predators' and other beneficial organisms. Pest predators can naturally maintain pests below economically damaging threshold levels.

IPM programs are crop specific and provide a comprehensive approach to a multitude of potential pests. That is, an IPM program should deal with weed pests, insect pests, and diseases. If IPM programs have not been developed for a crop, IPM principles should be used. The principles of IPM have been discussed in Module 3. IPM works as a long-term pest control strategy by purposefully using many different techniques to solve pest problems. *Diversity of pest control measures is key to providing an IPM program that will not easily be defeated by pest adaptation.*

If an environmental analysis shows that a certain pesticide has a *low* or *very low* hazard, IPM is still required. IPM helps to determine if any control method is needed. Even if a pesticide is called for, the *low* or *very low* hazard pesticide may not be the best choice from an IPM standpoint. Chronic use of a low risk pesticide can lead to pest resistance that may require the use of a high risk pesticide in the future.

Module 5, Part D, Section 14— Environmental Risk Analysis: Pest Management

Using NAPRA as a Decision Tool in Planning

Supporting Objectives

- Explain when you would choose to do NAPRA analysis.
- Explain how NAPRA differs from WIN-PST.
- Describe how NAPRA was used in Idaho to discover a potentially high pesticide hazard.
- Describe the actions that took place as a result of NAPRA screening.
- Describe how NAPRA was used in New York to create best management practices to reduce environmental risk.

Introduction

Both WIN-PST and NAPRA can be used in pest management decisionmaking. NAPRA, however, is much more comprehensive than WIN-PST. Generally, NAPRA is used where significant threats from offsite pesticide movement to resource concerns have been identified and pesticide BMPs need to be developed. This may occur in watersheds where a pesticide TMDL has been set or where pesticide use is impacting source waters used for public drinking water supplies. It‘s a fairly lengthy process to create NAPRA output and interpretations, usually taking at least one full time NAPRA specialist 1 year to be trained and to produce useable interpretations. When those interpretations have been completed and BMPs have been developed, the resulting BMPs will be tailored to fit local conditions including climate, crops, and soils.

NAPRA is used to:

- refine WIN-PST results
- develop pesticide Best Management Practices (BMPs)
- develop the pest management component of a conservation plan
- help meet pesticide Total Maximum Daily Load (TMDL) requirements
- help meet State Management Plan (SMP) requirements
- help meet Safe Drinking Water Act (SDWA) requirements

NAPRA is based on the USDA-ARS Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) model, and allows multiple GLEAMS runs to be made for different pesticides, pesticide application rates and methods, and crop and tillage systems using local climate conditions. The GLEAMS model is a daily time step model that can estimate hydrology as well as pesticide movement and sediment delivery past the edge of the field. The results developed by NAPRA are climate-based estimates of the potential hazard from offsite (edge of field and bottom of root zone) movement of pesticides. Pesticide concentrations at the edge of the field are compared to toxicity thresholds (figure 5.3). Results can be graphed from highest to lowest loss and normalized for toxicity (figure 5.4). This provides an easy to understand comparison of pesticides that have differing toxicity thresholds. These graphs represent the relative hazard potential of pesticides that have moved past the edge of the field, estimated from 49 years of local precipitation.

As has been mentioned earlier, NAPRA does not give a direct estimate of ground or surface water vulnerability. It does though, give an estimate of the potential for contamination from offsite movement. Pesticide concentration in surface water may be several orders of magnitude lower than the estimates made at the edge of the field. As a general rule of thumb, in-stream concentrations will be two orders of magnitude (100 fold) lower than at the edge of field, and ground water concentrations will attenuate about 1 order of magnitude (10 fold less). These rules are very general and may not represent every situation. Depth to ground water, vadose zone characteristics, distance to surface water, and presence of buffers or riparian areas can all effect the magnitude of attenuation.

NAPRA can be used either preemptively or in response to an identified pesticide impacting a water resource. Preemptive use of NAPRA can be used to identify pesticide management strategies that are potentially risky even though those strategies have not yet been identified as being problems. Typically, areas that are prime candidates for preemptive NAPRA analysis have had past pesticide usage that has caused water resource degradation. Public perception concerning pesticide contamination is another important reason for preemptive NAPRA analysis. An example of a preemptive use of NAPRA occurred at the Ft. Hall Indian reservation in Idaho. Past problems with EDB contamination of ground water sensitized tribal leaders to be concerned with current pest management practices. NAPRA analysis showed that there may be significant risk to ground water from several pesticides used as soil fumigants to control nematodes and disease. *See Sidebar: Pesticide Risk Analysis at the Ft. Hall Indian Reservation, ID.*

Pesticide Risk Analysis at the Ft. Hall Indian Reservation, ID

Background

Nitrate and pesticide concentrations in ground water have been found above drinking water standards on the Fort Hall Indian Reservation, Fort Hall, Idaho. Given the intensity of crop production on the reservation and the level of agrichemical use, agriculture has been targeted as the primary source. The Shoshone-Bannock Tribes initiated a cooperative effort with several Federal, State and private organizations and farmers to address ground water quality problems and to develop viable solutions for resource protection. These cooperative efforts included initial characterizations of the ground water quality on the Reservation by USGS: a preliminary investigation addressing the ground water quality problems on the reservation by the Natural Resources Conservation Service–NRCS; a River Basin Study by NRCS; a Water Quality Incentive Project by USDA FSA/NRCS; two Pollution Prevention Projects by EPA; as well as ongoing Tribal leadership in addressing agricultural management on the reservation. A demonstration/evaluation project was used to work with farmers to gather site specific information from their fields to better understand current management impacts to ground water and opportunities for improvement. Field and research data were used to develop a mandatory management strategy for nitrogen applications.

Ethylene dibromide (EDB), a soil fumigant used to control nematodes and plant diseases on the reservation in the 1960's, 70's and early 80's, has and continues to be found in ground water above the drinking water standard of 0.05 (g/L or ppb. When EDB was found in one of the Tribal Public water supplies, EPA issued an emergency administrative order requiring further investigation and use of Best Management Practices within 30 days. Although EPA removed EDB from the market on September 30, 1983, it continues to be found in ground water and, consequently, poses a significant risk to human health.

The NRCS National Agricultural Pesticide Risk Analysis (NAPRA) process was used to evaluate past EDB use (figure 5.9), as well as current pesticide management strategies (figure 5.10). Since 1990, as a part of the Tribal Agricultural Management Program, pesticide applications on the reservation have been reported to the Ag Resources Department. NAPRA analysis uses the Ground Water Loading Effects of Agricultural Management Systems (GLEAMS) model to simulate pesticide movement to the edge of the field and/or bottom of the root zone. The model used 50 years of climate data from a weather station nearby and modeled the use of several pesticides currently used on potatoes. Other input variables include site specific information on tillage, pesticide application methods and timing, irrigation methods and timing, and soil type and organic matter content. Leachate pesticide concentrations were compared to an established Maximum Contaminant Level (MCL), Health Advisory (HA), an estimated HA or Chronic Human Carcinogen Level (CHCL) developed by NAPRA to approximate an EPA MCL.

NAPRA analysis confirmed the high potential of EDB to leach below the root zone at concentrations well above the MCL (figure 5.7). The graph shows that 98 percent of the time the 0.05(g/L MCL was exceeded by a factor of more than 1000.

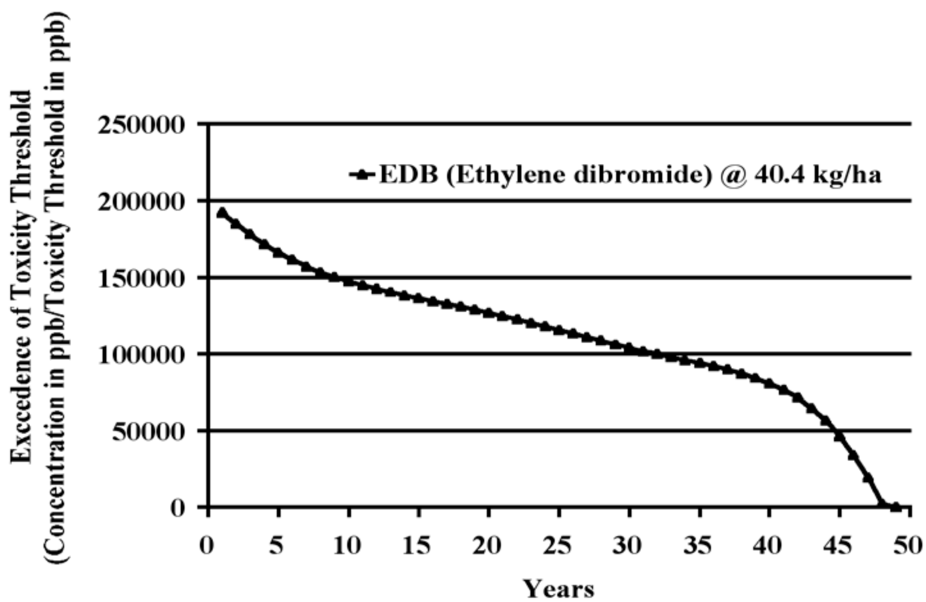


Figure 5.7 NAPRA analysis results of EDB leaching below the root zone in excess of the 0.05 g/L MCL, Fort Hall, Idaho.

In addition, NAPRA analysis indicated that 1, 3-dichloropropene (Telone) and metam sodium (Vapam), currently used both intensively and extensively on the reservation and on cropland surround the reservation, may be leaching past the root zone at concentrations significantly higher than their respective CHCLs (figure 5.8).

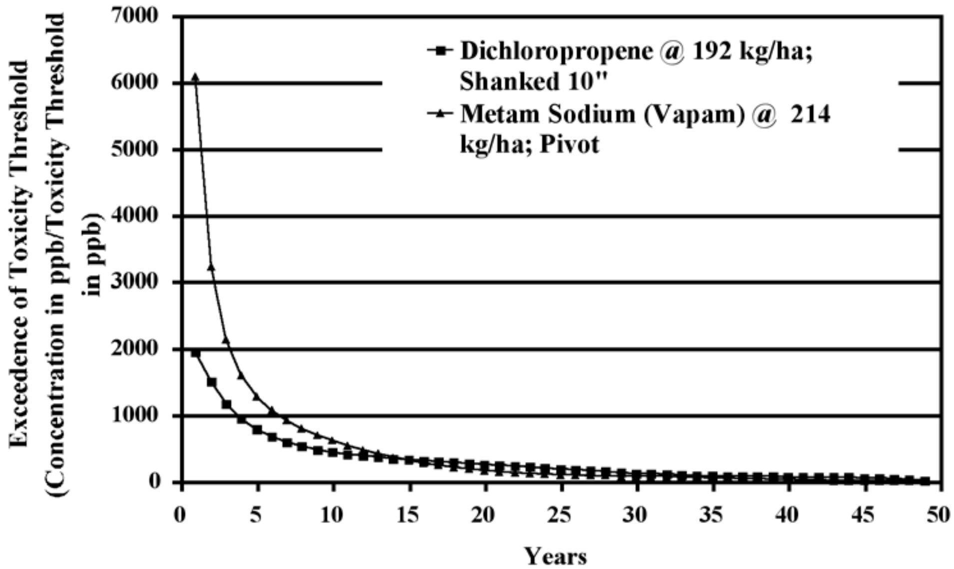


Figure 5.8 NAPRA analysis results of 1,3 Dichloropropene and Metam Sodium leaching below the root zone in excess of the 2.0 and 1.8 (g/L CHCL, respectively, Fort Hall, Idaho.

Prior to completing NAPRA analysis, these chemicals had not been monitored in ground water on the reservation. Since then ground water samples have been collected from several shallow monitoring wells and tested for both chemicals with no detections. EPA is currently requiring Dow-Elanco to conduct an extensive tap-water monitoring study of 1, 3-dichloropropene (Telone) for re-registration. The Shoshone-Bannock Tribes have partnered with the Idaho Soil Conservation Commission (SCC), Idaho State Department of Agriculture (ISDA), U.S. Geological Survey (USGS) and USDA, NRCS to monitoring the movement of 1,3-dichloropropene (Telone II) and metam-sodium (Vapam) through the soil profile on the Fort Hall Indian Reservation in Southeastern Idaho. The goal of this project is to confirm that 1,3-dichloropropene (Telone II) and metam-sodium (Vapam) are not a potential threat to ground water quality. The project primarily will examine the migration and persistence of 1,3-dichloropropene and it's degradation products through the soil profile after application to crop fields. A secondary objective will be to monitor movement of the degradation products of metam-sodium (compounds reported to rapidly degrade in soil) through the soil profile. Monitoring movement and persistence of these compounds in soil will provide information on the potential for future ground water contamination problems.

Integrated pest management strategies where nematode populations in a crop field are intensely sampled to identify site-specific infestations that occur above economic thresholds. Infestations that occur above the threshold will be spot treated instead of treating the entire field. This technique also eliminates the need for precautionary soil fumigation by farmers. The Dutch in the Netherlands have been using this IPM technique for about the last 10 years and have reduced nematicide applications in similar intense agricultural areas by as much as 90 percent.

As mentioned earlier, some areas are intrinsically vulnerable. The Ft. Hall example above is intrinsically vulnerable because of low organic matter sandy soils over an at-risk aquifer. Extrinsic management factors also influence vulnerability because irrespective of intrinsic site characteristics, water quality contamination usually does not occur without cropping systems that provide contaminant loading. In the Ft. Hall example, 1,3-dicholopropene and metam sodium fumigants were applied at labeled rates (>150lbs AI/acre or >168 kg AI/ha) that far exceed typical pesticide application rates (0.10 to 4 lbs AI/acre or 0.12 to 4.5 kg/ha). In this case both intrinsic site characteristics and extrinsic management factors make this site highly vulnerable.

Monitoring at this site had previously determined that ground water was contaminated with EDB, but 1,3 dichloropropene and metam sodium were not included in the monitoring analysis. In this case, 1,3-dichloropropene and metam sodium where identified as potential ground water risks with NAPRA analysis. Whether these chemicals actually pose a risk, is the subject of a monitoring study initiated, in part, because of NAPRA risk analysis modeling.

NAPRA in New York

The NAPRA process is currently being used in several New York watersheds to develop pest management BMPs for protecting surface and ground waters NAPRA was run by the Erie County Soil and Water Conservation District for each pesticide alternative recommended by Cornell Cooperative Extension for a specific crop and pest, and 'risk rankings' were developed. Loss probabilities of recommended pesticide alternatives are compared graphically (figure 5.9). Developing risk rankings further simplified data presentation to decisionmakers (table 5.7). Risk rankings were based on multiple factors such as the number of years the toxicity threshold was exceeded and the magnitude of that exceedence. The risk ranking indicates the extent of mitigation needed. The higher the risk rating, the greater the number of BMPs that should be used (table 5.8). The results are provided to crop consultants and producers as a color pamphlet and associated 'risk rating' sheets. The pamphlet contains generic advise on BMPs that can reduce hazardous off-site pesticide movement, along with guidance on what risk levels warrant BMPs, and the number of BMPs needed. Further, the effectiveness of several best management practices for reducing off-site pesticide movement is listed (table 5.9). Risk rating sheets are specific for a crop and pest, and list the pesticide alternatives recommended for that crop. Planners and crop consultants can use these pamphlets to assist producers in choosing the safest alternative/mitigation combination. Currently, risk ratings for recommended pesticide alternatives on over nine crops have been developed for two New York watersheds.

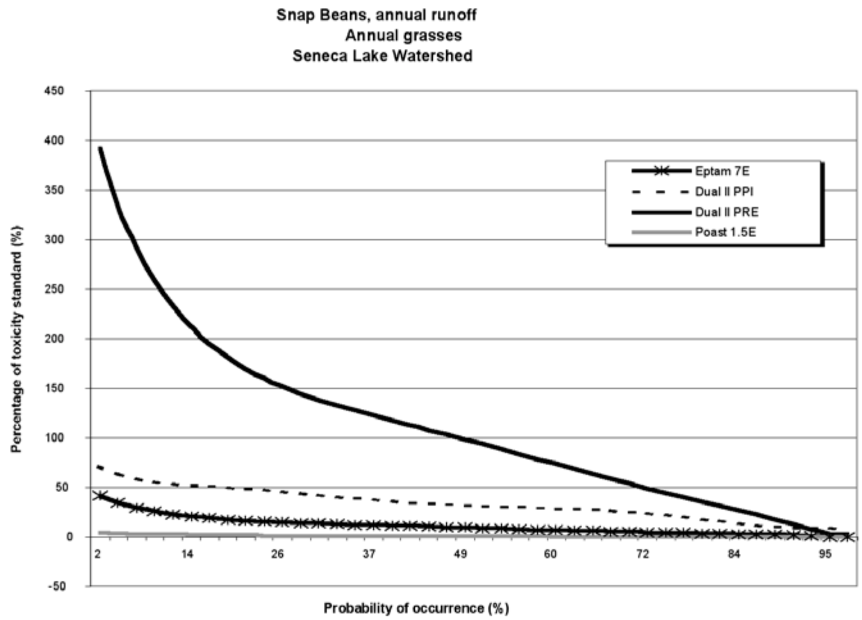


Figure 5.9 NAPRA results for evaluating recommended pesticide alternatives used to control annual grasses in snap beans, Seneca Lake Watershed, New York.

Table 5.7 National Agricultural Pesticide Risk Analysis (NAPRA) Environmental Risk Rating for pesticide applications for controlling annual grasses in snap beans, Seneca Lake Watershed, New York.

Pesticide Trade	Rate of Application	Application Method and Timing	Environmental Risk Rating: Human Lifetime Health Advisory – Leaching	Human Lifetime Health Advisory – Runoff	Aquatic Level of Concern – Leaching	Aquatic Level of Concern – Runoff
Assure II (quizalofop-p-ethyl)	0.375 - 0.75 pt/ac	early postemergenc	1	1	1	1
Dual II (metolachlor)	1.5 - 3.0 pt/ac	preplant incorporat	1	1.3	1	1
Dual II (metolachlor)	1.5 - 3.0 pt/ac	pre-emergence	1	4.7	1	1
Eptam 7E (EPTC)	3.5 - 4.5 pt/ac	preplant incorporat	1	1	1	1
Poast 1.5E (sethoxydim)	1.0 - 1.5 pt/ac	early postemergenc	1	1	1	1

Environmental Risk Rating

1 ⟵⟶ 8

Very Low Risk — Very High Risk

Table 5.8 Number of best management practices recommended by Erie County Soil and Water Conservation District, developed from NAPRA environmental risk evaluation Seneca Lake Watershed, New York.

Environmental Risk Rating	*Recommended Best Management Practices*
1	Practice Integrated Pest Management
1 to 2	Practice IPM and implement **one or more** BMPs
3 to 4	Practice IPM and implement **two or more** BMPs
5 to 6	Practice IPM and implement **three or more** BMPs
7 to 8	Practice IPM and implement **four or more** BMPs

Table 5.9 Best management practices to reduce environmental risk from pesticide applications for the Seneca Lake Watershed, New York, developed using NAPRA to evaluate environmental risk.

Pesticide Best Management Practices to Reduce Environmental Risk			
*Pesticide Best Management Practice**	*Potential Effect*		
*** These BMPs may be more or less effective depending on field characteristics such as topography or soil type.*	*Runoff*	*Leaching (see Note below)*	*Erosion*
Use crop residue management (conservation tillage) to reduce runoff and soil-adhered pesticide loss	↓↓↓	←→	↓↓↓
Increase organic matter in soil	←→	High Koc ↓↓ Low Koc ↑ *	↓↓
Use mechanical cultivation to decrease pesticide use	↓↓	↑↑	←→
Plant winter cover crops or inter-row crops	↓	←→	↓↓
Incorporate appropriate pesticides	↓↓↓	↑↑	↑↑
Use contour planting	↓	↑	↓↓
Install terraces or retention basins on steep slopes	↓↓↓↓	↑	↓↓↓↓
Plant strip crops	↓	↑	↓↓
Plant vegetative filter strips to increase infiltration or trap chemical runoff	↓↓↓	↑↑	↓↓↓
Maintain buffer strips and remove sediment buildup	↓↓↓	↑↑	↓↓
Set up no-spray strips	↓↓	←→	←→
Install and maintain grassed waterways in conjunction with filter strips	↓↓↓	↑↑	↓↓↓↓
Implement proper subsurface drainage (do not outlet directly to stream)	↓↓↓	←→	↓
Use tillage practices that reduce compaction or surface crusting	↓↓↓↓	↑↑↑	↓↓
Time and monitor irrigation to minimize pesticide losses	↓↓↓	↓	↓↓
Time pesticide applications to avoid precipitation events that cause significant runoff or leaching	↓↓↓↓	↓↓↓	↓↓↓

↓Decrease ←→May be an increase or decrease depending on existing soil or field conditions.

↑ Increase

A greater number of arrows indicates a greater potential for reduction in off-site movement of pesticides.

*Increasing organic matter increaes soil structure, which increases water infiltration. Pesticides with extremely low K_{oc}'s (less than 10 ml/g) are relatively insensitive to filtration by organic matter and could cause an increase in pesticide leaching.

Note: Runoff-reducing management practices frequently increase infiltration. It is preferable to use the ability of the soil to filter and biologically degrade pesticides than allow the chemicals to leave the field in runoff.

Student Activity 6

1. Briefly describe, a) the Tier 1 evaluation step, b) the importance of Tier 1 for efficient use of time and c) how the Tier 1 tool, WIN-PST, relates to the pest management component of a conservation plan.

2. Briefly describe how WIN-PST Loss Potentials differ from WIN-PST Hazard ratings.

3. Does a WIN-PST Loss Potential rating of *Intermediate* or *High*, indicate a potential risk of chemical movement?

4. Which tier/tool would you use to deal with the following situations (and give a brief explanation of why):

   a. TMDL in a watershed.

   b. Development of the pest management component of conservation plan.

   c. Prevent losses from an identified high risk field where fish kills have been documented.

   d. Determine potential high risk areas within a watershed.

   e. Develop local best management practices to reduce pesticide loss from specific crop.

____

____

____

____

____

____

5. The following table shows a WIN-PST Soils Report. The soils listed below are identical in their texture and hydrologic soil group. Assume they have the same hydrologic properties (hydraulic conductivity, permeability, bulk density, etc) and therefore, would leach the same volume of water. Using what you have learned about pesticide/soil interactions, what two soil parameters are responsible for the large difference in estimated soil leaching potentials? Explain how they are critical in estimating potential leaching.

```
                              WIN-PST SPISP II
                   SOIL SENSITIVITY TO PESTICIDE LOSS RATING REPORT
=============================================================================================

Soils Data Table: SOIL_IL   Sort Order: MUSYM

---------------------------------------------------------------------------------------------

ADAMS COUNTY, ILLINOIS: IL1
                                                                  SPISP II Ratings
                                                                  --------------------------
                                                                           Solution Adsorbed
                                                  SURFACE                 Leaching Runoff   Runoff
MUSYM/SEQ# COMPONENT/TEXTURE/MU%    HYD KFACT DEPTH    % OM     (SLP)    (SSRP)   (SARP)
========== ======================== === ===== =======  =====   ======== ======== ========
37A 1         Worthen SIL 100%       B   0.32    33"    3.5%      L        I        I
-----------------------------------------------------------------------------------------
477B 1        Winfield SIL 100%      B   0.37    10"    1.0%      I        I        I
-----------------------------------------------------------------------------------------
477B2 1      Winfield SIL 100%       B   0.37    8"     1.0%      H        I        I
-----------------------------------------------------------------------------------------

(.\REPORTS\M5DSA614.TXT generated on 04/16/01 at 12:09:05)
=============================================================================================


H -- High
I -- Intermediate
L -- Low
V -- Very Low

Conditions that affect ratings:
m -- There are macropores in the surface horizon deeper than 24"
w -- The high water table comes within 24" of the surface during the growing season
s -- The field slope is greater than 15%

SPISP II S-Ratings:
SLP  -- Soil Leaching Potential
SSRP -- Soil Solution Runoff Potential
SARP -- Soil Adsorbed Runoff Potential
```

6. The pesticide properties of acetochlor, alachlor and dicamba are listed below. Based on these properties:

SPISP II Ratings

Active Ingredient Common Name	Solubility In Water	Half-Life	KOC	Human Toxicity
Acetochlor (ANSI)	223	14	150	21 CHCL*
Alachlor (ANSI)	240	15	170	2 MCL
Dicamba, dimethylamine salt	400000	14	2	200 HA*

a. Which pesticide is more likely to leach and why?

b. Which chemical's leaching would be similar among the soils listed in exercise 5. Briefly explain why.

c. Which chemical could potentially pose the greatest hazard to human when applied to the Winfield SIL with the 1.0 percent OM and 8 inch surface horizon (MUSYM 477B2)? Briefly explain.

d. Which might potentially pose the least human hazard when applied to the same soil as c. above and why?

____

____

____

____

7. A WIN-PST soil/pesticide interaction, pesticide, and soils report has been developed for a producer who grows continuous grain corn and has infestations of corn root worm. The producer uses a conservation tillage (minimum tillage) approach on both fields. The resources of concern are human exposure from drinking water from nearby shallow wells of a small housing development immediately adjacent to the first field comprised of Sparta LFS. The second field (Winfield SIL) has a perennial stream that is immediately adjacent to the field. Fish kills have been noted in the stream in June, soon after the producer treats for corn root worm. The producer farms right up to the property line of the housing development. The farmer also farms up to the stream (within 10 feet) and is very careful not to directly contaminate the stream. The Producer is currently using Turbufos on both fields. The pesticides that have been presented in the WIN-PST reports shown on the following pages, are recommend for controlling root worm by Extension.

