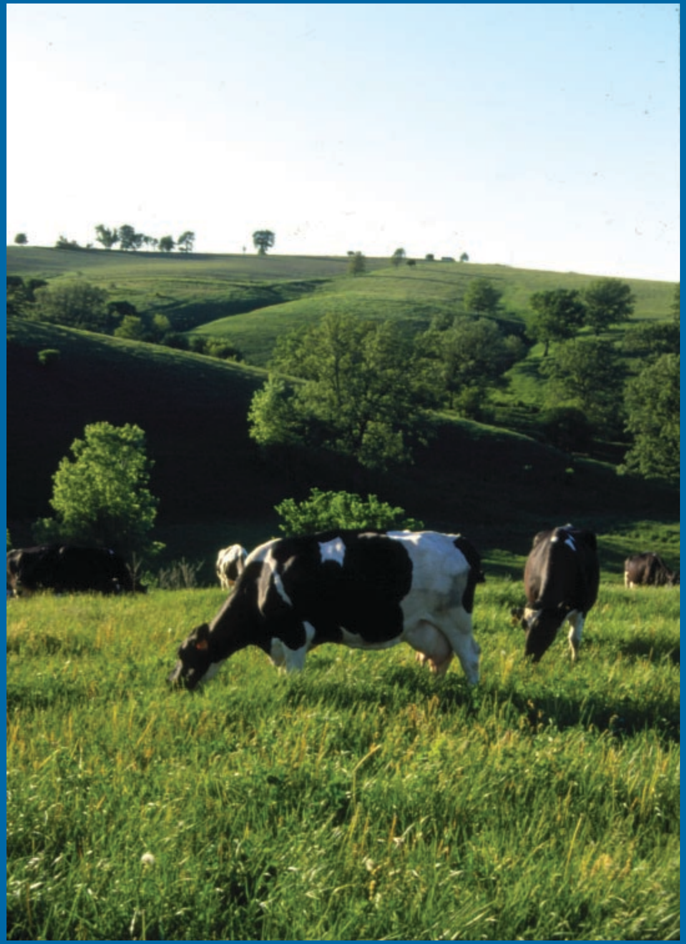

The
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Healthy Soil, Healthy Food, Healthy People®

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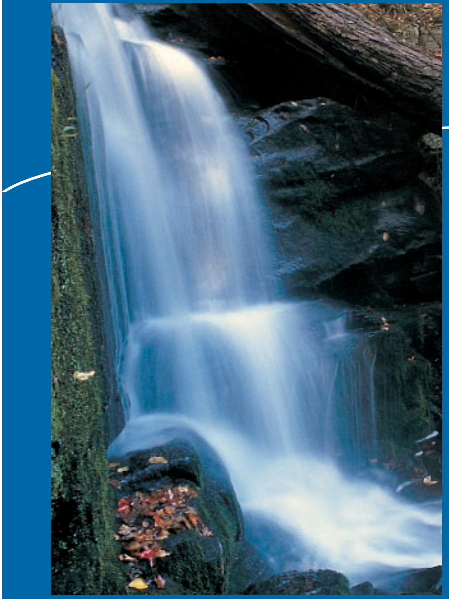
THE RODALE INSTITUTE®

WATER AGRICULTURE AND YOU



Contents

WATER, AGRICULTURE, AND YOU
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The Rodale Institute® is a private, publicly-supported nonprofit organization under section 501 (c)3 of the Internal Revenue Code. The Institute shares its expertise on organic/regenerative farming methods with people worldwide to achieve a regenerative food system that renews environmental and human health. "Healthy Soil, Healthy Food, Healthy People®" has been The Rodale Institute's message for the past 56 years. Funded in large part by donations from individuals, government agencies, private foundations and corporations, The Rodale Institute continues to promote soil and water quality practices to farmers worldwide.

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February, 2004
Kutztown, Pennsylvania

Executive Summary

For more than 50 years, The Rodale Institute® has advocated the adoption of regenerative/organic agriculture to produce healthy, abundant food locally, regionally, and globally while improving or regenerating the natural resource base and the environment. At the same time, Pennsylvania's Department of Environmental Protection (DEP) has actively sponsored programs to maintain and improve our water resources, especially as they are used in the production of food and fiber. Together we share a mission to develop a scientific understanding of our water resources and promote good management and conservation of these resources.