Report 1

```
                              WIN-PST SOIL / PESTICIDE INTERACTION
                           LOSS POTENTIAL and HAZARD RATINGS REPORT
============================================================================================

Soils Data Table: SOIL_IL   Sort Order: COMPONENT
Pesticide Data Table Sort Order: NAME


                                                                        SOILS

                                 7088B: Sparta LFS 100%|        477B:  Winfield SIL 100%
                                 HYDRO: A              |        HYDRO: B
PESTICIDES                       ADAMS COUNTY,         |        ADAMS COUNTY,
                                 ILLINOIS: IL1         |        ILLINOIS: IL1
===================================================================================================
COUNTER 15G SYSTEMIC INSECTICIDE-NEMATICIDE   REG_NO: 00024100238
  ________________________________________________________________________________________
  15.00% Terbufos (ANSI)
                                 Loss         Human      Fish      | Loss         Human     Fish     |
                                 Potential    Hazard     Hazard    | Potential    Hazard    Hazard   |
       pH 4                      --------------------------------|-------------------------------|
       Leaching   (ILP):         I            X          X         | L            H         H        |
       Solution Runoff (ISRP):   L            H          H         | I            X         X        |
       Adsorbed Runoff (IARP):   L                       I         | L                      I        |
====================================================================================================
FORCE 3G INSECTICIDE   REG_NO: 01018200373
  _________________________________________________________________________________________
  3.00% Tefluthrin (ANSI)
                                 Loss         Human      Fish      | Loss         Human     Fish     |
                                 Potential    Hazard     Hazard    | Potential    Hazard    Hazard   |
                                 --------------------------------| ------------------------------|
  Leaching   (ILP):              L (l)        L          H         |  V (l)       V         I        |
  Solution Runoff (ISRP):        L (l)        L          H         |  L (l)       L         H        |
  Adsorbed Runoff (IARP):        L (l)                   I         |  L (l)                 I        |
===================================================================================================
LORSBAN 15G   REG_NO: 06271900034
       ____________________________________________________________________________________
       15.00% Chlorpyrifos (ANSI)
                                 Loss         Human      Fish      | Loss         Human     Fish     |
                                 Potential    Hazard     Hazard    | Potential    Hazard    Hazard   |
                                --------------------------------- |-------------------------------|
       Leaching   (ILP):         L (fb)       L          H         | V (fb)       V         I        |
       Solution Runoff (ISRP):   L (fb)       L          H         | L (fb)       L         H        |
       Adsorbed Runoff (IARP):   L (fb)                  L         | L (fb)                 L        |
===================================================================================================
PHORATE 20-G   REG_NO: 00977900293
       ____________________________________________________________________________________
       20.00% Phorate (ANSI)
                                 Loss         Human      Fish      | Loss         Human     Fish     |
                                 Potential    Hazard     Hazard    | Potential    Hazard    Hazard   |
                                 --------------------------------|-------------------------------|
       Leaching   (ILP):         L (b)        I          H         | V (b)        L         I        |
       Solution Runoff (ISRP):   L (b)        I          H         | I (b)        H         X        |
       Adsorbed Runoff (IARP):   L (b)                   L         | I (b)                  I        |
====================================================================================================

(.\REPORTS\INTSTU2.TXT generated on 04/16/01 at 12:39:32)
================================================================================================
```

Report 1, continued

```
X -- eXtra high
H -- High
I -- Intermediate
L -- Low
V -- Very low

Conditions that affect ratings:
(none) -- Broadcast application (default); applied to more than 1/2 the field
b      -- Banded application; applied to 1/2 the field or less

(none) -- Surface applied (default); applied to the soil surface
i      -- Soil incorporated; with light tillage or irrigation
f      -- Foliar application; directed spray at nearly full crop/weed canopy

(none) -- Standard application rate (default); greater than 1/4 lb/acre
l      -- Low rate of application; 1/10 to 1/4 lb/acre
<ul>   -- Ultra Low rate of application; 1/10 lb/acre or less

m      -- There are macropores in the surface horizon deeper than 24"
w      -- The high water table comes within 24" of the surface during the growing season
s      -- The field slope is greater than 15%

r      -- Residue management

<hl>   -- High probability of rain, Low  efficiency irrigation
<lh>   -- Low  probability of rain, High efficiency irrigation
<ln>   -- Low  probability of rain, No irrigation

SPISP II I-Ratings:
ILP    -- Soil / Pesticide Interaction Leaching Potential
ISRP   -- Soil / Pesticide Interaction Solution Runoff Potential
IARP   -- Soil / Pesticide Interaction Adsorbed Runoff Potential
```

Report 2

WIN-PST SPISP II

PESTICIDE ACTIVE INGREDIENT RATING REPORT

PRODUCTS Data; Table Sort Order: NAME

Active Ingredient Common Name	pH	Solubility In Water (ppm)	Half-Life (days)	KOC (mL/g)	Human Toxicity (ppb)	Fish Toxicity MATC* (ppb)	Fish Toxicity STV	SPISP II Ratings PLP	SPISP II Ratings PSRP	SPISP II Ratings PARP	Exposure Toxicity Adjusted Category Water Human	Water Fish	Sediment Fish
COUNTER 15G SYSTEMIC INSECTICIDE-NEMATICIDE REG_NO: 00024100238													
15.00% Terbufos (ANSI)	4	5	5	500	0.9 HA	0.0473	24	L	I	L	X	X	H
FORCE 3G INSECTICIDE REG_NO: 01018200373													
3.00% Tefluthrin (ANSI)		0.02	24	20000	35 HA*	0.0029	57	V (l)	L (l)	L (l)	I	X	H
LORSBAN 15G REG_NO: 06271900034													
15.00% Chlorpyrifos (ANSI)		0.4	30	6070	20 HA	0.3666	2225	V (fb)	L (fb)	L (fb)	I	X	L
PHORATE 20-G REG_NO: 00977900293													
20.00% Phorate (ANSI)		22	60	1000	4 HA*	0.1351	135	V (b)	I (b)	I (b)	H	X	I

(.\REPORTS\PSTSTU2.TXT generated on 04/16/01 at 12:39:29)

PARP -- Pesticide Adsorbed Runoff Potential

Report 2, continued

```
X      --  eXtra high
H      --  High
I      --  Intermediate
L      --  Low
V      --  Very low

Conditions that affect ratings:
(none) --  Broadcast application (default); applied to more than 1/2 the field
b      --  Banded application; applied to 1/2 the field or less

(none) --  Surface applied (default); applied to the soil surface
i      --  Soil incorporated; with light tillage or irrigation
f      --  Foliar application; directed spray at nearly full crop/weed canopy

(none) --  Standard application rate (default); greater than 1/4 lb/acre
l      --  Low rate of application; 1/10 to 1/4 lb/acre
<ul>   --  Ultra Low rate of application; 1/10 lb/acre or less

SPISP II P-Ratings:
PLP    --  Pesticide Leaching Potential
PSRP   --  Pesticide Solution Runoff Potential
```

Report 3

```
                              WIN-PST SPISP II
               SOIL SENSITIVITY TO PESTICIDE LOSS RATING REPORT
=============================================================================================

Soils Data Table: SOIL_IL   Sort Order: COMPONENT

---------------------------------------------------------------------------------------------

ADAMS COUNTY, ILLINOIS: IL1

                                                                  SPISP II Ratings
                                                                  ----------------------------
                                                                            Solution Adsorbed
                                                    SURFACE       Leaching  Runoff   Runoff
MUSYM/SEQ# COMPONENT/TEXTURE/MU%  HYD   KFACT   DEPTH   % OM  (SLP)     (SSRP)   (SARP)
========== ====================  ===   =====   ======  ===== ======    ======   ======
7088B 1    Sparta LFS 100%       A     0.17    12"     1.5%  H         L        L
---------------------------------------------------------------------------------------------
477B 1     Winfield SIL 100%     B     0.37    10"     1.0%  I         I        I
---------------------------------------------------------------------------------------------

(.\REPORTS\SOI5STU2.TXT generated on 04/16/01 at 12:39:30)
=============================================================================================


H    -- High
I    -- Intermediate
L    -- Low
V    -- Very Low

Conditions that affect ratings:
m    -- There are macropores in the surface horizon deeper than 24"
w    -- The high water table comes within 24" of the surface during the growing season
s    -- The field slope is greater than 15%

SPISP II S-Ratings:
SLP  -- Soil Leaching Potential
SSRP -- Soil Solution Runoff Potential
SARP -- Soil Adsorbed Runoff Potential
```

a. What kind of information do the three WIN-PST reports provide?

b. Briefly list the points you need to bring up to educate the producer about the hazards created by pesticide leaching and runoff.

c. What actions might be taken assuming the reports are for:

1) A benchmark condition where no IPM has been implemented.

2) Alternatives recommended by a crop consultant but not using an IPM program or principles?

3) Alternatives developed within an established IPM program?

8. Identify three environmental discriminators/toxicity values/ recommended criteria and describe how they can be used to evaluate potential water quality impacts.

9. List some of the benefits you would discuss with the producer for limiting offsite pesticide leaching and runoff.

References

USDA-NRCS National Planning Procedures Handbook. Explains in detail the planning process that NRCS has used and modified over the last 50 plus years of its history.

USDA-NRCS Field Office Technical Guide. The repository of technical information used by NRCS.

U.S. Environmental Protection Agency. Quality Criteria for Water 1986. Sometimes referred to as the gold book, this document included information about major contaminants of concern to water quality.

Your State Water Quality Standards. Water quality standards are developed for each state. State water quality or environmental agencies are responsible for this document and can provide a copy.

Your State 305(b) Report. 305(b) reports are developed for each State. State water quality or environmental agencies are responsible for this document and can provide a copy

USDA-NRCS. 1993. Agrichemical-chemical Management Materials for Development of State Training Program. This training program and associated materials were developed originally to "Train the Trainer." Four sessions were held across the nation and a copy of the supporting materials was provided to each state.

USDA-NRCS. Agricultural Chemicals Management (Draft Manuscript). This draft document is a product of an NRCS team to provide current concepts regarding the management of agricultural chemicals and the impact they have on water. This document compliments the planning process by providing the technical information needed to understand how conservation practices affect fate and transport of agricultural chemicals.

USDA-NRCS. Windows® Pesticide Screening Tool (WIN-PST). http://www.wcc.nrcs.usda.gov/water/quality/common/pestmgt/winpst.htm. This the NRCS Water and Climate Center website for access to WIN-PST.

USDA-NRCS. 1992. National Agricultural Pesticide Risk Assessment. This document describes the need for pesticide environmental risk analysis, the NRCS three-tiered pesticide environmental risk analysis, the NAPRA process, NAPRA software physical design, and NAPRA-advantages and disadvantages of computer modeling.

USDA-NRCS. 1994. The Phosphorus Index—A Phosphorus Assessment Tool. The phosphorus index provides field staffs, watershed planners, and land users with a tool to assess the various landforms and management practices for potential risk of phosphorus movement to waterbodies.

Section II of the Field Office Technical Guide (FOTG). This section should include Leaching Index values for local planning areas.

Proceedings from the 1988 SCS Water Quality Workshop, Integrating Water Quality and Quantity into Conservation Planning. October, 1988. Background information for how to develop a Leaching Index.

Williams, J.R., and D.E. Kissel. 1991. *Water percolation: An indicator of nitrate nitrogen leaching potential*. (In) R.F. Follett, D. R. Keeny, and R. M. Cruse (eds.), Managing Nitrogen for Groundwater Quality and Farm Profitability. Soil Science Society of America. Madison, WI. Science behind the development of the Leaching Index.

Activity Answers

Student Activity 1

1. List the three primary human considerations and explain why they are important in conservation planning.

   Cultural, economic, and social considerations.

   Human considerations have a significant impact on the way land users choose to adopt and apply conservation practices. Decisionmaker perceptions of the resource problem and solutions (conservation practices/systems) as influenced by cultural values and social and economic limitations must be considered to complete the Resource Management System (RMS) planning process. Without this consideration the planning process will likely never be complete and important conservation practices will not be implemented.

   Farmers, ranchers, and other land users decide whether to adopt conservation practices or systems based on how they perceive the RMS will meet their needs, fit their operation, maintain their economic viability, give them expected results, whether or not they are consistent with local cultural values, and meet society's expectations (including those required by law, as well as desired expectations).

2. Which sections of the Field Office Technical Guide and the National Planning Procedures Handbook are applicable to nutrient and pest management?

   All of them are applicable.

   - *Section I—References*
   - *Section II—Soils, SPISP, Nitrogen Leaching Index*

- *Section III—Quality Criteria*
- *Section IV—Conservation Practices*
- Section V—Conservation Practice Effects
- *9 steps of planning, from problem identification (step 1) to plan evaluation.*

3. Describe a Resource Management System (RMS).

   A Resource Management System is a combination of structural, vegetative, and management practices that:

   a. when planned, will at a minimum meet established quality criteria levels for all resources, and when installed;

   b. will provide for the conservation, wise use, and protection of the resource base for soil, water, air, plant, and animal resources.

Student Activity 2

1. What is the overall goal of the Clean Water Act?

   Fishable/Swimmable Waters throughout the U.S.

   The objective of the CWA is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters, and wherever attainable, to achieve a level of water quality that provides for the propagation of fish, shellfish, and wildlife, and for recreation in and on the water. This is referred to as the fishable/swimmable" goal of the CWA.

2. What are Water Quality Standards as authorized under Section 303(c) of the Clean Water Act.

   Section 303(c) of the Clean Water Act authorizes States to develop and implement water quality standards, which measure the attainment of the "fishable/swimmable" goal. The Act states that waters shall be protected through designated beneficial uses and setting criteria to protect those uses. Water quality standards are laws or regulations that States and Tribes adopt to enhance water quality and protect human health. Water quality standards consist of three components: 1) the designated beneficial use or uses of a waterbody or segment of a waterbody; 2) the water quality criteria necessary to protect the use or uses of that waterbody, and 3) an antidegradation policy. When establishing water quality standards, each state must designate Uses for each waterbody (the goals), and adopt water quality criteria to protect the designated uses.

3. Define use as it applies to Water Quality Standards.

   The formal use or goal for which the water resource is designated. Typically these uses are established by state water resource or environmental agencies.

4. List five common uses identified in State Water Quality Standards.

   a. *Drinking water supply*

   b. *Agricultural water supply*

   c. *Industrial water supply*

   d. *Navigation*

   e *Mining*

   f. *Cold water biota*

   g. *Warm water biota*

h. Salmonid spawning

i. Shellfish propagation

j. Coral reef preservation

k. Primary contact recreation

l. Secondary contact recreation

m. Wildlife habitat

n. Aesthetics

5. List two potential environmental problems associated with excess nutrients and pesticides and their relationship to the uses of the water.

Excess nutrient in surface water—May result in nutrient enrichment and depending on the degree of enrichment it may impair one or more of the uses.

- *Aquatic life*
- *Aesthetics*
- *Agricultural water supply*
- *Domestic water supply*

Excess nutrients in ground water—May result in elevated nutrient concentrations in ground water and depending on the nutrient and the nature of the resource setting may impair one or more of the uses.

- *Domestic water supply*
- *Aquacultural water supply*

Most commonly nitrogen concentrations in ground water are a primary concern, especially when they occur near, at or above the drinking water standard of 10 mg/L nitrate-nitrogen. Nitrate concentrations may also be a *concern if the trend indicates increasing concentrations. In some cases surface water impairments may result from nitrogen and phosphorus concentrations in ground water that discharges to a sensitive surface water body.* ***This impairment could result from nitrate and phosphorus concentrations well below water quality standards associated with drinking water protection***

Pesticides in surface water—May result in pesticide concentrations in surface water and may impair one or more of the uses.

- *Aquatic life*
- *Agricultural water supply*
- *Domestic water supply;*

When pesticides are detected in surface water, there is obvious concern. This is especially the case for serious health or environmental problems that can occur when pesticide concentrations in surface water exceed the drinking water standard (MCL or HAL) or the acute/ chronic toxicity level of the species inhabiting the waterbody.

Pesticides in ground water—Depending on the pesticide and the nature of the resource setting may impair one or more of the uses.

- *Domestic water supply*
- *Aquacultural water supply*
- *Agricultural water supply;*

When pesticides are detected in ground water, there is obvious concern. This is especially the case for serious health problems that can occur when pesticide concentrations in ground water exceed the drinking *water standard (MCL or HAL). Pesticide concentrations may be of even greater concern if the trend indicates increasing concentrations. In some cases surface water impairments may result from pesticide concentrations in ground water that discharges to a sensitive surface waterbody.*

6. Describe the Criteria component of Water Quality Standards.

   Water quality criteria are limits on a particular pollutant or limits on a condition of a waterbody designed to protect and support a designated use. Criteria to protect these uses may include such things as a narrative sediment standard to protect coldwater biota and salmonid spawning uses or a numeric bacteria standard to protect Primary Contact Recreation (e.g. swimming).

7. How do the designated uses of a receiving waterbody, the status of support for those uses, and specific State or local water quality protection goals relate to NRCS/State Nutrient and Pest Management practices?

   NRCS/State Nutrient and Pest Management practices are essential methods for optimizing agrichemical use and minimizing potential adverse impacts on the environment. They are intended to provide the pollution reduction necessary for a waterbody to attain (or maintain) water quality standards, especially when nutrients and/or pesticides are identified as contaminants of concern. *TMDLs, source water protection plans, and other water quality protection plans are integral parts of a State's water quality management program. The goal is to achieve compliance with a State's water quality standards; to have fishable/swimmable waters. States have the primary responsibility for developing TMDLs and Source Water Protection Plans at levels necessary for attaining and maintaining water quality conditions necessary to support the designated uses.*

The designated beneficial use of a receiving waterbody, the status of support for those uses, specific State or local delineation's and water quality protection goals will often dictate how nutrient and pest management components of a conservation plan are formulated and additional mitigating practices (BMPs) that may be necessary to provide adequate resource protection. Certain uses like Drinking Water Supply may require special consideration because they are so important to human health. Other uses like Cold Water Biota and Salmonid Spawning may also require special consideration because they are so sensitive to relatively small reductions in water quality conditions. When a beneficial use for a receiving water body is not supported because of water quality limiting conditions, e.g. it's on the 303(d) list, additional considerations may be necessary. Plans should include additional mitigating practices that may be necessary to provide adequate resource protection, for example specific practices called for in a TMDL Implementation Plan and Source Water Protection Plans.

TMDL implementation plans and Source Water Protection Plans focus on identifying specific best management practices for non-point sources in specific geographic areas needed to meet load allocations in the TMDL and Source Water Protection Plans. The overall conservation plan or resource management system will identify specific BMPs that will often include nutrient and pest management on cropland. The implementation of these BMPs together with other important BMPs (collectively a system of BMPs or a Resource Management System) will be a critical step towards actually achieving the load reductions targeted in a TMDL or a Source Water Protection Plan, especially when nutrients and/or pesticides are identified as contaminants of concern.

Student Activity 3

1. Describe three site characteristics (intrinsic) and how they influence a site's vulnerability to surface or ground water contamination.

   Refer to Part C, pages 39–40

2. Indicate (increase or decrease) how the following Site Characteristics (Intrinsic) influence vulnerability.

Site Characteristics (Intrinsic)	Vulnerability	
	Surface Water	**Ground Water**
Intense summer rainfall	Increase	Increase
Steep slopes	Increase	Decrease/no change
Highly permeable soils	Decrease	Increase
Closed basin	Decrease	Increase
Short distance to water body	Increase	Increase
Shallow to ground water	Increase	Increase/no change
High runoff class	Increase	N/A
Significant deep percolation	N/A	Increase
Shallow to impermeable layer	Increase	N/A
K factor >0.32	Increase	N/A
Long residence time in waterbody	Increase	N/A
Slow aquifer hydraulic conductivity	N/A	Increase

3. Describe three management factors (extrinsic) and how they can influence a site's vulnerability to surface or ground water contamination.

   Refer to Part C, pages 53–54

4. Indicate (increase or decrease) how the following management (extrinsic) factors influence vulnerability.

Management (Extrinsic)	Vulnerability	
	Surface Water	**Ground Water**
Conventional tillage	Increase	Decrease
Sprinkler irrigation	Decrease	Decrease/Increase
Residue management or conservation tillage	Decrease	Decrease/Increase
Surface irrigation	Increase	Increase
Conversion to CRP	Decrease	Decrease
High input crop	Increase	Increase
Fall fertilizer application	Increase	Increase
High erosion rate	Increase	N/A
Surface applied fertilizer	Increase	Increase

5. Describe the difference between intrinsic vulnerability and extrinsic vulnerability.

Some natural regions, areas, and field sites are intrinsically vulnerable. Intrinsic vulnerability includes natural intrinsic characteristics (physical and biological) of the site that allow contaminant movement, either below the rootzone or beyond the edge of the field. Site characteristics (intrinsic) include climate, soil properties, vadose zone properties, depth to groundwater and slope and distance to water bodies. Management (extrinsic) includes agricultural management systems that introduce pollutants including nutrients (commercial fertilizer and organic materials) and pesticides.

6. Why is resource vulnerability important to water quality?

   Resource vulnerability combines natural intrinsic characteristics and extrinsic management factors. As such, vulnerability provides an overall assessment of water pollution potential. Extrinsic management factors are critical to a vulnerability assessment because irrespective of intrinsic site characteristics, water quality contamination usually does not occur without cropping systems that provide contaminant loading. With this concept in mind, it is important to consider all of the factors under our control and how they can be manipulated to reduce the potential for ground and surface water contamination.

7. Which of the following are intrinsic vulnerability factors? Circle the letter.

   (a.) *Soil texture*

   b. Crop rotation

   c. Irrigation

   (d.) *Field slope*

   (e.) *Depth to ground water*

8. Field A contains a deep sandy loam soil over fractured bedrock. Field B contains a deep sandy loam soil over karst topography. Field C contains a clay loam over a confined aquifer. Field D contains a loamy sand over a shallow, unconfined aquifer that is used for drinking water supply.

   Rank these fields in descending order of their intrinsic vulnerability to pesticide contamination (the most vulnerable would receive a raking of 1).

   1. *D*

   2. *B*

   3. *A*

   4. *C*

9. The following soil property influence ground water vulnerability. Indicate how vulnerability can be increased and decreased with management.

   Low organic matter content
   Surface connected macropores
   High water table

   Decrease vulnerability by:

   Increasing organic matter with residue management (reduced tillage), green manure, or animal manure.

   Disrupting macropores with tillage or timing agrichemical applications to avoid heavy rainfall or irrigation soon after application.

   Lower water table by installing tile drainage.

   Increase vulnerability by:

   Further decreasing organic matter with conventional tillage and low residue crops in rotation.

Appling agrichemicals just before intense rainfall or irrigation, or not mechanically incorporating agrichemicals and disrupting macropores.

Frequently over irrigating, application of highly leachable pesticides, or over application of nutrients.

10. List four ways a pesticide may enter surface or ground water.

- *surface runoff*
- *drift from aerial applicator*
- *direct application*
- *rain*
- *leaching*
- *spills*

11. What combinations of pesticide and soil properties are most likely to result in pesticide movement to ground water?

Pesticide properties—high water solubility, low K_{oc}, slow degradation (persistent)

Soil properties—high permeability, shallow water table, low organic matter, and clay

12. Rank the following soils from high to low vulnerability to pesticide movement with infiltrating water (1 is highest and 4 is the lowest):

	Rank
a. loam	*3*
b. gravelly sandy loam	*1*
c. silt loam	*2*
d. silty clay	*4*

13. Would a field with a steep slope be more vulnerable to surface water or ground water contamination, all other factors being the same? Explain your answer.

    More sensitive to surface water contamination because more susceptible to runoff.

14. Explain how site characteristics (intrinsic) and management (extrinsic) can be used to develop local water quality vulnerability assessment tools and how these tools can be used in conservation planning.

    Important site characteristics (intrinsic) and management (extrinsic—human induced impacts) can be used to establish vulnerability ratings for specific water resources within delineated areas. These water quality vulnerability assessment tools can then be used to assess an area's potential for nutrient and pesticide contamination. Water quality vulnerability assessment tools can be used to target nutrient and pest management, as well as to identify where additional conservation practices (BMPs) are needed to mitigate potential offsite impacts. Targeted management identifies those field sites with the most likely potential for contamination to occur and where the greatest intensity of management is required to protect water quality.

Student Activity 4

Hypothetical Field 1

Soil erosion (weight = 1.5) is 1.5 ton/ac/yr (=LOW, value = 1)	1.5 x 1 = 1.5
Irrigation erosion (weight = 1.5) is 20 tons/ac/yr (=VERY HIGH, value =8)	1.5 x 8 = 12
Runoff class (weight = 0.5) is LOW (value = 1)	0.5 x 1 = 0.5
Soil P test (weight = 1.0) is High (=HIGH, value = 4)	1.0 x 4 = 4.0
P fertilizer application rate (weight = 0.75) is 25 lb/ac (=LOW, value = 1)	0.75 x 1 = 0.75
P fertilizer application method (weight = 0.5) is placed with planter (=LOW, value = 1)	0.5 x 1 = 0.5
Organic P source application rate (weight = 1.0) is 95 lb/ac (=VERY HIGH, value = 8)	1.0 x 8 = 8.0
Organic P source application method (weight = 1.0) is surface applied in the Fall prior to a Spring crop (=VERY HIGH, value =8)	1.0 x 8 = 8.0
Sum Total of all weighted values = 35.25	

Use the hypothetical example above for Field 1 and table 1 in Technical Note No. 1901 to answer the following questions:

1. List the overall vulnerability of this site and explain the general vulnerability to P loss.

   The overall vulnerability of this site is 35.25 or Very High. This hypothetical field has a Very High potential for P loss and adverse impacts to surface water quality. All necessary soil and water conservation measures must be implemented to minimize the P loss.

2. Using the individual site characteristics, identify the primary factors of concern that are contributing to the site vulnerability rating.

   - *Irrigation erosion*
   - *Soil P Test*
   - *Organic P Application Rate*
   - *Organic P Application Method*

3. Using the primary factors identified in question 2, list some management options that could be used to reduce the site vulnerability.

   Irrigation erosion—Use residue management or reduced tillage to decrease the irrigation erosion rate. Irrigation water management practices should also be used to manage irrigation water and reduce erosion. In some cases irrigation system changes may be necessary. With surface irrigation, at least 20-25 percent surface runoff is necessary for adequate irrigation at the bottom of the field. Surface runoff can be reduced with improvements like surge irrigation. Surface runoff can be reduced to nearly zero by including improvements like a tailwater recovery with a pumpback system or with a properly designed and managed sprinkler system.

   Improving both management and the irrigation system can reduce the amount of water applied and more effectively use existing water supplies. Improving water management, including irrigation scheduling and adequate water measurement, is always the first recommended increment of change. Improving existing irrigation systems is the next. Unless the existing irrigation system is unsuitable for the site (including unacceptable water quality impacts), crop grown, or water supply, converting to another irrigation method seldom produces benefits equal to improvements in water management.

Some States have very strict requirements guiding the proper application of animal waste. The application of animal manure on irrigated fields with runoff typically has specific regulatory requirements. These requirements must be investigated and complied with at the local level.

Soil P Test—The long-term goal should be to conduct a comprehensive soil testing program on the entire farm to determine fields with lower soil test P levels that are more suitable for additions of phosphorus. For fields with excessive P levels, estimates should be made to determine the time required to deplete the soil P to optimum levels.

Organic P Application Rate—Considering the long-term management options recommended under Soil P Test, the organic P application rate should either be reduced to crop P uptake or less, or no organic P should be applied to this field until the soil P test is depleted back to an optimum level. The organic P material should be applied to fields with lower soil P test and index values. In this case the organic P materials should not be applied to this field until the irrigation erosion problem on this field is corrected.

Organic P Application Method—If the organic P material has to be applied, it should be injected or incorporated if possible, and applied immediately before the crop is planted.

Hypothetical Field 2

Annual Precipitation	25 inches
Seasonal Precipitation from October to March	12 inches
Soil Hydrologic Group	C
Percolation Index, PI	0.55 inches
Seasonal Index, SI	0.99
Leaching Index, LI	0.55 inches

Use the hypothetical example on the previous page for Field 2 and the Guidelines for Leaching Assessment to answer the following questions:

7. List the Leaching Index for this site and indicate whether or not nitrate leaching may be a concern.

   The Leaching Index is 0.55 inches. Since the Leaching Index is below 2 inches, this site would probably not contribute to soluble nitrogen leaching below the root zone.

5. Would nitrogen management be important on this field?

   Yes. Although the concern for nitrogen leaching below the root zone is minimal, nitrogen management is important to assure that nitrogen is managed in the crop root zone to optimize crop production and to minimize nitrogen leaching.

Hypothetical Field 3

Annual Precipitation	45 inches
Seasonal Precipitation from October to March	30 inches
Soil Hydrologic Group	B
Percolation Index, PI	13.28 inches
Seasonal Index, SI	1.1
Leaching Index, LI	14.61 inches

Use the hypothetical example above for Field 3 and the Guidelines for Leaching Assessment to answer the following questions:

6. List the Leaching Index for this site and indicate whether or not nitrate leaching may be a concern.

   The Leaching Index is 14.61 inches. Since the Leaching Index is greater than 10 inches, this site will contribute to soluble nitrogen leaching below the root zone.

7. Would nitrogen management be important on this field?

   Yes, especially since the Leaching Index indicates that this site will contribute to soluble nitrogen leaching below the root zone. Nitrogen management is important to assure that nitrogen is managed in the crop root zone to optimize crop production and to minimize nitrogen leaching.

8. What sort of nitrogen management should be considered for this field?

   A nitrogen budget should be developed to accounts for all significant nitrogen sources and to match the application rate to the remaining amount needed to achieve a realistic yield goal. Intense nitrogen management must be employed to minimize nitrate nitrogen movement. This would include careful management of applied nitrogen, precise timing to match crop utilization, conservation practices that restrict water percolation and leaching, and cover crops that capture and retain nutrients in the upper soil profile. Nutrient management practices and techniques such as split nitrogen application rates, pre-sidedress nitrate nitrogen testing or other locally recommended nitrogen testing, and use of a nitrification inhibitor.

Student Activity 5

1. What are the active ingredients in BASIS GOLD®?

   Nicosulfuron, rimsulfuron, atrazine

2. What is the generic class of pests that it controls?

   a. diseases

   b. insects

   (c.) *weeds*

   d. mollusks

   e. rodents

3. BASIS GOLD® is 'selective'. What does selective mean?

   It only controls certain weeds or kinds of weeds

5. What pests does BASIS GOLD® control? Give 3 examples.

   Certain broadleaves and grasses; examples: foxtails; barnyardgrass; crabgrass-large; panicum-fall; shattercane; johnsongrass; quackgrass; signalgrass-broadleaf; wild oats; volunteer cereals; millet-wild proso; cupgrass-wooly; sandbur-field; Italian ryegrass; Texas panicum; velvetleaf; cocklebur; lambsquarters; pigweeds; ragweeds-common, giant; nightshade-eastern, black; smartweed-PA, jimsonweed; morningglories; sunflower; waterhemp; Partial control: yellow nutsedge, Canada thistle, common milkweed, hemp dogbane, pokeweed

5. What BASIS GOLD® active ingredient has been found in ground water?

   Atrazine

6. Name two site/soil conditions under which BASIS GOLD® should not be used.

   Ground water close to the surface and very permeable soils.

7. What is the setback for a:

   a. perennial or intermittent stream

      50 ft mixing, 66 ft application

   b. Natural or impounded lake or reservoir.

      50 ft mixing, 200 ft application

8. What is the active ingredient in BANVEL®?

   Dimethylamine salt of dicamba (dicamba is also acceptable)

9. What is the generic class of pests that it controls? (diseases insects, weeds, mollusks, rodents)

   Weeds

10. What is the EPA Reg. No. (EPA registration Number) of BANVEL®?

    51036-289

11. What specific type of pests does BANVEL® control?

    Broadleaves

12. What BANVEL® active ingredient has been found in ground water?

    Dicamba

13. Under what conditions should BANVEL® not be used, list 3?

    Under conditions that favor runoff; within 50 ft of wells; applications to impervious substrates in areas of high potential for ground water contamination; do not apply to soils classified as sands with less than 3 percent OM and where ground water depth is shallow; do not apply through irrigation equipment nor by flood or furrow irrigation.

14. What is the rate of application for Preplant/Preemergence in No-tillage Corn on an 'Alpha' SIL at 1.5 percent Organic matter?

    0.5 pints per treated acre

Student Activity 6

1. Briefly, a) describe the Tier 1 evaluation step, b) the importance of Tier 1 for efficient use of time, and c) how the Tier 1 tool, WIN-PST, relates to the pest management component of a conservation plan.

    a. *Tier 1 is used to screen pesticide/soil combinations for their potential to runoff or leach.*

    b. *Tier 1 requires a minimal amount of time to learn and minimal time and effort to perform a risk analysis.*

    c. *The WIN-PST tool comprises a first tier. The tool is used to determine the potential hazard of off-site pesticide movement and, when mitigation practices need to be applied. If the WIN-PST soil/pesticide interaction: a) has a low hazard potential to the resource of concern b) the pesticide fits in an IPM program and the pesticide is acceptable to the decisionmaker, then the evaluation ends and the decision is recorded in the conservation plan. If the soil/pesticide combination hazard rates as an Intermediate or High, then appropriate mitigation strategies should be applied. If the soil/pesticide combination hazard rating is Extra High, then mitigation may not be sufficient to prevent hazardous losses from occurring.*

2. Briefly describe how WIN-PST Loss Potentials differ from WIN-PST Hazard ratings

   WIN-PST Loss Potentials estimate the potential for a pesticide to move past the edge of field and bottom of the root zone. WIN-PST Hazard ratings estimate the potential hazards for those losses relative to humans or fish by taking the potential for exposure (Win-PST loss potentials) and combining it with toxicity to determine the hazard that the chemical poses when it leaches or runs off. That is, a chemical that has a high potential to runoff (in solution) and is not very toxic is less hazardous than a chemical that has a high potential to runoff and has a high toxicity.

3. Does a WIN-PST Loss Potential rating of *Intermediate* or *High*, indicate a potential risk of chemical movement?

   Yes, Intermediate and High indicate a potential risk of chemical movement.

4. Which tier/tool would you use to deal with the following situations: (and give a brief explanation of why):

   TMDL in a watershed? *Tier 2 NAPRA. NAPRA can determine edge of field concentrations and therefore can be used to quantify the effects of mitigation.*

   Development of the pest management component of conservation plan? *Tier 1. WIN-PST. WIN-PST is easy to use and provides hazard ratings that can be used to determine when mitigation should be used to prevent hazardous losses.*

   Prevent losses from an identified high risk field where fish kill have been documented? *Tier 2 When specific fields have an identified high risk to, it may be necessary to provide specific, prescribed, application information and mitigation practices to reduce hazardous pesticide losses.*

Determine potential high risk areas within a watershed? *Tier 1. WIN-PST (SPIPS 2) soils ratings can be applied to digitized soils maps to provide leaching and runoff ratings.*

Develop local best management practices to reduce pesticide loss from specific crop? *Tier 2. NAPRA can be run for local climate conditions, and, for any one of a number of crops.*

5. The following table shows a WIN-PST Soils Report. The soils listed below are identical in their texture and hydrologic soil group. Assume they have the same hydrologic properties (hydraulic conductivity, permeability, bulk density, etc) and therefore, would leach the same volume of water. Using what you have learned about pesticide/soil interactions, what two soil parameters are responsible for the large difference in estimated soil leaching potentials? Explain how they are critical in estimating potential leaching (see following page).

```
                              WIN-PST SPISP II
                 SOIL SENSITIVITY TO PESTICIDE LOSS RATING REPORT
=============================================================================================

Soils Data Table: SOIL_IL   Sort Order: MUSYM

---------------------------------------------------------------------------------------------

ADAMS COUNTY, ILLINOIS: IL1
                                                                    SPISP II Ratings
                                                                    --------------------------
                                                                             Solution Adsorbed
                                                SURFACE             Leaching Runoff   Runoff
MUSYM/SEQ# COMPONENT/TEXTURE/MU%    HYD KFACT DEPTH    % OM     (SLP)    (SSRP)   (SARP)
========== ======================== === ===== =======  =====   ======== ======== ========
37A 1        Worthen SIL 100%        B  0.32    33"    3.5%      L        I        I
-----------------------------------------------------------------------------------------
477B 1       Winfield SIL 100%       B  0.37    10"    1.0%      I        I        I
-----------------------------------------------------------------------------------------
477B2 1      Winfield SIL 100%       B  0.37    8"     1.0%      H        I        I
-----------------------------------------------------------------------------------------

(.\REPORTS\M5DSA614.TXT generated on 04/16/01 at 12:09:05)
=============================================================================================


H -- High
I -- Intermediate
L -- Low
V -- Very Low

Conditions that affect ratings:
m -- There are macropores in the surface horizon deeper than 24"
w -- The high water table comes within 24" of the surface during the growing season
s -- The field slope is greater than 15%

SPISP II S-Ratings:
SLP  -- Soil Leaching Potential
SSRP -- Soil Solution Runoff Potential
SARP -- Soil Adsorbed Runoff Potential
```

Depth of surface horizon and organic matter content of the surface horizon. Many pesticides bind to organic matter. The organic contentment of the soil acts to filter out pesticides. While these soils may leach the same amount of water the soil that has the higher soil organic matter (organic matter percent and thicker organic matter rich layers) will filter more pesticide, especially one with a higher K_{oc}s.

6. The pesticide properties of acetochlor, alachlor, and dicamba are listed below. Based on these properties:

SPISP II Ratings

Active Ingredient Common Name	Solubility In Water	Half-Life	KOC	Human Toxicity
Acetochlor (ANSI)	223	14	150	21 CHCL*
Alachlor (ANSI)	240	15	170	2 MCL
Dicamba, dimethylamine salt	400000	14	2	200 HA*

a. Which pesticide is more likely to leach and why?

Dicamba. Low K_{oc}, high water solubility.

b. Which chemical would leach about the same in the soils listed in the exercise. Briefly explain why.

Dicamba. Dicamba's K_{oc} would make it insensitive to organic matter content of the soil.

c. Which chemical could potentially pose the greatest hazard to humans when applied to the Winfield SIL with the 1.0% OM and 8 inch surface horizon (MUSYM 477B2)? Briefly explain.

Alachlor. It is the most toxic to humans.

d. Which might potentially pose the least human hazard when applied to the same soil as c. above and why?

Dicamba. It is the least toxic to humans, even though it would leach more.

7. A WIN-PST soil/pesticide interaction, pesticide, and soils reports have been developed for a producer who grows continuous grain corn and has infestations of corn rootworm. The producer uses conservation tillage (minimum tillage) on both fields. The resources of concern are human exposure from drinking water from nearby shallow wells of a small housing development immediately adjacent to the first field comprised of Sparta LFS. The second field (Winfield SIL) has a perennial stream that is immediately adjacent to the field. Fish kills have been noted in the stream in June, soon after the producer treats for rootworm. The producer farms right up to the property line of the housing development. The farmer also farms up to the stream (within 10 feet) and is careful not to directly contaminate the stream. The producer is currently using turbufos on both fields. The pesticides that have been presented in the WIN-PST reports are recommended for controlling rootworm by Cooperative Extension.

   a. What kind of information do the three WIN-PST reports provide?

      The Interaction Report provides loss (movement) ratings for soil/pesticide combinations and the potential hazards that those losses could poses to humans and fish. The Pesticide Report shows the pesticide loss potentials, toxicity threshold, and the exposure adjusted toxicity rating. The Soils Report shows the soil leaching, runoff, and sorbed sediment loss potentials on either a map unit or component basis.

   b. Briefly list the points you need to bring up with to educate the producer about the hazards created by of pesticide leaching and runoff.

      Answers might include but not limited to (Instructor leeway):

      - *explain how soils either leach or have runoff (uses soil survey or WIN-PST soils report)*

- *explain that pesticides have different characteristics that make some more likely to leach, runoff or get sorbed to sediment. (Use WIN-PST report and/or other chemicals familiar to the produce.*

- *explain the importance of using IPM, including decreased environmental risk, need for a diverse approach to prevent pest resistance to control measures.*

- *explain how different pesticide application techniques can reduce/increase risk of off site movement.*

- *explain the different cost share programs available and practices that reduce environmental risk.*

c. What actions might be taken? Assume the results are:

1) Benchmark conditions are that no IPM has been implemented?

   Answers should include but limited to:

   - *Encourage producer to consult with crop consultant/advisor or cooperative extension for IPM program (specifically to deal with root worm?)*

   - *Suggest crop rotation with a crop such as soybeans*

   - *Recommend mitigation strategies for each alternative (student may get more specific). Mitigation may include application techniques, timing, and changes in crop rotation.*

   - *Encourage farmer to choose the least hazardous pesticide to the resource concern*

- *Explain that mitigation practices might not work with interactions that rate as Extra High*

2) Alternative recommended by a crop consultant but not using an IPM program or principles?

   - *Encourage producer to consult with crop consultant/advisor or cooperative extension for IPM program (specifically to deal with root worm?)*
   - *Recommend mitigation strategies for each alternative (student may get more specific). Mitigation may include application techniques, timing, and changes in crop rotation.*
   - *Explain that mitigation practices might not work with interactions that rate as Extra High*

3) Alternatives developed within an established IPM program?

   - *Recommend mitigation strategies for each alternative (student may get more specific)*
   - *Explain that mitigation practices might not work with interactions that rate as Extra High*

8. Identify three environmental discriminators/toxicity value/ recommended criteria and describe how they can be used to evaluate potential water quality impacts.

   For ground water that is used for drinking water, the Health Advisory (HA) or Maximum Contaminant Level (MCL) would be used as the environmental discriminator/ toxicity value.

   For surface water that is used for drinking water, the Health Advisory (HA) or Maximum Contaminant Level (MCL) would be used as the environmental discriminator/ toxicity value.

For surface water that is inhabited by a species of concern (fish or other aquatic organism), the Maximum Allowable Toxicant Concentration (MATC) for runoff or the Sediment Toxicity Value (STV) for sediment in runoff would be used as the environmental discriminator/toxicity value.

For surface water that is protected for aquatic biota, the recommended concentrations to prevent accelerated eutrophication would be used as the environmental discriminator/recommended criteria when other specific criteria do not exist.

Environmental discriminators/toxicity values/recommended criteria can be used in a risk assessment to evaluate existing and alternative agrichemical use and management. This can be accomplished by comparing the frequency at which a pesticide/nutrient exceeds their environmental discriminator (toxicity limit/concentration) at the edge of the field or bottom of the root zone. The results of this comparison can be used to evaluate the potential risks of off-site agrichemical movement, to formulate best management practices for protecting water quality, and to help farmers choose agrichemical management alternatives that reduce hazardous agrichemical losses to an acceptable level.

9. List some of the benefits you would discuss with the producer of limiting pesticide loss through leaching and runoff:

   The list may include but is not limited to:

   - *Decreasing pesticide loss increases efficacy and saves money*
   - *Keeping ground water (including the producer's own well) and surface water free from contamination (fishing or swimming)*

- *Cost share programs available for environment friendly pest management practices.*
- *Helps maintain positive relationship with the community by being seen as sensitive to environmental issues*
- *Helps avoid run-ins with pesticide regulators.*

Module 6—Planning and Applying Nutrient and Pest Management

Overall Learning Objective

Upon completion of this module, participants will be able to describe the process for planning the nutrient and pest management components of a conservation plan, including other conservation practices and/or management techniques necessary to reduce adverse environmental impacts.

Introduction

This module provides a generalized approach to planning and applying the nutrient and pest management components of a conservation plan. Conservation planning is used to help farmers evaluate potential environmental risk, to plan and apply nutrient and pest management, and, to provide mitigation strategies that reduce potentially harmful offsite losses.

The Natural Resources Conservation Service develops conservation practice standards. These standards are first developed at the national level to provide the minimum guidance for each State, working with the various partners, to then develop their own State specific standards. The NRCS State conservation practice standards, Nutrient Management (590) and Pest Management (595), give the overall guidance for how nutrients and pests will be managed for all land areas that require NRCS conservation plans or any other lands referenced in these standards. Other conservation practice standards are also available and can be integrated as additional components of the conservation plan to provide the overall mitigation strategy necessary to reduce potential adverse environmental impacts. Each of these standards and their associated job sheets (where available) are used to develop acceptable nutrient and pest management alternatives. However, because of the complexity of each planning area, each conservation plan will rely on the professional judgment of the conservation planner. This professional judgement is critical for developing a plan that meets the producer's objectives, while protecting the natural resource base (soil, water, air, plants, and animals).

Module 6, Part A—Nutrient Management Component of a Conservation Plan

Supporting Objective

- List the minimum requirements for the nutrient management component of an overall conservation plan.

Nutrient Management Component

A few basic elements need to be a part of the nutrient management component of the over-all conservation plan. These elements guide the producer in making decisions on the location, rate, timing, form, and method of nutrient application.

These elements are given to producers so that they are fully aware of the management requirements to successfully manage nutrients and protect the natural resources of the community. This list of nine elements is not intended to be all-inclusive, but is the minimum guidance to be included in the nutrient management planning component.

The implementation of the nutrient management component of the overall conservation plan will require frequent review, periodic monitoring of progress, and adjustments as needed. Planning sets the framework for results that are accomplished by implementation on the land.

The nine elements are:

- Aerial photograph or map and a soil map of the site.
- Current or planned plant production sequence or crop rotation.

- Results of soil, plant, water, manure, or organic by-product sample analyses
- Realistic yield goals for the crops in rotation
- Quantification of all nutrient sources
- Recommended nutrient rates, timing, form, and method of application
- Location of designated sensitive areas or resources and their associated nutrient management restrictions
- Guidance for implementation, operation, maintenance, and record-keeping
- Complete nutrient budget for nitrogen, phosphorus, and potassium for the rotation or crop sequence

How To Fill Out the Nutrient Management Job Sheet

The Nutrient Management conservation practice job sheet can be used in developing a nutrient management component of a conservation plan. The job sheet will document the decisions of the producer's nutrient management plan. The Nutrient Management job sheet will be discussed in more detail during the group-facilitated portion of Module 7 and will be used for the Module 7 Case Exercise. The following instructions can be used to fill out the job sheet. (Throughout these instructions the term nutrient management plan means the nutrient management component of a resource management system.)

General Information

Enter the landowner's name, field(s), who assisted with the planning, and the date.

Purpose

Check all purposes for which the practice will be applied.

Job sketch

Sketch the field or fields covered by this plan on the back page of the job sheet. Include the field location(s), field identification, any sensitive areas within or adjacent to the field and required setback areas. Within the boundaries of each field record the total acreage of the field and the acreage to which nutrients can be applied (considering required setbacks). Other relevant information, such as complementary practices or adjacent field or tract conditions, may be included.

The sketch should be prepared early in the planning process. A visual image of the fields with respect to surrounding areas is needed before developing the rest of the nutrient management plan. A completed nutrient management plan includes aerial photographs or maps (including a soil map) and soil interpretations that may be a part of the overall conservation plan. These maps and/or photos may be used to help prepare the sketch in the specification sheet.

Table 1 shows field conditions and nutrient application recommendations.

Crop Sequence/Rotation

The crop sequence/rotation should describe the sequence of crops for 5 years. Start with the past year's crop and project the crop rotation for the next 4 years. Crop rotation is important to calculate the total nutrient needs over the period of the rotation, nutrient build-up, and nutrient removal by way of harvest. The previous crop will indicate any nutrient credits, especially legume credits when present in the rotation. Circle the current crop.

Expected Yield

Enter the expected yield for the current crop. The expected yield is the basis for determining the nutrient requirement for the current crop. An unrealistic estimate of expected yield can result in either too much or too little nutrients being applied. Overapplying nutrients creates the potential for environmental contamination and inefficient use of the resource. Too few nutrients applied can cause crop stress and limit potential yield.

The expected yield should be based on realistic soil, climate, and management parameters including crop variety. Yield may be determined from producer records or county yield averages, soil productivity tables, or local research. Because climate can have a dramatic effect on yields, expected yield should be based on data from at least the past 5 years. Extreme climate years should not be included in the analysis, as they may bias the results. Expected yields may be calculated in a number of ways.

Current Soil Test Levels

The nutrient status of the soil is an important component of a nutrient management plan. This information is used to make recommendations for nutrient application. In this section, enter the soil test values for N, P, K, and other soil constituents as given in the report from the soil testing laboratory. Indicate whether the values are in parts per million (ppm) or pounds per acre (lb/acre).

Recommended Nutrients/Amendments to Meet Expected Yield

Using the soil test results and considering the expected yield, record the estimated amounts of nutrients and other soil amendments needed to produce the expected yield. The land grant university or other approved soil test laboratories will base nutrient requirements for the crop on the soil test results, crop yields from field research, and local climatic conditions. Consult the Extension agronomy guide or other publications from the land grant university. Extensive research results from similar soils and climatic conditions are used to develop recommended nutrient rates. Recommendations for micronutrients or other amendments may be entered in the blank columns.

In table 2, lines 7, 8, and 9 are the completion of the nutrient budget. A nutrient budget is the comparison between the quantity of all the sources of nutrients available to the producer and the requirement of nutrients to meet the crop and soil needs. The source can either be from on the farm, such as livestock manure or credits from legumes, or from off the farm, such as purchased fertilizer or irrigation water. The requirement is the amount of nutrients needed by the crop to obtain the expected yields.

Although a nutrient budget is not an exact formula for supplying nutrients, it is one method to compare the nutrient needs of the crop with the nutrients available on the farm. Nutrient budgets can easily determine if there is a gross imbalance between the nutrients that are available and the amount required. Nutrient budgets are one of the best methods to see the overall supply of crop nutrients available compared to the estimated crop needs as given by historic records and field research. Continued use of soil testing, plant and water analyses, and yield monitoring are essential to maintain a good nutrient balance with desired results.

Nutrient Sources—Credits

A number of nutrient sources for crop production are available before the crop is planted. One source is the inherent nutrients in the soil determined by soil test levels of nitrogen, phosphorus, and potassium. Others become available to the crop through a process of recycling through animals, plants, air, water, and organic matter. Nitrogen from legumes and organic waste mineralization are examples.

Nitrogen Credits

Nitrogen is a mobile nutrient and occurs in the soil and plants in many forms. It can be stored in the soil's organic matter and released as the organic matter decomposes.

- Line 1. Credits from previous legume crops. Atmospheric nitrogen is fixed by legume plants and brought into the soil. Amounts of nitrogen added by legume production vary by plant species and growing conditions. Refer to local cooperative Extension information for the most appropriate legume nitrogen credits.

- Line 2. Residual from long-term manure applications. Not all the nitrogen applied in previous manure applications was available to the crop during the year of application. Some of the nutrients are tied up in organic complexes that require organic material decomposition before the nutrients are made available for plants. A percentage of the past year's manure application and an even smaller percentage of previous applications will become plant available during this crop season. Use local manure mineralization rates to determine the amount of nitrogen released from previous manure application. Phosphorus and potassium are considered to be almost 100 percent plant available in the year of application; therefore, little or no residual amounts are calculated for these nutrients.

- Line 3. Irrigation water. Irrigation water, especially from shallow aquifers, contains some nitrogen in the form of nitrate nitrogen. This nitrogen is available for crop use. To calculate the amount of nitrogen applied with irrigation water, determine the concentration of nitrate nitrogen in the water (in ppm or mg/L). This requires a water analysis. The amount of nitrogen added in irrigation water will equal the nitrate nitrogen concentration (in ppm or mg/L), multiplied by the irrigation water volume (in acre-inches), times 0.23. The factor 0.23 converts ppm or mg/L and acre-inches into pounds per acre.

- Line 4. Other. Other nitrogen credits come from atmospheric deposition from dust and ammonia in rainwater. This value is recorded by a number of weather stations throughout the U.S., and can be obtained from National Atmospheric Deposition Program, Fort Collins, CO. Atmospheric deposition may range from a few pounds nitrogen per acre per year to over 30 pounds.

The nutrient content of any other material that is brought onto the site, like mulch or compost, can be determined by estimating the mass weight and per cent concentration of nitrogen of the material.

Plant Available Nutrients Applied to the Field

The producer has the capability to bring various sources of nutrients onto the field to supply the requirements of the crop. The nutrient budget is designed to allocate the sources of nutrients available and adjust the amounts based on the calculations to match the crop's needs. Use the column "Trial A" for calculating the first budget trial.

- Line 6. Credits. Total nutrient credits are summed in Line 5 and entered here.

- Line 7. Fertilizer. If additional fertilizer is required (such as starter fertilizer to overcome the effects of cool, wet soil, or sidedressed anhydrous ammonia), enter the amounts on the appropriate line. Note how and when this fertilizer will be applied in the Nutrient Management Specifications box at the bottom of the page.

- Line 8. Manure/Organic Material. Manure and other organic sources can be produced either on the farm or transported to the farm with the expressed purpose of using the nutrients. Manure application rates should be based on crop nutrient requirements, but can also be applied in lesser rates to distribute organic material and micronutrients over more fields.

Manure application rates in line 8 are based on plant available nutrients delivered to crop. Manure nutrient content is calculated from information gathered from the moisture content and nutrient analysis of the manure. In lieu of nutrient analysis, a published estimate of plant available nutrients from specific sources of manure can be used. These book values are based on State university research and inventory data, and offer guidance for land application. A historic average of the farm or storage manure consistency can be used if the history is based on laboratory analyses over a period of years.

The losses caused by field application, namely nitrogen volatilization in the form of ammonia, have been considered in the calculation. The values for nutrients placed in line 8 are plant available nutrients, so the total quantities applied may be higher depending on the field application losses. The Waste Utilization (633) job sheet should be used to calculate the storage volume of manure, the nutrient analysis of the manure, and the potential for field losses depending on the application timing and methods. States should provide appropriate field loss estimates, such as ammonia volatilization with surface application.

Nutrient Status

The nutrient sources available for field application are subtotaled on line 9.

Next, the nutrient recommendations to meet expected yield are taken from table 1 and put on line 10. Subtracting the nutrient requirements (line 10) from the nutrients available (line 9) give a nutrient status (line 11).

If line 11 is a negative number, the amount shown on this line represents a deficiency of nutrients for the crop based on obtaining the expected yield. This amount of nutrients must be supplied to field to supplement the nutrient credits, starter fertilizer, and manure already applied. This supplement is usually provided by commercial fertilizer, but can be added by additional rates of manure or even irrigation water. Enter the method and timing of the application in the appropriate place on the specification sheet.

If line 11 is a positive number, the amount shown on this line represents an excess of nutrients needed for the crop, again based on obtaining the expected yield. There is no reason for nitrogen nutrition to be applied in quantities greater than crop requirements. Phosphorus and potassium are over-applied when animal manure or organic material is applied at rates to meet the nitrogen needs of the crop.

The nitrogen credits in lines 1–4 cannot be controlled by management. They are a result of previous management activities and the local environment. All adjustments to the nutrient budget must in occur in the amounts of fertilizer and manure applied in the current year.

Recommended Method and Timing of Application

Record the amount of each nutrient to be applied (from step 10) and the planned method, form and time application in this block. The efficiency of nutrient use by plants is significantly affected by the timing and method of nutrient application. Nitrogen should be applied as near as possible to the time of maximum plant uptake to minimize potential losses from leaching or volatilization. Both nitrogen and phosphorus fertilizer should be injected or incorporated to reduce the risk of loss in runoff water or attached to sediment.

Operation and Maintenance

On the second page of the job sheet in the box "Perform the following operations and maintenance" enter the information requested. Nutrient management plans should normally be reviewed annually by the producer, and a more thorough review performed at least every 5 years unless there are significant changes in the operation.

Field records should be maintained for at least 5 years. State regulations may require a longer period of record retention. Some producers may wish to maintain records indefinitely.

Application equipment should be calibrated so that it will apply nutrients to within 10 percent of the expected rate. Uniform application across the field is vital. Generally, no more than 10 to 15 percent variance in the required application rate from the actual amount applied is allowed. Commercial fertilizer applicators are easier to calibrate than manure spreaders. An added complication with manure spreaders is the uncertainty of available nutrient content in the manure.

All nutrient material should be handled with caution. Ammonium-containing material, especially anhydrous ammonia, may be caustic. Protective clothing should be worn when handling these materials. Goggles are appropriate when handling any fertilizer material, including organic material.

Fertilizer material remaining when fertilizer application is complete should be washed from application equipment and disposed of in a safe manner. Fertilizer material left in application equipment may corrode or otherwise damage the equipment.

Observe all state and local setback requirements for applications adjacent to waterbodies and watercourses.

Perform periodic soil, water, plant, and organic material analyses based on State guidelines.

Fertilizer and manure storage facilities shall be protected from weather and accidental leakage or spillage that may adversely affect the environment.

Additional Specifications and Notes

Write any additional specifications and notes in the box provided. Additional notes may include any constraints not previously noted, special nutrient requirements of the crop, equipment constraints, constraints due to pest pressures, residue limitations, conservation buffer requirements, local regulations, and any other information of interest to the producer. Additional notes may also refer to sources of information used to calculate available nutrients and nutrient requirements.

Example Nutrient Management Job Sheet

Nutrient Management

Conservation Practice Job Sheet **590**

Natural Resources Conservation Service (NRCS) ***March 1999***

Landowner____

Definition

Nutrient management is managing the source, rate, form, timing, and placement of nutrients.

Purpose

Nutrient management effectively and efficiently uses scarce nutrient resources to adequately supply soils and plants to produce food, forage, fiber, and cover while minimizing environmental degradation.

Where Used

Nutrient management is applicable to all lands where plant nutrients and soil amendments are applied.

Conservation Management Systems

Nutrient management may be a component of a conservation management system. It is used in conjunction with Crop Rotation, Residue Management, Pest Management, conservation buffer practices, and/or other practices needed on a site-specific basis to address natural resource concerns and the landowner's objectives. The major role of nutrient management is to minimize nutrient losses from fields, thus helping protect surface and ground water supplies.

Nutrient Management Planning

Nutrient management components of the conservation plan will include the following information:

- field map and soil map
- crop rotation or sequence
- results of soil, water, plant, and organic material samples analyses
- expected yield
- sources of nutrients to be applied
- nutrient budget, including credits of nutrients available
- recommended nutrient rates, form, timing, and method of application
- location of designated sensitive areas
- guidelines for operation and maintenance

Nutrient management is most effective when used with other agronomic practices, such as cover and green manure crops, residue management, conservation buffers, water management, pest management, and crop rotation.

General Nutrient Management Considerations

- Test soil, plants, water and organic material for nutrient content.
- Set realistic yield goals.
- Apply nutrients according to soil test recommendations.
- Account for nutrient credits from all sources.
- Consider effects of drought or excess moisture on quantities of available nutrients.
- Use a water budget to guide timing of nutrient applications.
- Use cover and green manure crops where possible to recover and retain residual nitrogen and other nutrients between cropping periods.
- Use split applications of nitrogen fertilizer for greater nutrient efficiency.

Guidelines for Operation and Maintenance

- Review nutrient management component of the conservation plan annually and make adjustments when needed.
- Calibrate application equipment to ensure uniform distribution and accurate application rates.
- Protect nutrient storage areas from weather to minimize runoff and leakage.
- Avoid unnecessary exposure to fertilizer and organic waste, and wear protective clothing when necessary.
- Observe setbacks required for nutrient applications adjacent to waterbodies, drainageways, and other sensitive areas.
- Maintain records of nutrient application as required by state and local regulations.
- Clean up residual material from equipment and dispose of properly.

Nutrient Management Assessment

Make a site-specific environmental assessment of the potential risk of nutrient management. The boundary of the nutrient management assessment is the agricultural management zone (AMZ), which is defined as the edge of field, bottom of root zone, and top of crop canopy. Environmental risk is difficult to assess beyond the AMZ.

Within an area designated as having impaired or protected natural resources (soil, water, air, plants, and animals), the nutrient management plan should include an assessment of the potential risk for nitrogen and phosphorus to contribute to water quality impairment.

The Leaching Index (LI), Nitrogen Leaching and Economic Analysis Package (NLEAP), the Phosphorus Index (PI), erosion prediction models, water quality monitoring, or any other acceptable assessment tools may be used to make risk assessments.

Evaluate other areas that might have high levels of nutrients, produced or applied, that may contribute to environmental degradation. For example, areas with high livestock concentrations or large areas of high-intensity cropping, such as continuous potatoes, corn, or specialty crops, may be contributing heavy nutrient loads to surface or ground water.

Conservation practices and management techniques will be implemented with nutrient management to mitigate any unacceptable risks.

Nutrient Management – Design and Specifications Sheet

Landowner Alexandria J. Simmons **Field number** 142 south quarter

Assisted by John Doe **Date** 4-27-99

Purpose (check all that apply)	
☑ Budget and supply nutrients for plant production	☑ Utilize manure/organic material as a nutrient source
☑ Minimize agricultural nonpoint source pollution (water quality)	☐ Maintain or improve soil condition

Table 1 Field Conditions and Recommendations

Crop sequence/rotation (circle current crop)						Expected yield
1998 soybeans	1999 corn	2000 sorghum	2001 soybeans	2002 corn	2003 soybeans	Corn 140

Current soil test levels (ppm or lb/ac)					
N	P	K	pH	S.O.M.%	EC
10 ppm	70 ppm	150 ppm	6.2	2.2	N/A

Recommended nutrients/amendments to meet expected yield (lb/ac)					
N	P_2O_5	K_2O	Lime	Other Zinc	Other
150	0	100	0	10	10

Table 2 Nutrient Sources

Credits		N		P_2O_5		K_2O	
				Pounds per acre			
1. Nitrogen credits from previous legume crop		40					
2. Residual from long-term manure application		6					
3. Irrigation water		18					
4. Other (e.g., atmospheric deposition)		8					
5.	Total credits	72					
Plant-available nutrients applied to field		N		P_2O_5		K_2O	
(Circle column that is landowner's decision)		Trial A	Trial B	Trial A	Trial B	Trial A	Trial B
6. Credits (from row 5, above)		72	72	0	0	0	0
7. Fertilizer	Starter	5	5	10	10	5	5
	Other	0	0	0	0	0	0
8. Manure/organic material		160	80	80	40	200	100
9.	Subtotal (sum of lines 6, 7, and 8)	237	157	90	50	205	105
10.	Nutrients recommended (from table 1)	150	150	0	0	100	100
11.	Nutrient status (subtract line 10 from line 9)	+87	+7	+90	+50	+105	+5

If line 11 is a negative number, this the amount of additional nutrients needed to meet the crop recommendation.

If line 11 is a positive number, this is the amount by which the available nutrients exceed the crop requirements.

Nutrient Management Specifications

Amount to be applied (lb/ac)	N	85	P_2O_5	50	K_2O	105

Method, form, and timing of application:

Applied nutrients will come from manure and starter fertilizer.

Broadcast apply 10 ton/acre beef cattle manure two weeks prior to planting.

Do not apply manure within 50 feet of the perennial stream which forms the boundary between fields 142 and 144.

Incorporated the manure applied within a 100 foot radius of the sinkhole in field 142.

Apply 100 lb/ac of 5-10-5 as a starter fertilizer at planting time.

Nutrient Management – Job Sketch

Draw of sketch the field, showing any sensitive areas and required setback zones. Inside each sketched field, enter total field acres and net application acres. Other relevant information, such as complementary practices or adjacent field or tract conditions may be included.

Scale 1"=________ ft. (NA indicates sketch not to scale: grid size=1/2" by 1/2")

Perform the following operations and maintenance:
Review this nutrient management plan every ________ years.
Maintain field records for 5 years.
Calibrate application equipment to apply within ± ________ % of the recommended rate.
Handle all nutrient material with caution. Wear appropriate protective clothing.
Clean up residual material from equipment and dispose of properly.
Additional specifications and notes:

Landowner ______________________ Assisted by ______________________ Date ______________________

Year			
Field number/crop	N	P_2O_5	K_2O

Information on form, rate, and timing of application:

Year			
Field number/crop	N	P_2O_5	K_2O

Information on form, rate, and timing of application:

Year			
Field number/crop	N	P_2O_5	K_2O

Information on form, rate, and timing of application:

Year			
Field number/crop	N	P_2O_5	K_2O

Information on form, rate, and timing of application:

NATURAL RESOURCES CONSERVATION SERVICE
CONSERVATION PRACTICE STANDARD

NUTRIENT MANAGEMENT

(Acre)

CODE 590

DEFINITION

Managing the amount, source, placement, form and timing of the application of nutrients and soil amendments.

PURPOSES

- To budget and supply nutrients for plant production.
- To properly utilize manure or organic by-products as a plant nutrient source.
- To minimize agricultural nonpoint source pollution of surface and ground water resources.
- To maintain or improve the physical, chemical and biological condition of soil.

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to all lands where plant nutrients and soil amendments are applied.

CRITERIA

General Criteria Applicable to All Purposes

Plans for nutrient management shall comply with all applicable Federal, state, and local laws and regulations.

Plans for nutrient management shall be developed in accordance with policy requirements of the NRCS General Manual Title 450, Part 401.03 (Technical Guides, Policy and Responsibilities) and Title 190, Part 402 (Ecological Sciences, Nutrient Management, Policy); technical requirements of the NRCS Field Office Technical Guide (FOTG); procedures contained in the National Planning Procedures Handbook (NPPH), and the NRCS National Agronomy Manual (NAM) Section 503.

Persons who review or approve plans for nutrient management shall be certified through any certification program acceptable to NRCS within the state.

Plans for nutrient management that are elements of a more comprehensive conservation plan shall recognize other requirements of the conservation plan and be compatible with its other requirements.

A nutrient budget for nitrogen, phosphorus, and potassium shall be developed that considers all potential sources of nutrients including, but not limited to animal manure and organic by-products, waste water, commercial fertilizer, crop residues, legume credits, and irrigation water.

Realistic yield goals shall be established based on soil productivity information, historical yield data, climatic conditions, level of management and/or local research on similar soil, cropping systems, and soil and manure/organic by-products tests. For new crops or varieties, industry yield recommendations may be used until documented yield information is available.

Plans for nutrient management shall specify the form, source, amount, timing and method of application of nutrients on each field to achieve realistic production goals, while minimizing nitrogen and/or phosphorus movement to surface and/or ground waters.

Erosion, runoff, and water management controls shall be installed, as needed, on fields that receive nutrients.

Conservation practice standards are reviewed periodically, and updated if needed. To obtain the current version of this standard, contact the Natural Resources conservation Service.

NRCS, NHCP

April, 1999

Soil Sampling and Laboratory Analysis (Testing)

Nutrient planning shall be based on current soil test results developed in accordance with Land Grant University guidance or industry practice if recognized by the Land Grant University. Current soil tests are those that are no older than five years.

Soil samples shall be collected and prepared according to the Land Grant University guidance or standard industry practice. Soil test analyses shall be performed by laboratories that are accepted in one or more of the following programs:

- State Certified Programs,
- The North American Proficiency Testing Program (Soil Science Society of America), or
- Laboratories whose tests are accepted by the Land Grant University in the state in which the tests will be used.

Soil testing shall include analysis for any nutrients for which specific information is needed to develop the nutrient plan. Request analyses pertinent to monitoring or amending the annual nutrient budget, e.g. pH, electrical conductivity (EC), soil organic matter, nitrogen, phosphorus, and potassium.

Plant Tissue Testing

Tissue sampling and testing, where used, shall be done in accordance with Land Grant University standards or recommendations.

Nutrient Application Rates

Soil amendments shall be applied, as needed, to adjust soil pH to the specific range of the crop for optimum availability and utilization of nutrients.

Recommended nutrient application rates shall be based on Land Grant University recommendations (and/or industry practice when recognized by the university) that consider current soil test results, realistic yield goals and management capabilities. If the Land Grant University does not provide specific recommendations, application shall be based on realistic yield goals and associated plant nutrient uptake rates.

The planned rates of nutrient application, as documented in the nutrient budget, shall be determined based on the following guidance:

- **Nitrogen Application** - Planned nitrogen application rates shall match the recommended rates as closely as possible, except when manure or other organic by-products are a source of nutrients. When manure or other organic by-products are a source of nutrients, see "Additional Criteria" below.
- **Phosphorus Application -** Planned phosphorus application rates shall match the recommended rates as closely as possible, except when manure or other organic by-products are a source of nutrients. When manure or other organic by-products are a source of nutrients, see "Additional Criteria" below.
- **Potassium Application** - Excess potassium shall not be applied in situations in which it causes unacceptable nutrient imbalances in crops or forages. When forage quality is an issue associated with excess potassium application, state standards shall be used to set forage quality guidelines.
- **Other Plant Nutrients -** The planned rates of application of other nutrients shall be consistent with Land Grant University guidance or industry practice if recognized by the Land Grant University in the state.
- **Starter Fertilizers** - Starter fertilizers containing nitrogen, phosphorus and potassium may be applied in accordance with Land Grant University recommendations, or industry practice if recognized by the Land Grant University within the state. When starter fertilizers are used, they shall be included in the nutrient budget.

Nutrient Application Timing

Timing and method of nutrient application shall correspond as closely as possible with plant nutrient uptake characteristics, while considering cropping system limitations, weather and climatic conditions, and field accessibility.

Nutrient Application Methods

Nutrients shall not be applied to frozen, snow-covered, or saturated soil if the potential risk for runoff exists.

Nutrient applications associated with irrigation systems shall be applied in accordance with the requirements of Irrigation Water Management (Code 449).

Additional Criteria Applicable to Manure or Organic By-Products Applied as a Plant Nutrient Source

Nutrient values of manure and organic by-products (excluding sewage sludge) shall be determined prior to land application based on laboratory analysis, acceptable "book values" recognized by the NRCS and/or the Land Grant University, or historic records for the operation, if they accurately estimate the nutrient content of the material. Book values recognized by NRCS may be found in the Agricultural Waste Management Field Handbook, Chapter 4 - Agricultural Waste Characteristics.

Nutrient Application Rates

The application rate (in/hr) for material applied through irrigation shall not exceed the soil intake/infiltration rate. The total application shall not exceed the field capacity of the soil.

The planned rates of nitrogen and phosphorus application recorded in the plan shall be determined based on the following guidance:

- **Nitrogen Application -** When the plan is being implemented on a phosphorus standard, manure or other organic by-products shall be applied at rates consistent with the phosphorus standard. In such situations, an additional nitrogen application, from non-organic sources, may be required to supply the recommended amounts of nitrogen.

  Manure or other organic by-products may be applied on legumes at rates equal to the estimated removal of nitrogen in harvested plant biomass.

- **Phosphorus Application** - When manure or other organic by-products are used, the planned rates of phosphorus application shall be consistent with any one of the following options:

  - **Phosphorus Index (PI) Rating.** Nitrogen based manure application on Low or Medium Risk Sites, phosphorus based or no manure application on High and Very High Risk Sites.**

  - **Soil Phosphorus Threshold Values.** Nitrogen based manure application on sites on which the soil test phosphorus levels are below the threshold values. Phosphorus based or no manure application on sites on which soil phosphorus levels equal or exceed threshold values.**

  - **Soil Test.** Nitrogen based manure application on sites on which there is a soil test recommendation to apply phosphorus. Phosphorus based or no manure application on sites on which there is no soil test recommendation to apply phosphorus.**

    ** Acceptable phosphorus based manure application rates shall be determined as a function of soil test recommendation or estimated phosphorus removal in harvested plant biomass. Guidance for developing these acceptable rates is found in the NRCS General Manual, Title 190, Part 402 (Ecological Sciences, Nutrient Management, Policy), and the National Agronomy Manual, Section 503.

A single application of phosphorus applied as manure may be made at a rate equal to the recommended phosphorus application or estimated phosphorus removal in harvested plant biomass for the crop rotation or multiple years in the crop sequence. When such applications are made, the application rate shall:

- not exceed the recommended nitrogen application rate during the year of application, or
- not exceed the estimated nitrogen removal in harvested plant biomass during the year of application when

there is no recommended nitrogen application.

- not be made on sites considered vulnerable to off-site phosphorus transport unless appropriate conservation practices, best management practices, or management activities are used to reduce the vulnerability.

Field Risk Assessment

When animal manures or other organic by-products are applied, a field-specific assessment of the potential for phosphorus transport from the field shall be completed. This assessment may be done using the Phosphorus Index or other recognized assessment tool. In such cases, plans shall include:

- ♦ a record of the assessment rating for each field or sub-field, and
- ♦ information about conservation practices and management activities that can reduce the potential for phosphorus movement from the site.

When such assessments are done, the results of the assessment and recommendations shall be discussed with the producer during the development of the plan.

Heavy Metals Monitoring

When sewage sludge is applied, the accumulation of potential pollutants (including arsenic, cadmium, copper, lead, mercury, selenium, and zinc) in the soil shall be monitored in accordance with the US Code, Reference 40 CFR, Parts 403 and 503, and/or any applicable state and local laws or regulations.

Additional Criteria to Minimize Agricultural Non-point Source Pollution of Surface and Ground Water Resources

In areas with an identified or designated nutrient-related water quality impairment, an assessment shall be completed of the potential for nitrogen and/or phosphorus transport from the field. The Leaching Index (LI) and/or Phosphorus Index (PI), or other recognized assessment tools, may be used to make these assessments. The results of these assessments and recommendations shall be discussed with the producer and included in the plan.

Plans developed to minimize agricultural nonpoint source pollution of surface or ground water resources shall include practices and/or management activities that can reduce the risk of nitrogen or phosphorus movement from the field.

Additional Criteria to Improve the Physical, Chemical, and Biological Condition of the Soil.

Nutrients shall be applied in such a manner as not to degrade the soil's structure, chemical properties, or biological condition. Use of nutrient sources with high salt content will be minimized unless provisions are used to leach salts below the crop root zone.

Nutrients shall not be applied to flooded or saturated soils when the potential for soil compaction and creation of ruts is high.

CONSIDERATIONS

Consider induced deficiencies of nutrients due to excessive levels of other nutrients.

Consider additional practices such as Conservation Cover (327), Grassed Waterway (412), Contour Buffer Strips (332), Filter Strips (393), Irrigation Water Management (449), Riparian Forest Buffer (391A), Conservation Crop Rotation (328), Cover and Green Manure (340), and Residue Management (329A, 329B, or 329C, and 344) to improve soil nutrient and water storage, infiltration, aeration, tilth, diversity of soil organisms and to protect or improve water quality.

Consider cover crops whenever possible to utilize and recycle residual nitrogen.

Consider application methods and timing that reduce the risk of nutrients being transported to ground and surface waters, or into the atmosphere. Suggestions include:

- ♦ split applications of nitrogen to provide nutrients at the times of maximum crop utilization,
- ♦ avoiding winter nutrient application for spring seeded crops,

- band applications of phosphorus near the seed row,
- applying nutrient materials uniformly to application areas or as prescribed by precision agricultural techniques, and/or
- immediate incorporation of land applied manures or organic by-products,
- delaying field application of animal manures or other organic by-products if precipitation capable of producing runoff and erosion is forecast within 24 hours of the time of the planned application.

Consider minimum application setback distances from environmentally sensitive areas, such as sinkholes, wells, gullies, ditches, surface inlets or rapidly permeable soil areas.

Consider the potential problems from odors associated with the land application of animal manures, especially when applied near or upwind of residences.

Consider nitrogen volatilization losses associated with the land application of animal manures. Volatilization losses can become significant, if manure is not immediately incorporated into the soil after application.

Consider the potential to affect National Register listed or eligible cultural resources.

Consider using soil test information no older than one year when developing new plans, particularly if animal manures are to be a nutrient source.

Consider annual reviews to determine if changes in the nutrient budget are desirable (or needed) for the next planned crop.

On sites on which there are special environmental concerns, consider other sampling techniques. (For example: Soil profile sampling for nitrogen, Pre-Sidedress Nitrogen Test (PSNT), Pre-Plant Soil Nitrate Test (PPSN) or soil surface sampling for phosphorus accumulation or pH changes.)

Consider ways to modify the chemistry of animal manure, including modification of the animal's diet to reduce the manure nutrient content, to enhance the producer's ability to manage manure effectively.

PLANS AND SPECIFICATIONS

Plans and specifications shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose(s), using nutrients to achieve production goals and to prevent or minimize water quality impairment.

The following components shall be included in the nutrient management plan:

- aerial photograph or map and a soil map of the site,
- current and/or planned plant production sequence or crop rotation,
- results of soil, plant, water, manure or organic by-product sample analyses,
- realistic yield goals for the crops in the rotation,
- quantification of all nutrient sources,
- recommended nutrient rates, timing, form, and method of application and incorporation,
- location of designated sensitive areas or resources and the associated, nutrient management restriction,
- guidance for implementation, operation, maintenance, recordkeeping, and
- complete nutrient budget for nitrogen, phosphorus, and potassium for the rotation or crop sequence.

If increases in soil phosphorus levels are expected, plans shall document:

- the soil phosphorus levels at which it may be desirable to convert to phosphorus based implementation,
- the relationship between soil phosphorus levels and potential for phosphorus transport from the field, and
- the potential for soil phosphorus drawdown from the production and harvesting of crops.

When applicable, plans shall include other practices or management activities as determined by specific regulation, program requirements, or producer goals.

NRCS, NHCP

April, 1999

In addition to the requirements described above, plans for nutrient management shall also include:

- discussion about the relationship between nitrogen and phosphorus transport and water quality impairment. The discussion about nitrogen should include information about nitrogen leaching into shallow ground water and potential health impacts. The discussion about phosphorus should include information about phosphorus accumulation in the soil, the increased potential for phosphorus transport in soluble form, and the types of water quality impairment that could result from phosphorus movement into surface water bodies.
- discussion about how the plan is intended to prevent the nutrients (nitrogen and phosphorus) supplied for production purposes from contributing to water quality impairment.
- a statement that the plan was developed based on the requirements of the current standard and any applicable Federal, state, or local regulations or policies; and that changes in any of these requirements may necessitate a revision of the plan.

OPERATION AND MAINTENANCE

The owner/client is responsible for safe operation and maintenance of this practice including all equipment. Operation and maintenance addresses the following:

- periodic plan review to determine if adjustments or modifications to the plan are needed. As a minimum, plans will be reviewed and revised with each soil test cycle.
- protection of fertilizer and organic by-product storage facilities from weather and accidental leakage or spillage.
- calibration of application equipment to ensure uniform distribution of material at planned rates.
- documentation of the actual rate at which nutrients were applied. When the actual rates used differ from or exceed the recommended and planned rates, records will indicate the reasons for the differences.
- Maintaining records to document plan implementation. As applicable, records include:
    - soil test results and recommendations for nutrient application,
    - quantities, analyses and sources of nutrients applied,
    - dates and method of nutrient applications,
    - crops planted, planting and harvest dates, yields, and crop residues removed,
    - results of water, plant, and organic by-product analyses, and
    - dates of review and person performing the review, and recommendations that resulted from the review.

Records should be maintained for five years; or for a period longer than five years if required by other Federal, state, or local ordinances, or program or contract requirements.

Workers should be protected from and avoid unnecessary contact with chemical fertilizers and organic by-products. Protection should include the use of protective clothing when working with plant nutrients. Extra caution must be taken when handling ammonia sources of nutrients, or when dealing with organic wastes stored in unventilated enclosures.

The disposal of material generated by the cleaning nutrient application equipment should be accomplished properly. Excess material should be collected and stored or field applied in an appropriate manner. Excess material should not be applied on areas of high potential risk for runoff and leaching.

The disposal or recycling of nutrient containers should be done according to state and local guidelines or regulations.

Student Activity 1

1. List the minimum requirements for the nutrient management component of an overall conservation plan.

Module 6, Part B—Pest Management Component of a Conservation Plan

Supporting Objective

- List the minimum requirements for the pest management component of an overall conservation plan.

Pest Management Component

A few basic elements need to be a part of the pest management component of the overall conservation plan. These elements guide the producer in making decisions necessary to manage pests including weeds, insects, diseases, and animals.

These elements are given to the producers so that they are fully aware of the management requirements to successfully manage pests and protect the natural resources of the community. This list of elements is not intended to be all-inclusive, but is the minimum guidance to be included in the pest management planning component.

The implementation of the pest management component of the overall conservation plan will require frequent review, periodic monitoring of progress, and adjustments as needed. Planning sets the framework for results that are accomplished by implementation on the land.

As a minimum, the pest management component of a conservation plan will include:

- Plan map and soils map of managed fields (use RMS maps if available)

- Location of sensitive resources if applicable (use RMS maps if available)
- Environmental risk analysis for the *most likely* pest management recommendations (by crop and pest)
- Interpretation of the environmental risk analysis and identification of appropriate mitigation practices
- Operation and Maintenance requirements

Guidelines for Completing the "Pest Management Alternatives Worksheet", "Pest Management Alternatives Selected by the Producer" summary sheet, and the Pest Management Narrative

The pest management component of a resource management system (RMS) is a record of the producer's decisions for managing pest populations. The objective for applying pest management in accordance with the Pest Management conservation practice standard is to manage pest populations to enhance the quantity and quality of commodities while minimizing negative impacts of pest control on soil resources, water resources, air resources, plant resources, animal resources, and/or humans.

These guidelines are developed in accordance with National Pest Management Policy and the National Pest Management conservation practice standard. They are provided to assist with the development of pest management alternatives, documentation of alternatives selected by the producer and narratives to provide detailed descriptions of each alternative listed on the worksheets.

The procedure for completing the Pest Management Alternatives worksheet, Pest Management Alternatives Selected By The Producer summary sheet, and the Pest Management narrative (pages 35–37) is given below:

- Landuser and Date: Complete the spaces provided to identify the landuser and date of technical assistance.

- Name of Consultant: If applicable, enter the name of the consultant(s) providing the producer with pest management recommendations.

- Tract/Field(s): Identify the tract and field for which the plan is being developed. More than one tract or field can be included on a single sheet if the soils, crop, resource concern(s), target pests, and pest management recommendations are the same.

- Soils: Identify the soil(s) for the field(s) that will be used in the environmental risk analysis process.

- Crop Sequence/Rotation: Identify the crop(s) planned for the field(s). List the crops in the sequence they will be planted, if known. Scheduling the type and sequence of crops can help reduce pest pressures and avoid mistakes such as crop damage from herbicide carryover. Circle the crop(s) for which the sheet is applicable.

- Pest Management Resource Concern: Enter the resource concern(s) that may be impacted by pest management such as close proximity to endangered species habitat or a waterbody used as a drinking water supply.

- Target Pest: Enter the target pest(s) identified by the producer or their consultant for whom the pest management plan is being developed.

- Alternative Number: Enter an identifying number for each probable pest management alternative being evaluated for environmental risk.

- Alternative Description: Enter a short description of the pest management alternative (provided by the producer or their consultant) that is to be evaluated in the environmental risk analysis process. Use only the detail necessary to identify differences between the alternatives. The alternative descriptions may include management method, such as mechanical, cultural, biological, or chemical, and such applicable details as type of tillage, use of pest resistant varieties, biological predators, or name of the pesticide. Also include application techniques important to the analysis tool used. For WIN-PST this would include such management items as soil incorporated, banded, or low application rate.

- Analysis Tool: Identify the environmental risk analysis tool used. Available tools for pesticide risk analysis include the Windows Pesticide Screening Tool (WIN-PST), and the National Agricultural Pesticide Risk Analysis (NAPRA). Available tools to assess the impacts of non-chemical pest management alternatives on erosion and soil quality include the Revised Universal Soil Loss Equation (RUSLE), Wind Erosion Equation (WEQ), and the Soil Conditioning Index. Other assessment tools may be available locally.

- Mitigation Techniques: Provide information on mitigation techniques required to address natural resource concerns identified earlier. Mitigation may include conservation practices such as filter strips or conservation crop rotation and management techniques such as application method and timing that the landowner must install or put in place on the field.

- Assisted By: Enter the name of the planner providing technical assistance.

- Pest Management Narrative: This narrative is developed by the planner and accompanies the Pest Management Alternatives worksheet. It provides a more detailed description of each alternative listed on the worksheet. The following list of elements is provided as a guide:

— Resource concern(s) that may be impacted by individual alternative(s).

— Interpretation of environmental risk evaluation results including: a) The environmental risk evaluation tool used (RUSLE, WEPP, WIN-PST). b) Risk potential caveats (e.g., high risk caused by high soil runoff potential).

Note: Evaluate alternatives using the highest hazard component within a map unit and highest risk pesticide active ingredient within a pesticide product.

— Mitigation (a) Current mitigation (e.g. 15 foot grassed field border). (b) Additional practices needed (e.g. buffer strip at least 60 feet wide should be installed). (c) General statement of what planned mitigation needs to do (because of high pesticide solution runoff potential, the new buffer needs to be designed and installed to maximize infiltration)

— IPM opportunities (e.g., the producer should use the Land Grant University IPM program for mulch till grain corn).

— Overall conservation plan integration issues (to fully implement IPM, the producer will need to modify the conservation crop rotation to include crops other than continuous corn. As the producer migrates from mulch till to no-till, target pests will likely change and the Land Grant University IPM program for no-till grain corn will need to be adopted).

- Job Sketch: Provide a map showing the field location and acerage. Also, show the boundaries of any sensitive areas, such as waterbodies, set backs, or highly erodible soils, where restrictions to pest management methods may occur. If the conservation plan map includes these items, you may place a reference in the sketch area to the applicable field(s) on the plan map in lieu of completing a new drawing.

- Operation and Maintenance: A number of items are required to be assessed and performed routinely. These include calibration of equipment, maintaining a safe working environment, and review and update of the pest management component plan. The plan should be reviewed by the producer to determine if any short-term adjustments are needed for either the current or subsequent crops. Records of implementation shall be kept in accordance with Federal and State guidelines

- Additional Notes: Complete additional information or guidance, if needed. You may want to use this space to describe sensitive areas in detail or to continue items from previous pages, such as additional operation and maintenance.

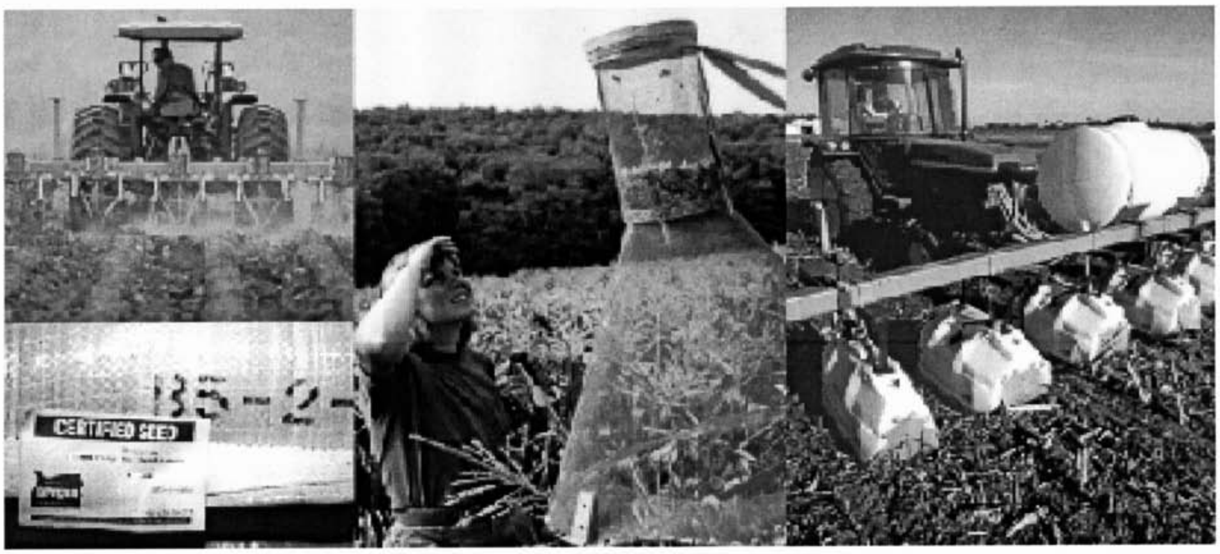
Pest Management

USDA

Conservation Practice Jobsheet *595*

Natural Resources Conservation Service

Landuser____Date____________________



Definition

Pest management is utilizing environmentally sensitive prevention, avoidance, monitoring, and suppression strategies, to manage weeds, insects, diseases, animals and other organisms that directly or indirectly cause damage or annoyance.

Purposes

Pest management is applied as part of a resource management system to:

- Enhance the quantity and quality of agricultural commodities.
- Minimize the negative impacts of pest control on soil resources, water resources, air resources, plant resources, animal resources and/or humans.

Pest Management Includes

- Environmental risks of pest management.
- Mitigation alternatives to minimize environmental risks.
- Adoption of Integrated Pest Management (IPM).
- Implementation of a pest management component of an overall conservation plan.

Benefits

Pest management systems:

- Maximize economic returns.
- Minimize environmental risks.
- Improve food, water and air quality.
- Integrate all aspects of pest management within the agricultural production system.

Resource Management System

Pest management is a component of a Resource Management System (RMS). It should be used in conjunction with conservation practices such as a filter strip, conservation crop rotation, irrigation water management and/or nutrient management on a site-specific basis to address both natural resource concerns and the landowner's objectives.

General Criteria

- Follow the attached pest management component of the overall conservation plan.
- Methods of pest management must comply with Federal, State, and local regulations.
- Utilize IPM that strives to balance economics, efficacy, and environmental risks. IPM information available for your crops is attached.
- Implement mitigation techniques planned to address the environmental risks of pest management activities. Mitigation techniques include conservation practices like a filter strip or conservation crop rotation, and management techniques like application method and timing. Mitigation techniques have been incorporated in the attached plan.
- All methods of pest management must be integrated with other components of the conservation plan.
- Pay special attention to all environmental hazards and site-specific application criteria listed on pesticide labels and contained in Extension and Crop Consultant recommendations.

Operation, Maintenance & Safety

- Review and update the plan periodically in order to incorporate new IPM technology, respond to cropping system and pest complex changes, and avoid the development of pest resistance.
- Maintain mitigation techniques identified in the plan in order to ensure continued effectiveness.
- Develop a safety plan for individuals exposed to chemicals including telephone numbers and addresses for emergency treatment centers and the telephone number for the nearest poison control center. For human exposure questions, the local center is:

Name: ______________________________
Location: ___________________________
Phone: ______________________________

The National Pesticide Telecommunications Network (NPTN) telephone number in Corvallis, Oregon for non-emergency information is:

1-800-424-7378

Monday - Friday
6:30 a.m. to 4:30 p.m. Pacific Time

For advice and assistance with emergency spills that involve agrichemicals, the local contact is:

Name: ______________________________
Location: ___________________________
Phone: ______________________________

The national 24-hour CHEMTREC telephone number for emergency assistance is:

1-800-424-9300

- Mix chemicals down gradient and a minimum of _____ feet from a well and a minimum of _____ feet from a surface water body.
- Post signs according to label directions and/or Federal, State, and local laws around sites that have been treated. Follow restricted entry intervals.
- Dispose of pesticides and pesticide containers in accordance with label directions and adhere to Federal, State, and local regulations.
- Read and follow label directions and maintain appropriate Material Safety Data Sheets (MSDS).
- Calibrate application equipment according to Extension and/or manufacturer recommendations before each seasonal use and with each major chemical change.
- Replace worn nozzle tips, cracked hoses, and faulty gauges.
- Maintain records of pest management for at least _____ years. Pesticide application records shall be in accordance with USDA Agricultural Marketing Service's Pesticide Record Keeping Program and state specific requirements

PEST MANAGEMENT ALTERNATIVES SELECTED BY THE PRODUCER

Landuser ______________________ Date ____________ Consultant ______________________

Tract & Field(s) ______________________ Soils ______________________

Crop Sequence/Rotation ______________________ (Circle Applicable Crops(s)

Pest Management Resource Concern ______________________

Target Pest Name(s)	Alternative Number	Alternative Description	Analysis Tool	Mitigation Techniques

Assisted by: ______________________

CONTINUATION SHEET

DRAFT

Sketch a map showing the field location, acreage and location of sensitive resource concerns (including required setback zones, water bodies and buildings).

Scale 1" = ______ ft. (NA indicates sketch not to scale: grid size = ½" by ½ ")

Operation and Maintenance:

Review this pest management plan whenever the production system changes substantially, or at least every (   ) years.

Maintain mitigation techniques identified in the plan.

Mix chemicals a minimum of (   ) feet from a well and a minimum of (   ) feet from a surface water body.

Post treatment signs according to label directions and/or Federal, State, and local laws. Follow label re-entry intervals.

Dispose of pesticides and pesticide containers in accordance with label directions.

Read and follow label directions and maintain appropriate Material Data Safety Sheets (MSDS).

Calibrate application equipment before each season of use and with each major chemical change.

Maintain records of pest management for at least (   ) years.

Additional specifications and notes:

RELEASE PENDING

595 - 1

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

PEST MANAGEMENT

(Acre)

CODE 595

DEFINITION

Utilizing environmentally sensitive prevention, avoidance, monitoring and suppression strategies, to manage weeds, insects, diseases, animals and other organisms (including invasive and non-invasive species), that directly or indirectly cause damage or annoyance.

PURPOSES

This practice is applied as part of a Resource Management System (RMS) to support one or more of the following purposes:

- Enhance quantity and quality of commodities.
- Minimize negative impacts of pest control on soil resources, water resources, air resources, plant resources, animal resources and/or humans.

CONDITIONS WHERE PRACTICE APPLIES

Wherever pests will be managed.

CRITERIA

General Criteria Applicable to All Purposes

A pest management component of a conservation plan shall be developed.

All methods of pest management must comply with Federal, State, and local regulations, including management plans for invasive pest species, noxious weeds and disease vectors. Compliance with the Food Quality Protection Act (FQPA); Federal Insecticide, Fungicide and Rodenticide Act (FIFRA); Worker Protection Standard (WPS); and Interim Endangered Species Protection Program (H7506C) is required for chemical pest control.

Integrated Pest Management (IPM) that strives to balance economics, efficacy and environmental risk, where available, shall be incorporated into planning alternatives. (IPM is a sustainable approach to pest control that combines the use of prevention, avoidance, monitoring and suppression strategies, to maintain pest populations below economically damaging levels, to minimize pest resistance, and to minimize harmful effects of pest control on human health and environmental resources. IPM suppression systems include biological controls, cultural controls and the judicious use of chemical controls.) [State Standards shall identify commodity-specific IPM available in the State]

An appropriate set of mitigation techniques must be planned and implemented to reduce the environmental risks of pest management activities in accordance with quality criteria in the local Field Office Technical Guide. Mitigation techniques include practices like a Filter Strip or Conservation Crop Rotation, and management techniques like application method or timing.

All methods of pest management must be integrated with other components of the conservation plan.

Clients shall be instructed to pay special attention to all environmental hazards and site-specific application criteria listed on pesticide labels and contained in Extension and Crop Consultant recommendations.

NRCS, NHCP

December 2000

595 - 3

RELEASE PENDING

CONSIDERATIONS

If commodity-specific IPM is not available, the following IPM principles should be considered:

- Prevention, such as using pest-free seeds and transplants, cleaning tillage and harvesting equipment between fields, irrigation scheduling to avoid situations conducive to disease development, etc.
- Avoidance, such as using pest resistant varieties, crop rotation, trap crops, etc.
- Monitoring, such as pest scouting, soil testing, weather forecasting, etc. to help target suppression strategies and avoid routine preventative pest control.
- Suppression, such as cultural, biological and chemical controls, that can reduce a pest population or its impacts. Chemical controls should be used judiciously in order to minimize environmental risk and pest resistance.

Adequate plant nutrients and soil moisture, including favorable pH and soil conditions, should be available to reduce plant stress, improve plant vigor and increase the plant's overall ability to tolerate pests.

On irrigated land, irrigation water management should be designed to minimize pest management environmental risk.

PLANS AND SPECIFICATIONS

The pest management component of a conservation plan shall be prepared in accordance with the criteria of this standard and shall describe the requirements for applying the practice to achieve its intended purpose(s).

As a minimum, the pest management component of a conservation plan shall include:

- Plan map and soil map of managed site, if applicable (use RMS plan maps if available).
- Location of sensitive resources and setbacks, if applicable (use RMS plan maps if available).
- Environmental risk analysis, with approved tools and/or procedures, for probable pest management recommendations by crop (if applicable) and pest.
- Interpretation of the environmental risk analysis and identification of appropriate mitigation techniques.
- Operation and maintenance requirements.

OPERATION AND MAINTENANCE

The pest management component of a conservation plan shall include appropriate operation and maintenance items for the client. These may include:

- Review and update the plan periodically in order to incorporate new IPM technology, respond to cropping system and pest complex changes, and avoid the development of pest resistance.
- Maintain mitigation techniques identified in the plan in order to ensure continued effectiveness.
- Develop a safety plan for individuals exposed to chemicals, including telephone numbers and addresses of emergency treatment centers for individuals exposed to chemicals and the telephone number for the nearest poison control center. The National Pesticide Telecommunications Network (NPTN) telephone number in Corvallis, Oregon may also be given for non-emergency information:

  1-800-424-7378

  Monday - Friday
  6:30 a.m. to 4:30 p.m. Pacific Time

  For advice and assistance with emergency spills that involve agrichemicals, the local emergency telephone number should be provided. The national 24-hour CHEMTREC telephone number may also be given:

  1-800-424-9300

- Follow label requirements for mixing/loading setbacks from wells, intermittent streams and rivers, natural or impounded ponds and lakes, or reservoirs. (State or local regulations may be more restrictive).
- Post signs according to label directions and/or Federal, State, and local laws around sites that have been treated. Follow restricted entry intervals.

NRCS, NHCP
December 2000

RELEASE PENDING

- Dispose of pesticides and pesticide containers in accordance with label directions and adhere to Federal, State, and local regulations.
- Read and follow label directions and maintain appropriate Material Safety Data Sheets (MSDS).
- Calibrate application equipment according to Extension and/or manufacturer recommendations before each seasonal use and with each major chemical change.
- Replace worn nozzle tips, cracked hoses, and faulty gauges.
- Maintain records of pest management for at least two years. Pesticide application records shall be in accordance with USDA Agricultural Marketing Service's Pesticide Record Keeping Program and state specific requirements. [State Standards shall describe record keeping requirements.]

Student Activity 3

1. List the minimum requirements for the pest management component of an overall conservation plan.

Module 6, Part C—Integrating Nutrient and Pest Management with Other Conservation Practices to Reduce Environmental Impacts

Supporting Objective

- List five surface water and five ground water examples of conservation practices that can be used to reduce the risk of nutrient and pesticide impacts in the environment.
- Determine expected nutrient and pesticide runoff and leaching losses resulting from the implementation of various conservation practices.

Introduction

Agricultural chemical inputs are often necessary for optimizing agronomic production. Agricultural chemical management should optimize the use of nutrient and pesticide inputs to maintain viable production and minimize detrimental impacts on surface and ground water resources. Agricultural chemicals remaining inside the agricultural management zone (AMZ) will not cause an adverse impact on water resources. The AMZ boundaries are:

- to the edge of the field site,
- to the bottom of the root zone, and
- from the soil surface to the top of the plant canopy.

The AMZ boundaries will be determined by the type of cropping system and conservation practices on the field. The edge of the field is where crop production ends and may include conservation practices that are intended to detain or retain sediment and runoff water. These include vegetated filter strips, water and sediment control basins, and wind barriers. The rooting depth of the crop and the soil physical and chemical properties determine the bottom of the root zone. The ambient surface above the soil surface will be affected by the height of plant canopy and wind barriers that affect air movement.

If applied agricultural chemicals are lost from the AMZ, the level of risk to the natural resources of concern, terrestrial and aquatic ecosystems, and human health must be identified. The risk involved may include unacceptable impacts on adjacent AMZ's as well as offsite soil, water, plant, animal and air resources. This training course focuses on the principles and processes of agrichemical management and protection of surface and ground water quality. Additional guidance should be considered and developed for other resources.

Agrichemicals have been detected in surface and ground water nationwide. Many instances can be attributed to point-source contamination, but non-point source contamination caused by normal agricultural practices is still a major concern. Traditionally, agricultural producers have made agrichemical management decisions based on efficacy and economics. We as a society now believe that pesticides should be used in the most prudent manner possible to minimize risk to the environment. To accomplish this goal, agricultural producers must carefully consider the environmental risk associated with their agrichemical management decisions. Reductions in agrichemical use, improved efficacy of agrichemicals applications through integrated crop management, matching agrichemicals and management practice selection to site conditions, and the use of pesticides that are less toxic to the environment are all viable solutions.

Without quantification of the environmental benefits of these practices, agricultural producers cannot make informed agrichemical management decisions. Our goal should be to actively help producers choose agrichemical management alternatives that reduce hazardous agrichemical losses from the AMZ that could impact drinking water and environmentally sensitive areas. Planning assistance should strike a balance among efficacy, economics, and the environment to provide for a voluntary sustainable agriculture.

The following materials were adapted with permission from the Aquatic dialogue group: pesticide risk assessment and mitigation from Baker JL, Barefoot AC, Beasley LE, Burns LA, Caulkins PP, Clark JE, Feulner RL, Giesy JP, Graney RL, Griggs RH, Jacoby HM, Laskowski DA, Maciorowski AF, Mihaich EM, Nelson Jr HP, Parrish PR, Siefert RE, Solomon KR, van der Schalie WH, editors. 1994. Society of Environmental Toxicology and Chemistry, Pensacola, FL.

Management Factors—Field Loss Reduction

Of all the management factors that affect a particular nutrient and pesticide concentration (and the one factor that has the most impact of the loss from the field) the rate of nutrient and pesticide application is most direct and usually the greatest effect. The method of pesticide application can also have a major effect on surface runoff if it affects placement relative to the route(s) of infiltration. Timing of application relative to subsequent storms is another major factor that can affect concentrations and losses. Where possible, choice of formulation (or additive) used, by affecting nutrient and pesticide properties, can affect concentrations and losses. Cropping sequence in both time and space (contour strip cropping), by affecting the needs for tillage, soil moisture, and weed and pest control, affects both hydrology and nutrient and pesticide inputs and, thus, concentrations and losses. Tillage, by affecting erosion rates and hydrology as well as needs for and method of nutrient and pesticide application, can potentially affect concentrations and losses. Water management in terms of drainage and irrigation also affects hydrology and thus potential losses.

In the following sections on mitigation practices to reduce nutrient and pesticide runoff losses from treated fields and to reduce the field-to-stream transport of nutrients and pesticides, a discussion of the likelihood of effect for each practice is given. It must be remembered this is just an estimate based on limited research (see References) and/or professional judgment. A better estimate can be made for more specific sets of conditions. Computer simulation models do exist that can predict pesticide and nutrient fate and loss, with varying degrees of accuracy, for specific conditions and practices.

Rate/Formulation

Lower Rate Feasibility

Rate of nutrient and pesticide application is one of the primary factors affecting leaching and runoff losses. Pesticide runoff loss with sediment and water is roughly proportional to the amount of pesticide in the thin mixing zone at the soil surface and/or on crop residue or foliage. The same is true for phosphorus. For example, if the amount applied is reduced by a factor of two, loss should be reduced by a factor of two. If this relationship deviates from linearity, losses should be reduced even more than the percentage the rate is reduced because the degree of soil adsorption usually increases as concentration (or the amount applied) decreases. The feasibility of lower rates is dependent on both the amount needed to achieve the level of pest control and crop growth desired and the accuracy of the application method. Realistically, a rate reduction beyond 25 to 50 percent is not likely, assuming the same pest control spectrum and crop growth is maintained. A reduced application rate can reduce other environmental losses (i.e., to ground water and the atmosphere) and potential adverse biological effects, as well as reduce energy and economic inputs. However, reduced application rate can increase the risk of inadequate control, buildup of resistance, lower yields, and economic losses plus the legal consequences of not following the label.

The factors of weather, hydrology, soil, and chemical properties should not greatly influence the predicted effect of rate reduction.

Partial Substitution

Partial substitution of the pesticide of concern by another pesticide or by other means of pest control can reduce the amount applied. The effect is the same as above, where the predicted effect on pesticide runoff loss with sediment and water is roughly proportional to the amount of substitution and therefore the amount of pesticide in the thin mixing zone at the soil surface and/or on crop residue or foliage. If suitable alternatives exist, it is feasible to reduce the rate of applications beyond that of elimination alone.

Again, a reduced application rate can reduce other environmental losses (i.e., to ground water and the atmosphere) and potential adverse biological effects as well as energy and economic inputs; there is also the potential for improved pest control with a mixture of pesticides or control methods. At the same time, there is the risk of reduced pest control with partial substitution; also, if one pesticide is substituted for another, the potential environmental impact of the substitute may be greater because of increased losses and/or greater toxicity.

If the combination of weather, hydrology, soil, and chemical factors favor greater loss of a substitute pesticide, the predicted benefit of this practice would be lessened.

Partial Treatment

Partial treatment, either on a field basis or within a row (band versus broadcast or directed spray versus an over-the-top application), can effectively reduce the rate of pesticide application. Pesticide loss with sediment and water is roughly proportional to the amount of pesticide in the thin mixing zone at the soil surface and/or on crop residue or foliage. Where a pesticide is applied in a band over only a portion of the row-width, a substantial reduction is possible, compared to a broadcast application where the whole area is treated. 'Spot treatment,' seed treatment, or directed spray may allow greater reductions.

Concentrated nutrient applications on the soil surface may accentuate runoff losses. Substituting organic nutrients for commercial fertilizer can save on input cost. The nutrients in organic waste may not be as readily available at time of crop uptake. Nutrients from organic waste are more difficult to balance with crop requirements because of the nitrogen to phosphorus ratio in the manure. Denitrification losses in bands are generally higher for organic waste than for nitrogen fertilizers, principally because of carbon available for denitrifying organisms.

Again, a reduced application rate can reduce other environmental losses (to ground water and the atmosphere) and potentially adverse biological effects, as well as energy and economic inputs. However, a reduced application rate can increase the risk of pest escapes, crop deficiencies and economic losses, plus the untreated area generally requires alternative treatment (timely mechanical cultivation for weed control), which may increase the potential for runoff and soil erosion.

The potential for alternative treatment will be influenced by weather, hydrology, and soil factors that affect trafficability in the case of ground-applied treatments.

Choice of Formulation

If different formulations are available, a formulation that alters soil adsorption and solubility can affect pesticide runoff losses. The degree of reduction will depend on the major transport mechanism for a certain pesticide in relation to the differences in its adsorption and solubility properties for the different formulations. Encapsulation represents a type of formulation that can directly influence the availability of a product for either leaching or runoff.

Other environmental losses (e.g., volatilization) may also be reduced. However, it is also possible that other environmental losses may be increased.

Weather, hydrology, and soil factors are important. Where they combine for good erosion control, increased soil adsorption is a positive factor. Where these factors combine for good infiltration, increased solubility should reduce surface runoff losses; however, leaching losses may be increased.

Soil Erodibility Special Restrictions

Rate restrictions tied to highly erodible land unprotected by crop residue have the potential to reduce runoff losses. This targeting to areas where soil erosion is expected to be severe and where application rates may be restricted by some percentage (e.g., 25 percent) should reduce pesticide runoff losses. In this example, the reduction would be at least 25 percent if maximum label rates were being used.

Targeting erodible areas that are more susceptible to both runoff and erosion may be more beneficial than a blanket restriction for the entire area, because there is a greater risk of pest damage if a reduced rate is used over a large area. Use of erosion control measures may also be promoted by this approach. However, a reduced application rate can increase the risk of pest escapes and economic losses. Frequently, the pesticide requirement for highly erodible soils may be greater than for other soils because pesticides are used for weed control in lieu of tillage. Pesticide selection becomes more critical for such soils.

The success of this targeting is related to weather, hydrology, and soil factors. A final important factor (pesticide properties) is that soil adsorption determines the potential for transport with eroded soil and the feasibility for this approach to be effective.

Method and Timing of Application

Soil Incorporation

Mechanical incorporation, by reducing the amount of nutrients and pesticides in the thin mixing zone at the soil surface and/or on crop residue or foliage, reduces the interaction with and transfer of nutrients and pesticides to runoff water and thereby reduces runoff loss. Incorporated material is more subject to downward movement.

With incorporation, other environmental losses may also be reduced, and nutrient management and pest control may be improved. However, mechanical incorporation with tillage may reduce soil protecting crop residue. Leaching losses may, but are not likely to, be increased, and the relative importance of the different loss pathways needs to be considered.

The feasibility of using incorporation as a mitigation practice depends on nutrient transformation and the pesticide mode of actions relative to position in the soil profile, and the potential for incorporation with irrigation depends on sufficient infiltration and solubility (in conjunction with limited soil adsorption) of the nutrient and pesticide. The use or availability of adequate irrigation can also be site specific.

Producers should consider timing relative to expected storms or planned irrigation applications. For some situations and certain nutrients and pesticides, a choice of application(s) timing is possible, that is, pre-emergence versus post-emergence with pesticides and split applications with nutrients. The first storm after nutrient and pesticide application will generally result in the highest nutrient and pesticide concentrations in runoff. Concentrations will decrease with time both during and between runoff events, so increasing the expected time interval between application and intense storms causing significant runoff could reduce nutrient and pesticide runoff losses in part because intervening smaller, more gentle rains may move nutrients and pesticides down out of the thin mixing zone at the soil surface. An additional positive effect is possible with post-emergent application of herbicides, where the weeds that are allowed to grow before treatment provide some cover for the soil to reduce runoff and erosion similar to crop residue.

Nutrients additions would be applied closer to the period of crop requirement and uptake. Other advantages include possibly extending the time for other operations and possibly improved pest control and nutrient management. However, poor timing may also reduce pest control or nutrient use efficiency and increase other environmental losses.

The historical timing of runoff-producing storms along with the mode of action and persistence of the pesticide and nutrient fate will determine the feasibility of this practice (dependent on weather, hydrology, soil, and nutrient and pesticide factors).

Tillage Systems

No-Till

The use of no-till, where only minor soil disturbance occurs at planting and all the crop residue from the previous crop is left on the soil surface, is increasing. Erosion and chemicals transported with sediment are usually reduced with no-till. Runoff volume, at least on a growing season or annual basis, is generally less than that from conventional moldboard plow tillage. While pesticide concentrations in no-till runoff may be higher, the total quantity of pesticide in runoff from no-till is usually less-sometimes much less-than from conventional tillage. The same is true for nutrients. Phosphorus because of its surface application may be more susceptible to movement with no-till.

The other advantages, besides erosion control, include reducing time and energy inputs for tillage. However, use of no-till may:

- require additional pesticide use (not an increase in rate of those used, but another product such as a burn-down herbicide);
- require additional nitrogen to build-up surface soil organic matter;
- make it impossible to incorporate pesticides by conventional means, therefore eliminating possible use of some more environmentally friendly pesticides;
- make it difficult to inject manure and organic waste;
- under some conditions, increase runoff and volatilization of pesticides intercepted by surface crop residue;
- increase runoff of soluble P washed from crop residue;
- increase runoff volume(s) for first storm(s) after chemical application relative to soil loosened by tillage; or

- result in more macropores at the soil surface, that may contribute to deeper leaching of pesticides and nitrate-nitrogen (both are detected more quickly and at deeper depths than expected based on their adsorption to soil).

However, if no-till results in use of a different *mix* of pesticides (lower rate, post-emergence herbicides, for example), the total pesticide runoff loss may be decreased depending on individual pesticide properties. In addition, the strong soil adsorption properties of the burndown herbicides most often used, paraquat and glyphosate, result in little environmental concern for runoff losses with the no-till system.

When soil (including slope) and weather conditions are conducive to erosion and for strongly adsorbed pesticides and phosphorus, no-till has its greatest potential for reducing chemical movement.

Conservation Tillage

Conservation tillage (reduced tillage or mulch tillage) involves some tillage but less than inversion moldboard plow tillage. To qualify as conservation tillage, the soil surface must be sufficiently covered with crop residue after planting to significantly reduce erosion. The reduction in runoff and erosion expected with conservation tillage reduces detachment and transport, and therefore losses of nutrients and pesticides. Ridge tillage may be a special case where, in addition to reduced pesticide losses from reduced runoff and erosion, reduced herbicide use through banding (feasible and generally done because of later ridge rebuilding cultivation) further reduces losses.

Advantages besides erosion control include reduced time and energy inputs for tillage. However, as with no-till, conservation tillage: may require additional chemical use (possibly, a burn-down herbicide); reduce the ability to incorporate nutrients and pesticides by conventional means, possibly eliminating the use of more environmentally friendly pesticides; under some conditions, increase runoff and some volatilization of pesticides intercepted by surface residue or phosphorus concentrated on the soil surface; or result in more macropores at the soil surface possibly contributing to deeper leaching of nutrients and pesticides, but to a much lesser degree than no-till.

This practice has the most potential for reducing losses in runoff when soil, slope, and weather conditions are conducive to erosion, when strongly adsorbed pesticides are used or surface soil is high in nutrients, especially phosphorus.

Water Management

Subsurface Drainage

Artificial subsurface drainage, achieved mainly by removing water from the soil profile between rainfall events by using drainage tubes and ditches, lowers the antecedent soil moisture content and allows increased infiltration during a subsequent rainfall event. Therefore, subsurface drainage allows water to move through the soil profileand reduces the volume of surface runoff. Nutrient and pesticide losses are generally reduced when the soil is allowed to act as a filter. In the case of weakly adsorbed pesticides or nitrate-nitrogen and sandy, low organic matter or clay soils, losses may not be decreased.

Other advantages are that subsurface drainage makes possible more timely field operations and provides for better soil moisture conditions for crop growth. Drainage is needed or used only in areas with potential for waterlogged soil; the beneficial effect of subsurface drainage in reducing nutrient and pesticide runoff losses is generally greater for moderately adsorbed pesticides and phosphorus.

Surface Sealing/Compaction

Surface sealing of unprotected soil and compaction because of traffic can reduce infiltration rates. Because the interval between initiation of rainfall and initiation of runoff decreases, the rate and volume of runoff increases. Because nutrient and pesticide concentrations decrease with time during a runoff event (as nutrients and pesticide are leached out of the thin mixing zone at the soil surface), more runoff, particularly early in the rainfall event when concentrations are higher, results in greater losses. Protecting the soil surface with living or dead crop residue absorbs rainfall energy and reduces sealing. Reduced or controlled traffic along with reducing the amount of tillage can reduce compaction.

Other advantages of controlling surface sealing/compaction include more infiltration and better soil aeration, which generally mean better growing conditions for crops and likely more microbiological activity. There are usually no disadvantages.

The problem of surface sealing/compaction is more important on soil that has good internal drainage in areas with excess precipitation. Potential problems associated with sealing are worse for less strongly adsorbed pesticides or more soluble nutrients.

Irrigation

Irrigation management practices can have a significant effect on the quantity and quality of runoff water. Applying irrigation water above soil intake/infiltration rate or percolation capacity may cause runoff and leaching. Specific practices that should be considered include:

- Surge flow. Applying irrigation water in ‘pulses’ or surges instead of in continuous flow, used in furrow irrigation. The goal is to increase application uniformity along the furrow and reduce the amount of induced runoff, erosion, and percolation (and therefore, both runoff and leaching losses; this practice usually reduces total water input).

- Low-energy precision application (LEPA). A type of center pivot or linear irrigation system that will increase application efficiency and reduce the amount of excess water applied. This practice will minimize the potential for runoff.

- Drip or microjet. Precision methods for irrigating that reduce the amount of excess water applied, thus reducing runoff, erosion, and percolation losses.

- Furrow diking. The practice of mechanically making small dikes within the furrows to pond water, thus eliminating (in some areas it is illegal for irrigation tailwaters to leave the site) or reducing runoff and erosion.

- High-volume traveling or overhead guns. Apply large volumes of water in short time. Where runoff is likely, more frequent applications of shorter duration will minimize the potential for runoff.

- Retention pond. A reservoir for collecting irrigation tailwaters for reuse, to eliminate runoff leaving the field.

- Chemigation. Application of agrichemicals through irrigation systems. On permeable or impermeable soil that has high slope, the probability of leaching or runoff, respectively, is high. Nutrient applications in small, frequent doses to the irrigation water will improve nutrient uptake efficiency.

Cropping

Strip Cropping

Strip cropping is where two different crops are planted in alternate strips, or where three or more crops are planted sequentially in strips, usually on the contour or at least across the slope (or perpendicular to the direction of prevailing winds in areas where wind erosion is a concern). The width of strips may range from 20 feet wide, up to 200 feet or more. The potential of strip cropping to reduce pesticide runoff losses results from:

- possibly decreasing chemical use (if one of the crops does not require nutrients or pesticides, and

- decreasing chemical transport where the untreated crop could act as a buffer strip (discussed later) and reduce erosion, runoff, and sediment transport (particularly if the crop is a close-grown crop acting like a vegetated filter strip [also discussed later]). The potential advantage of reducing chemical runoff losses is likely greater for more strongly adsorbed pesticides and sediment-bound nutrients, like phosphorus. With a 50 percent reduction in application (assuming equal alternating areas of treated and untreated crops), losses could be reduced compared to a monoculture. The feasibility of strip cropping depends on soil, slope, and irrigation suitability of crops.

Other advantages include reductions in other environmental pesticide losses as well as reduced inputs and reduced erosion. Crop yields in some cases may be increased as well. Possible disadvantages include more management time spent keeping track of the locations of the strips and care in use of some pesticides on one crop if the adjacent crop is susceptible to pesticide damage. In addition, if narrow strip cropping is used, the beneficial rotation effect may be reduced if pests move from one strip to another. For example, corn rootworm adults could move from soybean strips (rotated from corn the previous year in a corn-soybean strip-cropped field), requiring an insecticide treatment.

Crop Rotation

The use of crop rotation (e.g., corn following soybeans) has considerable potential for reducing nutrient and pesticide runoff losses by decreasing or eliminating the need for some pesticides and reducing nutrient requirements. For example, in corn following soybeans, the need for a rootworm insecticide is much reduced compared to continuous corn. The corn crop also requires less applied nitrogen following a legume like soybeans. A rotation with a sod crop will reduce erosion and runoff while that crop is being grown, as well as having a carry-over effect for at least the first year out of sod. Accumulated nutrients and improved soil conditions are also advantages of a sod crop in the rotation.

In addition to reduced chemical losses to other resources, crop rotation often has the advantage of increased yields, with all other inputs being equal. One disadvantage is that economics of certain crops or farm programs do not allow the flexibility required to rotate crops (also true for strip cropping).

In addition to economics, including government incentives, the feasibility of crop rotations is determined by climate and soil factors.

Management Factors—Field-to-Stream Transport Reduction

Structural practices, such as terraces, can reduce field-to-stream transport of nutrients and pesticides by reducing sediment transport and runoff. Likewise, landscape reconfiguration, including the use of buffer strips and wetlands within watersheds or as riparian zones, can potentially attenuate the amount of pesticides carried with sediment and dissolved in water upon passage through these features.

Structures

Terraces/detention ponds

Terraces and detention ponds are components of a resource management system that reduce sheet and rill erosion, and reduce sediment movement off of sloping land. The major type of terrace of economic importance used in the U.S. is the broad-base terrace. In terrace construction, an embankment is usually built to either allow water to slowly drain down a nearly level channel (graded terraces) or to dam the water and force infiltration (level terraces), or provide a tile outlet from the detention pond (tile-outlet terraces). Because of construction costs and the desire to avoid crop damage, most terraces built today are of the tile-outlet (or detention pond) type. As such, they are designed to release the runoff from a 10-year 24-hour return interval storm within a 48-hour period through an underground tile system. In that period, some infiltration will occur, reducing runoff somewhat, but the major effect is the reduction of sediment load in the outflow because of sediment deposition in the pond or terrace basin. Thus, terraces reduce the amount of chemical transported with sediment and runoff, depending on how much of the nutrient or pesticide is adsorbed or transported with sediment.

Other advantages of terraces are the effects of reduced erosion on the land and reduced sediment (and chemical) transport to water resources. In addition, depending upon the retention time of the ponds and the route of degradation, detention ponds may also result in degradation of the pesticide and transformation of nutrients. This may be especially true if a pesticide of concern undergoes rapid hydrolysis. Ponding of water on the surface will increase movement of water and agrichemicals by leaching.

The concerns with terraces are their initial and maintenance costs, their effect on the farmability of the land, and the land they may take out of production (on steeper slopes, push-up terraces are often constructed with the steep backslope seeded to grass).

How effectively terraces reduce field-to-stream transport of nutrients and pesticides is closely tied to the soil adsorption properties of the pesticides and nutrients, especially soil phosphorus. For strongly adsorbed nutrients and pesticides, the effectiveness will be much greater than for those that are weakly or moderately adsorbed. For the particular case of tile-outlet terraces and a weakly or moderately adsorbed pesticide like atrazine, there is concern that direct transport to a stream from the field through underground tile eliminates any possibility of attenuation in the transport process. A vegetated buffer around either the inlet or the outlet will help alleviate this concern.

Constructed Wetlands

Constructed wetlands are designed to simulate natural wetlands, and consist of saturated substrates, emergent and submergent vegetation, animal life, and water. Constructed wetlands have the potential to remove nutrients and pesticides dissolved in water and associated with sediment in surface runoff. In general, wetlands are effective in removal of suspended particles and chemicals attached to them and not nearly as effective in removing chemicals dissolved in water. Retention time or travel time of flow through a wetland is important. The longer the travel times, the more likely dissolved chemicals will be removed.

Other advantages of constructed wetlands are nutrient (particularly nitrate) removal from agricultural drainage and the possible use of the wetlands as a water source for some needs. Concerns include the cost of construction and maintenance and land taken out of production. In addition, the wetlands themselves may be considered important ecological areas that require protection. If growers construct wetlands for runoff mitigation, then the concentrations of nutrients and pesticides in the wetlands should not be regulated the same as “natural” surface water.

Pesticide properties, particularly soil adsorption, degradation, and transformation fate are major factors in determining how effective wetlands can be in the reduction of field-to-stream transport of nutrients and pesticides.

Landscape Reconfiguration

Buffer Strips

A buffer strip is an area of a field border that is not treated with agrichemicals. It can be planted to the same crop as the rest of the field, left in fallow, or be planted to some other crop (if planted to grass or some other close-grown forage crop, it will be considered a vegetated filter strip). The purpose of the buffer strip is three-fold: first, it can physically separate a resource of concern (a stream) from a treated area; second, it reduces the amount of nutrients and pesticides used in the watershed (however, usually by only a small amount); and third, if overland flow from the treated area passes through the untreated area, there is the potential for attenuation by adsorption or deposition of the nutrients and pesticides concentration carried in the surface runoff. Infiltration in the buffer strip may also reduce runoff volume. Increased infiltration will not greatly increase leaching to ground water.

Buffer strips also reduce the risk of losses to ground water and the atmosphere by reducing agrichemical application. The efficiency of buffer strips depends on the size of the contributing watershed in relation to the size of the buffer strip (the larger the ratio, the lower the efficiency) and the path of water flowing through the buffer strip (the more channelized the flow, the less interaction with materials in the buffer strip and the less the attenuation). Economic disadvantages could come with decreased pest control (where the buffer strip is in the same crop), decreased crop area (where the buffer strip is kept fallow), and decreased crop production (where the buffer strip is in another less productive crop, or one susceptible to the nutrient and pesticide in runoff from the treated area).

Other major factors influencing the predicted effect include how strongly a nutrient or pesticide is adsorbed. Transport of less soluble, more strongly adsorbed agrichemicals will be reduced the most with sediment deposition and/or runoff interaction with in-place soil. In a similar vein, a combination of climate, hydrologic, and soil factors resulting in more erosion could make this practice more effective.

Mixing/Loading/Handling Set-Backs

These set-backs are distances that must be maintained from a point of mixing/loading/handling of an agrichemical to a water resource of concern such as a stream, lake, reservoir, or ground water well. With the exception of some inconvenience in certain instances, there is little cost to this method of preventing agrichemical spills.

Vegetative filter strip

A vegetative filter strip is a buffer strip planted to grass or some other close-grown plants, normally of a forage type (but might include shrubs or even trees). As with the buffer strip, the purpose of the vegetated filter strip is to remove nutrients and pesticides in solution or associated with sediment from runoff by filtration, deposition, infiltration, adsorption, decomposition, and/or volatilization. By both slowing runoff velocity and providing more biological surface area (living and dead) for interaction, the vegetative filter strip is moderately efficient in reducing the field-to-stream transport of nutrients and pesticides.

Other advantages and concerns are similar to those for buffer strips. Specifically, to be effective, runoff must not concentrate or channelize, but must pass through the vegetation in nearly uniform sheet flow. The vegetation must be erosion- and pesticide-resistant. The lower the ratio of contributing watershed area to filter strip area, the longer the contact time and the greater the removal efficiency.

Removal efficiency depends on nutrient and pesticide properties, with less soluble, more strongly adsorbed pesticides and sediment attached nutrients likely to be more affected. In addition, as with buffer strips, climate, hydrologic, and soil factors resulting in more erosion could make this practice more effective.

Grassed Waterways

Grassed waterways are a type of vegetative filter with a different orientation relative to inflow and outflow directions and a somewhat different purpose. Grassed waterways are generally designed to collect overland flow and then transport it down slope to an outlet without erosion. The grassed waterway acts as a vegetated filter strip as runoff enters from each side, with decreasing function as a filter as flow concentrates in the bottom of the channel. Because waterways have a much greater ratio of watershed to grassed areas, they are less effective than buffer strips or vegetative filter strips in reducing field-to-stream transport of agrichemicals.

Other advantages are the same as those for buffer or filter strips including erosion control. The concerns are also similar but with a particular concern for sediment deposition at the outer edges of the grassed waterway causing a "dam" to form. This dam prevents water from entering the waterway and causes concentrated flow and erosion in the unprotected soil bordering the waterway. Therefore, maintenance of the waterway and erosion control in the field above the waterway are both necessary.

Summary of Mitigation Options

The following tables provides a summary of all of the mitigation options discussed and provides a general (High, Moderate and Low) range of reductions expected and specific comments associated with each option. An important point to be remembered is that within these categories, the reductions are not necessarily additive. Implementing one option can possibly increase or decrease the percent reduction that may be obtained by implementing other options.

Table 6.1 Practice summary guide for nutrient runoff losses to surface water.

Practice Field Loss Reductions	Potential reduction of Runoff transport		Comments
	Nitrogen	Phosphorus	
lower application rate	H	H	loss reduction should correspond directly to rate reduction; soil testing and crediting all sources of nutrients reduces the necessity for amended fertilizer
partial substitution	L	L	no substitution for either nutrient in plant metabolism; some and water components can supply these nutrients to plants (soil organic matter, irrigation water, atmospheric nitrogen)
partial treatment	M	M	concentrating nutrients in bands lessens applied surface area exposed to runoff and erosion; application in partial doses near the time of plant utilization is more efficient and lessens opportunity for surface transport
formulation	M	M	nitrate-N form of nitrogen more soluble, organic material (like manure) less dense, so mores more readily than soil
soil erodibility runoff special restrictions	H	H	soluble N and P moves with runoff, sediment-attached nutrients with erosion restrict N and P applications, soil test levels, on fields susceptible to runoff and erosion
soil incorporation	M	H	reduces surface runoff contact and sediment enrichment of nutrients, organics
application timing	H	H	application before expected precipitation event can create situation for nutrient and organic erosion and runoff
no-till	M	M	erosion greatly reduced; runoff of surface applied or stratified nutrients may increase
conservation tillage	M	H	runoff reduction for first storm after application enhances infiltration and percolation; erosion also reduce
subsurface drainage	M	H	lowers antecedent soil moisture, improves infiltration, reduces runoff and erosion, percolates more water, higher crop production and transformation of nitrogen to plant available form; nutrients reaching tile lines will appear in surface waters
less soil sealing/compaction	H	H	non-crusted, non-compacted soils increase nutrient movement into the soil profile

Table 6.1 Practice summary guide for nutrient runoff losses to surface water, continued.

Practice Field Loss Reductions	Potential reduction of Runoff transport		Comments
	Nitrogen	Phosphorus	
irrigation management	H	H	irrigation lowers water use, lowers tail water losses with associated nutrients light water applications can move nutrients into soil profile
contour strip cropping	M	M	infiltration within close growing crop strip reduces runoff slightly; moderate erosion reduction
crop rotation	M	M	deep rooted crops returns soil nutrients to the soil surface, legumes capture atmospheric nitrogen, less erosion and runoff infiltration improves soil moisture
TRANSPORT REDUCTIONS			
terraces/detention ponds	H	H	sediment-borne nutrients and organic deposited in channels and ponds, soluble nutrients infiltrate soil profile
constructed wetlands	H	H	surface transported nutrients can be removed and treated
buffer strip	M	H	small, untreated buffer area reduces application field; enhanced infiltration in buffer; erosion is reduced and sediment deposited in crop field
set-back	M	M	more distance to surface water entry points; less inadvertent application directly into water course
vegetated filter strip	M	H	enhanced infiltration; filter reduces application area of field , entraps sediment and contaminated runoff
grassed waterway	L	M	some infiltration and entrapment of nutrients
The rough estimates of the likely effects are based on limited research, and professional judgment. It should be possible to predict a more consistent estimate for specific nutrients using a mathematical model for a specific set of soil, climate, and environmental conditions.			

Table 6.2 Practice summary guide for pesticide runoff losses to surface water.

Practice Field Loss Reductions	Potential reduction of Runoff transport		Comments
	*Strongly adsorbed	Weakly adsorbed	
lower application rate	M	M	loss reduction should correspond directly to rate reduction
partial substitution	M	M	lesser environmental concerns may exist for other pesticides; cultural practices may lower runoff risk
partial treatment	H	M	concentrated bands will lower amount of pesticides and surface area treated; other cultural practice will be necessary
formulation	L	L	varied on potential to move with surface runoff and erosion
soil erodibility runoff special restrictions	M	M	restrictions should be targeted to more strongly adsorbed pesticides on highly erodible and high runoff land
soil incorporation	M	H	mechanical incorporation reduces the amount in surface mixing zone; less soluble loss
application timing	M	H	loss decreases with time between application and storm runoff
no-till	H	M	great erosion control; runoff volume much less; higher pesticide runoff from surface residue
conservation tillage	M	M	runoff reduction for first storm after application; enhances infiltration and percolation
subsurface drainage	L	M	improved infiltration and percolation moves water into profile; reduces surface concentration of more soluble pesticides; leached pesticide can be transported to surface waters
less soil sealing/compaction	L	M	non-crusted, non-compacted soils allow increased pesticide movement into soil profile; less in surface mixing zone
irrigation management	H	H	irrigation management lowers water use, lowers runoff and erosion; greater infiltration lowers concentration of more soluble pesticides in the soil mixing zone

Table 6.2 Practice summary guide for pesticide runoff losses to surface water, continued.

Practice Field Loss Reductions	Potential reduction of Runoff transport		Comments
	*Strongly adsorbed	Weakly adsorbed	
contour strip cropping	H	H	infiltration within close growing crop strip decreases runoff slightly; sediment is deposited in the field; less over treated with some pesticide
crop rotation	H	H	pesticide use can be reduced due to rotational effects on pest
TRANSPORT REDUCTIONS			
terraces/detention ponds	H	M	erosion and sediment transport reduction; infiltration and ponding deposits sediment in channels and ponds
constructed wetlands	H	M	deposition of sediment and treatment of runoff
buffer strip	M	M	small, untreated buffer area reduces application field; some infiltration in buffer and sediment deposition
set-back	M	M	more distance to surface water entry points; less inadvertent application directly to water course
vegetated filter strip	H	M	enhanced infiltration; sediment deposited above filter area; filter reduces application area of field
grassed waterway	M	L	concentrated flow restricts treatment; some infiltration and entrapment of pesticides

The rough estimates of the likely effects are based on limited research, and professional judgment.
It should be possible to predict a more consistent estimate for specific pesticides using a mathematical model for a specific set of soil, climate, and environmental conditions.
*Partition coefficient (K_d or K_{oc}) typically > 100

Table 6.3 Practice summary guide for nutrient leaching losses to ground water.

Practice Field Loss Reductions	Potential reduction of Leaching transport		Comments
	*Strongly adsorbed	Weakly adsorbed	
lower application rate	H	H	loss reduction should correspond directly to rate reduction
partial substitution	L	M	organic waste substituted for fertilizer will slow leaching losses, but increase potential during non crop season
partial treatment	L	L	no substitution for other nutrients in plant metabolism; some concentrated bands of nutrients increase localized areas of leaching
formulation	M	M	nitrate-N readily leaches: ammonium-n and fertilizer P less mobile; organic more mobile than fertilizer P
soil leachability special restrictions	H	H	highly leachable soils can be targeted for application, management restriction soils low in iron and aluminum leach more P
soil incorporation	L	L	builds soil nitrate-N by speeding mineralization and nitrification rate; places nitrate-N lower in soil profile; reduces macropore flow
application timing	H	L	application before expected precipitation event can drive nutrient lower in profile, thus encourages leaching; less leaching when application matches timing of crop uptake
no-till	L	L	macropores created in soil profile speeds leaching, higher soil moisture
conservation tillage	L	L	runoff reduction enhances infiltration and percolation
subsurface drainage	M	L	improved infiltration: percolates more water; leached nutrient can be transported to surface waters
less soil sealing/compaction	L	L	non-crusted, non-compacted soils allow increased infiltration and percolation
Irrigation management	H	L	Irrigation management lowers water use, lowers leaching losses

Table 6.3 Practice summary guide for nutrient leaching losses to ground water, continued.

Practice Field Loss Reductions	**Potential reduction of Leaching transport**		**Comments**
	***Strongly adsorbed**	**Weakly adsorbed**	
Contour strip cropping	L	L	infiltration within close growing crop strip increases leaching slightly; alternate deep rooted with shallow rooted crops retrieves soil nutrients
Crop rotation	M	L	deep rooted crops bring up nutrients from lower soil profile; legumes provide nitrogen from the atmosphere
TRANSPORT REDUCTIONS			
Terraces Detention ponds	L	L	some enhanced leaching below terrace channel and bottom of pond
Constructed wetlands	L	L	leaching can be expected below wetlands
Buffer strip	L	L	small, untreated buffer area reduces application field; enhanced infiltration in buffer; lengthens flow path through soil
Set-back	M	L	more distance to ground water entry point like wells and sink holes
Vegetated filter strip	L	L	enhanced infiltration; filter reduces application area of field
Grassed waterway	L	L	concentrated flow restricts infiltration
The rough estimates likely effects are based on limited research, and professional judgment. It should be possible to predict a more consistent estimate for specific pesticides using a mathematical model for a specific set of soil, climate, and environmental conditions.			

Table 6.4 Practice summary guide for pesticide leaching losses to ground water.

Practice Field Loss Reductions	Potential reduction of Leaching transport		Comments
	*Highly Soluble	Slightly Soluble	
lower application rate	H	M	loss reduction should correspond directly to rate reduction
partial substitution	H	H	substitution of cultural practices for pesticides will reduce leaching loss; substitution of less soluble, lower higher K_d and persistent pesticide reduces loss
partial treatment	M	M	reducing quantity of pesticide used will reduce leaching
formulation	H	M	less soluble, lower higher K_d pesticides will move slower through soil profile
soil leachability special restrictions	H	L	highly leachable soils can be targeted for application, management restriction
soil incorporation	M	L	moves pesticide into soil profile, reduces macropore flow
application timing	H	L	application before expected precipitation event can drive pesticide lower in profile pre-emergent, thus encourages leaching; post-emergent susceptible to leaching than pre-planted
no-till	L	L	macropores created in soil profile speeds leaching, higher water infiltration as percolation
conservation tillage	M	L	runoff reduction enhances infiltration and percolation, reduces macropores
subsurface drainage	M	L	improved infiltration percolates more water, leached pesticide can be transported to surface waters
less soil sealing/compaction	L	L	non-crusted, non-compacted soils allow increased pesticide movement into soil profile
irrigation management	H	L	management lowers water use, lowers leaching losses

Table 6.4 Practice summary guide for pesticide leaching losses to ground water, continued.

Practice Field Loss Reductions	Potential reduction of Leaching transport		Comments
	*Highly Soluble	Slightly Soluble	
Contour strip cropping	L	L	Infiltration within close growing crop strip increases leaching slightly
crop rotation	M	L	rotating pesticide with crop reduces any one chemical to carry over and build up in soil profile
TRANSPORT REDUCTIONS			
terraces detention ponds	L	M	some enhanced leaching below terrace channel and bottom of pond
constructed wetlands	L	L	leaching can be expected below wetlands
buffer strip	L	L	small, untreated buffer area reduces application field; enhanced infiltration in buffer; lengthens flow path through soil
set-back	M	L	more distance to ground water entry point like wells and sink holes
vegetated filter strip	L	L	enhanced infiltration; filter reduces application area of field
grassed waterway	L	L	concentrated flow restricts infiltration

The rough estimates of the likely effects are based on limited research and professional judgment.
It should be possible to predict a more consistent estimate for specific pesticides using a mathematical model for a specific set of soil, climate, and environmental conditions.
* Partition coefficient (K_d or K_{oc}) typically <300 and solubility >30 ppm for highly soluble pesticides.

Student Activity 3

1. Provide five surface water and five ground water examples of conservation practices that can be used to reduce nutrient and pesticide impacts on the environment.

____

____

____

____

____

2. Indicate (increase-I, decrease-D, or no change-NC) what would likely be expected for nutrient runoff and leaching by implementing the following practices.

Practice	Nutrient Runoff		Nutrient Leaching	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Lower application rate				
Soil incorporation				
No-Till				
Conservation tillage				
Partial treatment				
Subsurface drainage				
Irrigation water management				
Crop rotation				
Terraces/detention ponds				
Constructed wetlands				
Buffer strips				
Vegetated filter strips				
Grassed waterways				

3. Indicate (increase-I, decrease-D, or no change-NC) what would likely be expected for pesticide runoff and leaching by implementing the following practices.

Practice	Pesticide Runoff		Pesticide Leaching	
	Strongly Adsorbed	Weakly Adsorbed	Highly Soluble	Slightly Soluble
Lower application rate				
Soil incorporation				
No-Till				
Conservation tillage				
Partial substitution				
Partial treatment				
Subsurface drainage				
Irrigation water management				
Crop rotation				
Terraces/detention ponds				
Constructed wetlands				
Buffer strips				
Vegetated filter strips				
Grassed waterways				

4. How does maintaining crop residue on the soil surface affect (a) the source, (b) availability, (c) detachment and (d) transport, of phosphorus from the soil surface?

References

Aquatic Dialogue Group: Pesticide Risk Assessment and Mitigation—Describes pesticide risk assessments and mitigation option. Subject matter included in pages 99–111 and SETAC Table 4-2 were adapted specifically for this training course with permission from the Aquatic dialogue group: pesticide risk assessment and mitigation from Baker JL, Barefoot AC, Beasley LE, Burns LA, Caulkins PP, Clark JE, Feulner RL, Giesy JP, Graney RL, Griggs RH, Jacoby HM, Laskowski DA, Maciorowski AF, Mihaich EM, Nelson Jr HP, Parrish PR, Siefert RE, Solomon KR, van der Schalie WH, editors. 1994. Society of Environmental Toxicology and Chemistry, Pensacola, FL.

USDA-NRCS. 1990. Supplementing nutrient and pest management practice standards. Technical Note 102. Developed to provide a strategy for prioritizing nutrient and pest management, for addressing what should be included in a nutrient and pest management plan, and to provide some general guidelines for the development of state nutrient and pest management practice standards.

USDA-NRCS. 1994. The Phosphorus Index—A Phosphorus Assessment Tool. The phosphorus index provides field staffs, watershed planners, and land users with a tool to assess the various landforms and management practices for potential risk of phosphorus movement to water bodies.

Your State Nutrient and Pest Management Standards. Each State should have a nutrient and pest management practice standard. Many states are currently revising these practice standards using the new national guidelines. The most recent version of these practice standards should be obtained. NRCS state agronomist or comparable technical representative can provide this information.

Congratulations! You have completed Modules 4–6.

Please go to the NEDC web site and take the posttest for Modules 4–6. This test is located at the following URL:

http://www.ftw.nrcs.usda.gov/iris/nutrient_pest.html

Activity Answers

Student Activity 1

1. List the minimum requirements that need to be a part of the nutrient management component of an overall conservation plan.

   - *Aerial photograph or map and a soil map of the site*
   - *Current and/or planned plant production sequence or crop rotation*
   - *Results of soil, plant, water, manure, or organic by-product sample analyses*
   - *Realistic yield goals for the crops in rotation*
   - *Quantification of all nutrient sources*
   - *Recommended nutrient rates, timing, form, and method of application and incorporation*
   - *Location of designated sensitive areas or resources and the associated nutrient management restrictions*
   - *Guidance for implementation, operation, maintenance, and recordkeeping*
   - *Complete nutrient budget for nitrogen, phosphorus, and potassium for the rotation or crop sequence*

Student Activity 2

1. List the minimum requirements that need to be a part of the pest management component of an overall conservation plan.

   - *Plan map and soils map of managed fields (use RMS maps if available)*
   - *Location of sensitive resources if applicable (use RMS maps if available)*
   - *Environmental risk analysis for the "most likely" pest management recommendations (by crop and pest)*
   - *Interpretation of the environmental risk analysis and identification of appropriate mitigation practices*
   - *Operation and Maintenance requirements*

Student Activity 3

1. Provide five surface water and five ground water examples of conservation practices that can be used to reduce nutrient and pesticide impacts on the environment.

Surface Water	Ground Water
Conservation Cover (327)	*Grasses and Legumes in Rotation (411)*
Conservation Tillage (329)	*Irrigation System–Trickle (441)*
Filter Strip (393)	*Conservation Cropping Sequence (328)*
Conservation Cover (327)	*Conservation Cover (327)*
Mulching (484)	*Subsurface Drain (606) w/Pumpback System (447)*
Water and Sediment Control Basin (638)	*Cover and Green Manure Crop (340)*
Nutrient Management (590)	*Nutrient Management (590)*
Pest Management (595)	*Pest Management (595)*

2. Indicate (increase-I, decrease-D, or no change-NC) what would likely be expected for nutrient runoff and leaching by implementing the following practices. (Note: Review comments in Practice Summary Guide for Nutrient Leaching Losses to Ground Water and Nutrient Runoff Losses to Surface Water.)

Practice	Nutrient Runoff		Nutrient Leaching	
	Nitrogen	Phosphorus	Nitrogen	Phosphorus
Lower application rate	*D*	*D*	*D*	*D*
Soil incorporation	*D*	*D*	*I*	*I or NC*
No-Till	*D*	*D*	*I*	*I or NC*
Conservation tillage	*D*	*D*	*I*	*I or NC*
Partial treatment	*D*	*D*	*D*	*D*
Subsurface drainage	*D or I*	*D*	*D*	*D or NC*
Irrigation water management	*D*	*D*	*D*	*D*
Crop rotation	*D*	*D*	*D*	*D*
Terraces/detention ponds	*D*	*D*	*I or NC*	*I or NC*
Constructed wetlands	*D*	*D*	*I or NC*	*I or NC*
Buffer strips	*D*	*D*	*I or NC*	*I or NC*
Vegetated filter strips	*D*	*D*	*I or NC*	*I or NC*
Grassed waterways	*D*	*D*	*I or NC*	*I or NC*

3. Indicate (increase-I, decrease-D, or no change-NC) what would likely be expected for pesticide runoff and leaching by implementing the following practices. (Note: Review comments in Practice Summary Guide for Pesticide Leaching Losses to Ground Water and Pesticide Runoff Losses to Surface Water.)

Practice	Pesticide Runoff		Pesticide Leaching	
	Strongly Adsorbed	Weakly Adsorbed	Highly Soluble	Slightly Soluble
Lower application rate	*D*	*D*	*D*	*D*
Soil incorporation	*D*	*D*	*D*	*I or NC*
No-Till	*D*	*D*	*I or NC*	*I or NC*
Conservation tillage	*D*	*D*	*I or NC*	*I or NC*
Partial substitution	*D*	*D*	*D*	*D*
Partial treatment	*D*	*D*	*D*	*D*
Subsurface drainage	*D or NC*	*D or I*	*D or I*	*D or I*
Irrigation water management	*D*	*D*	*D*	*D*
Crop rotation	*D*	*D*	*D*	*D*
Terraces/detention ponds	*D*	*D*	*I or NC*	*D or NC*
Constructed wetlands	*D*	*D*	*I or NC*	*D or NC*
Buffer strips	*D*	*D*	*I or NC*	*I or NC*
Vegetated filter strips	*D*	*D*	*I or NC*	*I or NC*
Grassed waterways	*D*	*D*	*I or NC*	*I or NC*

4. How does maintaining crop residue on the soil surface affect (a) the source, (b) availability, (c) detachment, and (d) transport, of phosphorus from the soil surface?

   a. *Crop residue reduces soil erosion and surface runoff as source of phosphorus in runoff water and sediment.*

   b. *Crop residue can both increase and decrease the availability of P. By maintaining residue on the soil surface, P is leached from the residue material and can be carried by runoff water. Crop residue can, however, hold P in place as an organic form as less susceptible to erosion and runoff.*

   c. *Residue protects the soil surface against detachment by wind and water. Residue also shields the soil particle from direct contact by runoff water which can desorb (resuspend) P attached to the soil.*

   d. *Transport of phosphorus is reduced if runoff and erosion are reduced.*

Glossary

Adsorption—The process by which molecules or ions are taken up and retained on the surfaces of solids by chemical or physical binding, that is, the adsorption of cations by negatively charged minerals.

Aeration—The exchange of air in soil with air from the atmosphere. Air in a well-aerated soil has a composition similar to the air in the atmosphere. Air in a poorly-aerated soil is higher in carbon dioxide and lower in oxygen than the air above the soil.

Aerobic—Growing in the presence of, or occurring only in the presence of, oxygen.

Agricultural Management Zone (AMZ)—The area directly influenced by agricultural activities; the boundaries of which are the bottom of the root zone, the top of the crop canapy, and the edge of the field.

Agronomic rate—The rate at which fertilizer, organic material, or other amendments can be added to the soil for optimum crop production.

Algae-available phosphorus—Phosphorus that is in a soluble and available form for uptake by algae and other micro-organisms in the water column.

Amendment—Any material, such as lime, gypsum, sawdust, or other conditioners, that is worked into the soil to make it more productive.

Ammonium fixation—Adsorption of ammonium to the cation exchange sites in the soil and/or becoming fixed within the clay particle structure (lattice) in the soil.

Ammonification—The biological process leading to the formation of ammoniacal nitrogen.

Ammonium (NH_4^+)—A form of nitrogen that is available to plants and is produced in the early stage of organic matter decomposition.

Ammonium phosphate—A type of phosphorus fertilizer manufactured by the reaction of anhydrous ammonia with superphosphoric acid to produce either solid or liquid fertilizer.

Anaerobic—Growing in the absence of, or occurring in the absence of, oxygen.

Application rate—The weight or volume of a fertilizer, soil amendment, or pesticide applied per unit area.

Aquiclude—A saturated body of sediment or rock that is incapable of transmitting significant quantities of water under ordinary hydraulic gradients.

Aquifer—A saturated permeable geologic unit of sediment or rock that can transmit significant quantities of water under hydraulic gradients.

Aquitard—A body of rock or sediment that retards but does not prevent the flow of water to or from an adjacent aquifer.

Available nutrient—The form of a nutrient that the plant is able to use. Many nutrients in the soil are in forms the plant cannot use (such as organic forms of nitrogen) and must be converted to forms available to the plant (such as nitrate nitrogen).

Available phosphorus—A chemically extracted amount of phosphorus from the soil that represents the portion of P that is available to a growing plant. This extracted amount of P is correlated to a field test measuring yield for the crop.

Available Water Capacity (AWC)—A traditional term used to express the amount of water held in the soil available for use by most plants.

Avoidance—Avoiding pest populations (using pest resistant varieties, crop rotation, trap crops). Avoidance is the 'A' in the "PAMS" approach to IPM.

Banded (nutrients)—Placing fertilizer close to the seed at planting, or surface or subsurface applications of solids or fluids in strips before or after planting.

Banded (pesticides)—Partial pesticide application either over the rows or in-between the rows to reduce the overall application rate per acre. (In WIN-PST, a banded application means that pesticide is applied to no more than 50 percent of the field.)

Bioavailable phosphorus—The form of phosphorus that is absorbed by biological organisms such as plants and animals. Mostly orthophosphates, but can be some forms of organic P.

Biochemical Oxygen Demand (BOD)—The quantity of oxygen used in the biochemical oxidation of organic and inorganic matter; an indirect measure of the biologically degradable material present in organic wastes.

Biodegradable—A substance able to be decomposed by biological processes.

Biological pest control—The process of conserving, augmenting or introducing beneficial living organisms to reduce a pest population or its impacts. It includes the use of insects, nematodes, mites, plant pathogens, plants, vertebrates, and other living organisms.

Biorational — Derived from items in nature. Biorational pest controls include pheromones, repellents, minerals, oils, botanicals, and microbials.

Biomass—The total weight of all organisms in a particular environment. See Microbial Biomass, Phytomass

Bioremediation—The use of biological agents to reclaim soil and water polluted by substances hazardous to human health or the environment.

Biosolid—Any organic material, such as livestock manure, compost, sewage sludge, or yard wastes applied to the soil to add nutrients or for soil improvement.

BOD— See Biochemical Oxygen Demand.

Broadcast—The application of fertilizer on the soil surface. Usually done before planting, and normally incorporated with tillage, but may be unincorporated in no-till systems.

Bulk density (Soil)—The mass of dry soil per unit volume. Can be used as an indirect measure of soil quality, as higher bulk densities tend to restrict water and air movement into the soil and restrict root growth.

Carbon cycle—The sequence of transformations in which carbon dioxide is converted to organic forms by photosynthesis or chemosynthesis, recycled through the biosphere, and ultimately returned to its original state through respiration or combustion.

Carbon-nitrogen (C:N) ratio—The ratio of the mass of organic carbon to the mass of organic nitrogen in the soil, organic material, or plants.

CASRN—Chemical Abstract Service Registration Number for an active ingredient. Format:XXXXXXX-YY-Z. 7 digits with no leading zeroes, a dash, then 2 digits with possible leading zeroes, a dash, then 1 digit.

Cation—A substance that has a positive electrical charge. Common soil cations are calcium, magnesium, hydrogen, sodium, and potassium.

Cation Exchange Capacity (CEC)—The amount of exchangeable cations that a soil can adsorb at a specific pH, expressed as centimoles per kilogram (cmol/kg) of soil or milliequivalents per liter (meq/L).

CHCL—Chronic Human Carcinogen Level. CHCL is a long-term pesticide toxicity value for human drinking water exposure. It is the concentration at which there is a 1/100,000 probability of contracting cancer calculated by using the EPA algorithm based on QSTAR from animal studies. This probability level provides a toxicity value comparable to an MCL. [Algorithm: CHCL=(70 Kg x 10^{-5})/(2 L/ day *QSTAR) 10^{-5}. 70 Kg represents the average weight of an adult. 2 L/day represents average consumption of water each day by an adult.]

Chemical Oxygen Demand (COD)—A measure of the oxygen-consuming capacity of organic and inorganic material present in water or wastewater. As with BOD, it is used to determine the degree of pollution in an effluent.

Chemical Pest Control—The use of pesticides, such as herbicides, insecticides, or fungicides, to reduce a pest population or its impacts.

Chemigation—The process where fertilizers, pesticides, and other agrichemicals are applied into irrigation water to fertilize crops, control pests or to amend soils.

Citrate-insoluble phosphorus—That portion of the P in fertilizers that is considered immediately unavailable to plants in the guaranteed analysis of fertilizer.

Citrate-soluble phosphorus—That part of the total P in fertilizer that, along with the water-soluble P, is considered immediately available to plants.

COD—See Chemical Oxygen Demand.

Compost—Organic material that has been well decomposed by organisms under conditions of good aeration and high temperature. Normally used to improve soil tilth, although it does supply small amounts of nutrients.

Conservation Management Unit (CMU)—A field, group of fields, or other land units of the same land use and having similar treatment needs and planned management. A CMU is a grouping by the planner to simplify planning activities and facilitate development of a Resource Management System (RMS). A CMU has definite boundaries, such as: fence lines, drainage ways, or changes in vegetation.

Cover crop—A crop grown to: (1) protect the soil from erosion during periods when it would otherwise be bare; (2) scavenge excess nutrients from a previous crop to prevent nutrient loss; or both.

Critical nutrient concentration—The nutrient concentration in the plant, or specific plant part, below which the nutrient becomes deficient for optimum growth.

Critical soil test concentration—That concentration of a nutrient at which 95 percent of maximum relative yield is attained.

Crop nutrient requirement—The amount of nutrients needed to grow a specified yield of a crop plant per unit area.

Crop rotation—A planned sequence of crops growing in a regularly recurring succession on the same area of land, as contrasted to continuous culture of one crop or growing a variable sequence of crops.

Cultural pest control—The use of farming practices other than chemical and biological controls to reduce a pest population or its impacts. Cultural controls include such techniques as rotating crops, using pest-free seed and transplants, using pest resistant varieties, using good sanitation practices, burning, and all forms of mechanical pest control.

Denitrification—The transformation of nitrates or nitrites to nitrogen or nitrogen oxide gas, occurring under anaerobic conditions.

Dissolved phosphorus—Phosphorus, either in organic or inorganic form, in solution with water. Determined by passing through a 0.45-micron filter.

Dissolved reactive phosphorus—inorganic P that reacts with molybdenum.

EC—The electrical conductivity of a soil, which is a measure of the salt content of that soil. EC is expressed in millimhos per centimeter (mmhos/cm) or deciseimens per meter (dS/m).

Effective precipitation—The portion of total precipitation that becomes available for plant growth.

Environmental risk—The potential to impact the ecosystem negatively.

Eutrophic—Having concentrations of nutrients optimal, or nearly so, for plant, animal, or microbial growth. (Said of nutrient or soil solutions, or bodies of water.) Compare Hypereutrophic.

Eutrophication—The enrichment of an ecosystem with nutrients that provides a potential for increase in biological production. Both N and P provide vital nutrient elements for plant growth.

Evapotranspiration—The combined loss of water from a given area by evaporation from soil and plant surfaces and by transpiration from plants.

Fertigation—Applying fertilizer through an irrigation system.

Fertility (soil)—The ability of a soil to supply the nutrients essential to plant growth.

Fertilization (foliar)—Application of a dilute solution of fertilizer to plant foliage, usually made to supplement soil-applied nutrients.

Fertilizer—Any organic or inorganic material of natural or synthetic origin (other than liming materials) that is added to a soil to supply one or more elements essential to plant growth.

Fertilizer analysis—The percent composition of a fertilizer, expressed as total N, available phosphoric acid (P_2O_5), and water-soluble potash (K_2O).

Fertilizer (controlled release)—A fertilizer product formulated so that its nutrients become available at a slower rate than conventional water-soluble fertilizer.

Fertilizer (fluid)—Fertilizer wholly or partially in solution that can be handled as a liquid, including clear liquids and liquids containing solids in suspension.

Fertilizer (Salt index of)—A measure of how much soluble salts a fertilizer product will add to the soil.

Fertilizer (starter)—A fertilizer applied in relatively small amounts with or near the seed for the purpose of accelerating early growth of the crop.

Fertilizer (suspension)—A fluid fertilizer containing dissolved and undissolved plant nutrients. The undissolved nutrients are kept in suspension, usually by swelling type clays.

Fertilizer (top-dressed)—A surface application of fertilizer applied to the soil after the crop is established.

Field capacity—The amount of water a well-drained soil holds after free water has drained because of gravity.

Fixed phosphorus—Adsorbed P bonded to mineral material in the soil (including iron, aluminum, and calcium) so tightly that the P is unavailable to plants and animals.

Foliar—Pesticide application directed at the crop and/or weed canopy. Foliar application increases interception of pesticide by the plant and decreases contact with the soil. (In WIN-PST, a foliar application means that pesticide is applied as a directed spray at nearly full crop/weed canopy.)

Genetically Modified Organism (GMO)—A living entity that has been modified or transformed with the application of recombinant DNA technology, commonly referred to as genetic engineering.

Grass tetany—A potentially serious condition that occurs primarily in lactating cattle, caused by high levels of potassium in forages and resulting in reduced magnesium intake by cattle. The resulting magnesium deficiency can cause serious illness or even death if not treated.

Green manure—Plant material incorporated into the soil while green or at maturity for soil improvement.

Greenhouse effect—The absorption of solar radiant energy by the earth's surface and its release as heat into the atmosphere; longer infrared heat waves are absorbed by the air, principally by carbon dioxide and water vapor, thus the atmosphere traps heat much as a greenhouse does.

Greenhouse gas—An atmospheric gas that helps hold the warmth, generated by solar radiation, close to the earth's surface. The primary greenhouse gases are water vapor (H_2O), nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4).

HA—Health Advisory. HA is a long-term pesticide toxicity value for human drinking water exposure determined by the EPA Office of Water. It is the concentration of a chemical in drinking water that is not expected to cause any adverse noncarcinogenic effects over a lifetime exposure with a margin of safety.

Half-life—Days required for one-half of the original quantity of pesticide active ingredient to break down or dissipate under field conditions. Sometimes referred to as field dissipation half-life. Half-life is a measure of pesticide persistence. Typically, a half-life less than 30 days would be considered non-persistent, a half-life between 30 and 100 days would be considered moderately persistent, and a half-life greater than 100 days would be considered persistent. Half-life can vary widely based on soil moisture, temperature, oxygen status, soil microbial population, and other factors. Resistance to degradation can change as the initial concentration of a pesticide decreases, so subsequent half-lives may be longer. In general, the longer the half-life, the greater the potential for pesticide movement.

Hazard—Pesticide toxicity combined with potential exposure.

Heavy metals—Metals that, when present at their normal trace levels in the soil and in soil amendments, are not harmful, but which may be toxic at higher levels. Cadmium (Cd), arsenic (As), chromium (Cr), mercury (Hg), lead (Pb), selenium (Se), and nickel (Ni) are the heavy metals of concern. Municipal sewage sludge applied as a soil amendment is the primary source of heavy metals in agriculture.

Hydrologic cycle—The fate of water from the time it falls as precipitation until the water has been returned to the atmosphere by evaporation and is ready to be precipitated again.

Hypereutrophic—A nutrient-rich lake characterized by frequent and severe nuisance algal blooms and low transparency.

Hypoxia—A depletion of dissolved oxygen in surface waters

Immobilization—The conversion of an element from the inorganic to the organic form in microbial tissues or plant tissues.

Infrared photography—A remote sensing method that can be used to monitor crop production systems. Healthy plants reflect a large amount of infrared light, and stressed plants reflect lesser amounts, depending on the degree of stress. On-site investigation may be needed to determine the source of stress, be it inadequate fertility, insect, disease, or poor drainage.

Inorganic phosphorus—Mineral or orthophosphate forms of P.

Integrated Pest Management (IPM)—A sustainable approach to pest control that combines the use of prevention, avoidance, monitoring, and suppression strategies to maintain pest populations below economically damaging levels, to minimize pest resistance, and to minimize harmful effects of pest control on human health and environmental resources. IPM suppression systems include biological controls, cultural controls and the judicious use of chemical controls as a last resort.

Irrigation efficiency—The ratio of the amount of water actually consumed by a crop on an irrigated area to the amount of water applied to the area.

Invasive species—Plants, animals, and microbes not native to a region which, when introduced either accidentally or intentionally, out-compete native species for available resources, reproduce prolifically, and dominate regions and ecosystems.

K_d—Distribution coefficient. The sorption of a particular pesticide to a particular soil is measured in a laboratory by mixing water, pesticide, and soil. After equilibrium has been reached, the amount of pesticide remaining in solution is measured. The concentration of pesticide sorbed to the soil in the mixture is divided by the pesticide concentration still in solution. This yields the distribution coefficient, K_d. A low distribution coefficient indicates that more of the pesticide is in solution; a higher value indicates that the pesticide is more strongly sorbed to that particular soil.

K_{oc}—soil Organic Carbon sorption coefficient expressed as ml chemical/gram of organic carbon. K_{oc} is derived by dividing K_d by the organic carbon content of the soil that was used in the K_d equilibrium test. K_{oc} is therefore independent of soil organic matter. The higher the K_{oc}, the more strongly the pesticide is sorbed to soil, and therefore less likely to move in solution. Pesticide K_{oc} values greater than 1000 indicate strong sorption to soil. Pesticides with K_{oc} values less than 500 tend to move more dissolved in water than sorbed to suspended sediment.

Labile phosphorus—Phosphorus that is weakly adsorbed or bound in the soil to minerals and organic material and can easily be extracted by some chemical or plant root and released into soil solution for plant uptake.

Leaching—The removal of material in solution by the passage of water through the soil.

Leaching Index (LI)—An estimate of the average annual percolation for a site, used in the NLEAP model. It is a function of annual precipitation, the seasonal distribution of precipitation, and hydrologic soil group.

Liebig's Law—The growth and reproduction of an organism is dependent on the nutrient substance that is available in minimum quantity.

Limiting nutrient—Any one nutrient that, if not available to the plant in adequate amounts, will limit the potential yield of a crop, even though all other nutrients are available in adequate amounts.

Luxury uptake—The absorption by plants of an essential nutrient in excess of their need for growth. Luxury concentrations in early growth may be used in later growth.

Macronutrient—A nutrient that a plant needs in relatively large amounts. Essential macronutrients are nitrogen (N), phosphorus (P), and potassium (K).

Macropore flow—The tendency for water applied to the soil surface at rates exceeding the infiltration capacity to move into the soil profile through macropores, bypassing micropores, and rapidly transporting solutes to the lower soil profile.

Maintenance application—Application of fertilizer material in amounts and at intervals to maintain available soil nutrients at levels necessary to produce a desired yield.

Management Allowed Depletion (MAD)—The percentage of the available soil water that can be depleted between irrigations without serious plant moisture stress.

MATC—Maximum Acceptable Toxicant Concentration. MATC is a long-term pesticide toxicity value for fish. The MATC for an active ingredient is determined empirically by performing long-term or early life-stage toxicity tests. These test results produce the No Observable Effect Concentration (NOEC)| and Lowest Observable Effect Concentration (LOEC). Empirically, the geometric mean of the NOEC and LOEC is the MATC. When NOEC or LOEC are unavailable, MATC can be estimated from 96-hour LC_{50}s with a regression equation described by Barnthouse et al., (1990).

MCL—Maximum Contaminant Level. MCL is a long-term pesticide toxicity value for human drinking water exposure determined by the EPA Office of Water. They define MCL as the maximum permissible level of a contaminant in water delivered to users of a public water system. (WIN-PST preferentially uses MCLs. If an MCL hasn't been developed, WIN-PST uses the HA. If neither an MCL or HA is available, WIN-PST uses a calculated HA or CHCL as appropriate.)

Mechanical pest control—A component of cultural pest control that uses physical methods to reduce a pest population or its impacts. Mechanical controls include cultivation, hoeing, hand weeding, mowing, pruning, or vacuuming.

Microbial biomass—The total mass of living micro-organisms in a given volume of soil.

Micronutrient—Nutrients that plants need in only small or trace amounts. Boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) are considered micronutrients.

Mineralization—The conversion of an element by soil organisms from an organic form to an inorganic form, such as the conversion of organic forms of nitrogen to nitrates.

Mitigation—The process of minimizing the potential for harmful impacts of pest or nutrient management activities on soil, water, air, plant, and animal resources through the application of conservation practices and/or management techniques.

Monitoring (pest)—Identifying the extent of pest populations and/or the probability of future populations (pest scouting, soil testing, weather forecasting). Monitoring is the 'M' in the "PAMS" approach to IPM.

NLEAP (Nitrate Leaching and Economic Analysis Package)—A simulation model that estimates the potential for nitrate-nitrogen leaching below the root zone.

National Agriculture Pesticide Risk Analysis (NAPRA)—A detailed pesticide environmental risk analysis tool designed for use by NRCS specialists and their technology partners. NAPRA quantitatively evaluates the potential for pesticides to be transported by water and adversely affect non-target organisms, by modeling crop management techniques under specific weather and soil conditions. Results include the probabilities of pesticide leaching below the root zone and runoff beyond the edge of the field to exceed toxicity thresholds for humans, fish, crustaceans, and algae. NAPRA can be used to refine Windows Pesticide Screening Tool (WIN-PST) results and quantify mitigation techniques needed to achieve RMS water quality criteria.

Nitrate (NO_3^-)—The form of nitrogen most readily available to plants, and the form found in greatest abundance in agricultural soils.

Nitrate toxicity—A variety of conditions in animals, resulting from ingestion of feed high in nitrate; the toxicity actually results when nitrate (NO^-_3) is reduced to nitrite (NO^-_2) in the rumen.

Nitrification—Biological oxidation of ammonium to nitrite and nitrate.

Nitrogen cycle—The sequence of biochemical changes undergone my nitrogen, in which it is used by a living organism, transformed upon the death and decomposition of the organism, and converted ultimately to its original state.

Nitrogen fixation—Conversion of molecular nitrogen to ammonia and subsequently to organic combinations or to forms useable in biological processes.

Nitrogen immobilization—The transformation of available forms of nitrogen, such as nitrates, into organic forms not readily available to plants.

Nutrient—Elements or compounds essential as raw materials for organism growth and development.

Nutrient balance—An undefined theoretical ratio of two or more plant nutrient concentrations for optimum growth rate and yield. An imbalance results when one or more nutrients are present either in deficit or in excess.

Nutrient Management Component of a Conservation Plan—A portion of the conservation plan that is developed by implementing the Nutrient Management (Code 590) conservation practice standard. The nutrient management component, at a minimum, contains the nine elements identified in the plans and specifications section of the standard.

Organic phosphorus—Phosphorus that is bound with organic carbon and forms organic molecules.

Orthophosphate—The inorganic form of phosphorus that is plant available. Two species are: $H_2PO_4^-$ and HPO_4^{-2}

Oxidation—The loss of electrons from a molecule and the charge becomes more positive. An example is the oxidation of ferrous phosphate, a relative soluble iron form of P, to ferric phosphate, an insoluble P form.

PAMS—Acronym for Prevention, Avoidance, Monitoring, and Suppression tactics used in IPM systems.

PC CODE—Pesticide Chemical Code. The PC CODE is assigned by the EPA, Office of Pesticide Programs, and is also commonly referred to as active ingredient code, Shaughnessy code and chemical code.

Pest—A weed, insect, disease, animal, and other organism (including invasive and non-invasive species) that directly or indirectly causes damage or annoyance by destroying food and fiber products, causing structural damage, or creating a poor environment for other organisms.

Pesticide—A substance or mixture of substances intended for preventing, destroying, repelling, or mitigating pests; or a substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant.

Pest management—Controlling organisms that cause damage or annoyance. NRCS defines pest management as using environmentally sensitive prevention, avoidance, monitoring, and suppression strategies to manage weeds, insects, diseases, animals, and other organisms (including invasive and non-invasive species) that directly or indirectly cause damage or annoyance.

Pest Management Component of a Conservation Plan—A portion of the conservation plan that is developed by implementing the Pest Management (Code 595) conservation practice standard. The pest management component, at a minimum, contains the five elements identified in the plans and specifications section of the standard.

Pest Management Environmental Risk Analysis—An evaluation of the potential for pest management (including the use of GMOs) to impact the ecosystem negatively. Organic Phosphorus—Phosphorus that is bound with organic carbon and forms organic molecules.

Plant regulator—Any substance or mixture of substances intended, through physiological action, for accelerating or retarding the rate of growth or rate of maturation, or for otherwise altering the behavior of plants or the produce thereof.

Prevention—Preventing pest populations (using pest-free seeds and transplants, cleaning tillage and harvesting equipment between fields, or scheduling irrigation to avoid situations conducive to disease development). Prevention is the ‘P’ in the “PAMS” approach to IPM.

P_2O_5—Phosphorus pentoxide; designation on the fertilizer label that denotes the percentage of available phosphorus.

Particulate phosphorus—Phosphorus that is attached to mineral or organic material on the soil surface and carried as sediment by erosion.

Parts per million (PPM)—A means of expressing concentration, usually by weight. Equivalent expressions are milligrams per liter (mg/l) and milligrams per kilogram (mg/kg).

Percolation—The downward movement of water through the soil profile.

Permanent wilting point—The soil-water content at which most plants cannot obtain sufficient water to prevent permanent tissue damage.

pH (Soil)—The degree of acidity or alkalinity of a soil, expressed on a scale from 0 to 14, with 7.0 indicating neutrality. Values higher indicate increasing alkalinity, and lower values indicate increasing acidity.

Phosphate—In fertilizer terminology, phosphate is the sum of water-soluble and citrate-soluble phosphoric acid (P_2O_5), also referred to as available phosphoric acid (P_2O_5).

Phosphorus—Essential nutrient both for plants and animals. Makes up cell walls, DNA, and energy transfer molecules.

Phosphorus Index (PI)—An assessment tool to show the potential for phosphorus losses from the landscape.

Plant nutrient—An element that is absorbed by plants and is necessary for the completion of its life cycle.

Reaction (Soil)—The degree of acidity or alkalinity of a soil, usually expressed as a pH value.

Redox (Oxidation-Reduction) potential—An important chemical characteristic of soil, related to soil aeration. This characteristic determines in which form a given nutrient will occur in the soil.

Remote sensing—The collection and analysis of data from a distance, using sensors that respond to different heat intensities or light wavelengths. Remotely-sensed data is often collected using cameras mounted on aircraft or in satellites.

Residual fertility—The available nutrient content of a soil carried over to subsequent crops.

Resource assessment—Analyzing soil, water, air, plants, and animals information and human considerations to determine resource vulnerability, current conditions, and trends.

Resource Management System (RMS)—A combination of conservation practices and resource management for the treatment of all identified resource concerns for soil, water, air, plants, and animals that meets or exceeds the quality criteria in the FOTG for resource sustainability.

Resource vulnerability—Degree of susceptibility to injury based on a combination of intrinsic site characteristics and extrinsic management factors. For example, ground water resource vulnerability is determined by intrinsic site characteristics, such as climate, soil properties, and depth to ground water; and extrinsic management factors, such as crop selection, pesticide application, and water management.

Rhizobia—Bacteria capable of living symbiotically in roots of leguminous plants, from which they receive energy and often use molecular nitrogen.

Phytomass—The total of all plant material, living or dead, in an ecosystem at a given time.

Runoff—That portion of the precipitation on an area that is discharged through stream channels before it enters the soil.

Salt-affected soil—Soil that has been adversely modified for the growth of most crop plants by the presence of soluble salts, exchangeable sodium, or both.

Salt tolerance—The ability of plants to resist the adverse, nonspecific effects of excessive soluble salts in the rooting medium.

Saturated hydraulic conductivity—The rate at which water moves through a saturated soil.

Secondary nutrients—Refers to calcium (Ca), magnesium (Mg), and sulfur (S) in fertilizers.

Sensitivity—A measure of the potential for environmental degradation of an area, based on the inherent characteristics of the site or area.

Slow release—See "Fertilizer, Controlled Release".

Soil amendment—Any material such as lime, gypsum, sawdust, compost, animal manures, crop residue, or synthetic soil conditioners that is worked into the soil or applied on the surface to enhance plant growth. Amendments may contain important fertilizer elements but the term commonly refers to added materials other than those commonly used as fertilizers.

Soil fertility—The quality of a soil that enables it to provide nutrients in adequate amounts and in proper balance for the growth of specified crops or plants.

Soil Organic Matter (SOM)—The organic fraction of the soil exclusive of undecayed plant and animal residues. Often used synonymously with "humus".

Soil salinity—The amount of soluble salts in a soil. The conventional measure of soil salinity is the electrical conductivity of a saturation extract.

Soil solution—The liquid portion of the soil contained in soil pores. Chemical molecules, including plant nutrients, are diffused or flow in soil solution.

Soil test—A chemical, physical, or biological procedure that estimates the plant availability of nutrients to support plant growth.

Soil water potential—A measure of all the forces working to either remove water from or retain water in the soil profile. The total soil water potential consists of:

- matric potential—the attractive forces on soil water as represented through adsorption and capillarity

- osmotic potential—the attractive forces caused by the presence of dissolved substances (salts, other minerals)
- gravitational potential—the attractive force of gravity on soil water Matric and osmotic forces usually work to hold water in the soil; gravitational forces remove water from the soil.

Soluble phosphorus—Phosphorus that mixes and is transported as a solution by water. The P can be in the organic or inorganic form.

Solute—Any material dissolved in another substance.

Solvent—A usually liquid substance capable of dissolving or dispersing one or more substances.

Sorption—the removal of an ion or molecule from solution by adsorption and absorption, often used when the exact nature of the method of removal is not known.

Source-sink—A relationship between two parts of a system, in which one part serves as the producer or source of the material that is moved to another, the sink, where the material accumulates or is consumed.

STV—Sediment Toxicity Value. STV is a long-term sediment-sorbed pesticide toxicity value for sediment dwelling animals. STV = MATC x K_{oc}. K_{oc} is used in the STV to estimate pesticide concentration in sediment pore water. Fish MATC is used in lieu of toxicity data for sediment dwelling animals because few studies have been conducted. (WIN-PST uses the same rating classes for both MATCs and STVs.)

Superphosphate (concentrated)—Also called “triple” or “treble” superphosphate, made with phosphoric acid and usually containing 19 to 21 percent P (44-48 P_2O_5).

Superphosphate (normal)—Also called "ordinary" or "single" superphosphate, made by reaction of phosphate rock with sulfuric acid, usually containing 7 to 10 percent P (16-22 percent P_2O_5).

Suppression—Suppressing a pest population or its impacts. IPM suppression systems include biological controls, cultural controls and the judicious use of chemical controls as a last resort. Suppression is the 'S' in the "PAMS" approach to IPM.

SWAPA—Soil, Water, Air, Plant, and Animal resources.

Tilth—The physical condition of the soil as it influences tillage, fitness as a seedbed, and impedance to seedling emergence and root penetration.

Third party vendor—An individual in either the public or private sector who has been certified by an approved, independent certification organization or natural resource conservation agent as being qualified to provide certain types of conservation assistance and who participates in the Department of Agriculture-Approved Vendor Process outlined in the NRCS Conservation Programs Manual, Part 504, Conservation Assistance from Third Party Vendors.

Total Maximum Daily Load (TMDL)—A plan that specifies a quantitative pollutant load necessary to bring a waterbody into compliance with water quality standards.

Total phosphorus—The sum total of all the phosphorus forms contained in the material, including organic, particulate, and soluble forms.

Vadose zone—The unsaturated area of soil/rock above the permanent water table.

Volatilization—The loss of a compounds in gaseous form from a solid or liquid surface. Ammonia volatilizes from the surface of organic material.

Vulnerability—A measure of the potential for environmental degradation of an area, based on the management practices used in that area. A combination of natural intrinsic characteristics and extrinsic management factors. As such, vulnerability provides an overall assessment of water pollution potential. Extrinsic management factors are critical to a vulnerability assessment because irrespective of intrinsic site characteristics, water quality contamination usually does not occur without cropping systems (management) that provide contaminant loading.

Water balance—A daily accounting of the water supply for a specific field (soil and crop type) during a specific time.

Water budget—A projected accounting of the water supply in the soil for a general area for a general period of time.

Windows Pesticide Screening Tool (WIN-PST)—A basic pesticide environmental risk screening tool, designed for use by NRCS field office staff, crop consultants, certified crop advisors, and other partners. WIN-PST qualitatively evaluates the potential for pesticides to be transported by water from the area of application and adversely affect non-target organisms. WIN-PST considers the influence of climate, irrigation, residue management, and pesticide application method and rate class on the potential for pesticide leaching below the rootzone and runoff beyond the edge of the field. It also incorporates long-term pesticide toxicity to humans and aquatic life in its overall risk ratings of *Extra High*, *High*, *Intermediate*, *Low*, or *Very Low*. WIN-PST provides environmental risk information that a planner can use to formulate appropriate mitigation techniques that meet RMS water quality criteria.

Yield—The amount of a specified substance produced (grain, straw, total dry matter) per unit area.

Yield goal—The yield expected under good husbandry, adequate fertility, and adequate moisture for the area of production.