To that end, the DEP and The Rodale Institute collaborated in a two-year study to document and demonstrate how changes in agricultural operations have a profound effect on the quality of water entering Pennsylvania's watersheds and aquifers. Using The Institute's unique in-field laboratories, The Rodale Institute Farming Systems Trial® and the Compost Utilization Trial, the study focused on three major objectives: 1) evaluating the effects of regenerative/organic soil management practices on water quality; 2) measuring nitrogen, phosphorus, and pesticide movements in organic and conventional cropping systems; and 3) evaluating water infiltration rates through a range of soils under various agricultural practices in Pennsylvania watersheds. The goal of these objectives is to increase awareness about the relationship between regenerative/organic agriculture and water quality among watershed management groups, farmers, municipal authorities, university students, and consumers. The Institute's research concluded that:

1. The corn herbicides atrazine and metolachlor readily leached past plant root systems into ground and surface water at alarming levels in the conventional agricultural system but not in organic systems.

2. Nitrate leaching losses can be a problem in both organic and conventional agricultural systems, but higher nitrate pulses after soluble synthetic fertilizer applications resulted in more frequent nitrate contamination of water (above regulatory levels) in the conventional system.

3. Nutrient leaching was reduced with compost amendments as compared with manure or synthetic fertilizer applications.

4. Surface water runoff was reduced and water percolation was increased in organic agricultural systems as compared with the conventional system.

5. All conventional and organic amendment approaches produced similar high competitive yield levels in the absence of drought stress.

6. In drought years, organic systems produced higher soybean and corn yields than the conventional system.

Introduction

AGRICULTURE'S ROLE IN GROUND WATER POLLUTION

In the United States, about two-thirds of all water pollution is caused by agriculture. Rain, snow, and irrigation water interact with plants and soil in agricultural fields. During the growing season, most of this water is used by plants for their growth and reproduction or evaporates directly from the soil into the atmosphere. During periods of heavy precipitation, however, or when plant growth slows or stops in the fall and winter, excess precipitation can pass quickly over the surface of a field without being absorbed. This process is called runoff. Runoff consists not only of water but also of soil particles carried from fields into streams and lakes, removing valuable topsoil from agricultural fields; many times, chemical pollutants, such as pesticides, nitrates, and phosphates, are carried along with the soil.

Excess precipitation can also move (percolate) through the root zone and deeper soil layers and enter underground aquifers. This water may dissolve materials from the soil as it percolates, carrying them into the aquifer in a process called leaching. Depending on a farm's systems of crop and soil management, this water can contain pollutants, such as nitrates, phosphates, bacteria, and pesticides, that contaminate ground water sources.

SOIL EROSION

Soil erosion occurs when soil particles, or sediments, are carried from fields in runoff water. Soil erosion rates in the United States average 7.6 tons per acre per year. This translates into 3 inches of water, 0.9 ton of organic matter, 13 pounds of nitrogen, and 0.05 inch of topsoil per acre per year (Pimentel et al. 1995).

Agricultural practices that lead to soil erosion include seedbed preparation, cultivation for weed control, and maintaining bare soil without plant cover. Sediments can contaminate surface waters, bury wetlands, and raise streambeds, increasing the severity of floods.

Sedimentation also clogs ditches and culverts and can destroy aquatic wildlife habitat. In addition, sediments may carry and distribute toxic materials such as crop nutrients and pesticides, which cling to soil particles (Chesapeake Bay Foundation 2003; USDA 2001).

AGRICULTURE IN PENNSYLVANIA

Land use critically affects the long-term sustainability of both the quality and quantity of water resources in Pennsylvania. Agriculture has long been identified as a non-point pollution source. Soil erosion leads to excessive silt in surface waters, nutrient leaching, and chemical pesticide contamination.

National water quality surveys showed that of the 19 percent of river miles surveyed, 25 percent were polluted by agriculture. Of the 40 percent of lake acres surveyed, 19 percent were polluted by agriculture. Pesticide pollution is ranked as one of the top 10 high-priority pollution categories for the state of Pennsylvania. Synthetic organic compounds, which can result from pesticide use, exceeded maximum daily loads in 1 percent of the samples taken from public water supply wells in 1995 and 1996 (511 of 51,289 samples). For the same years, 23 percent of the samples (5,736 of 25,420) showed nitrate levels that exceeded maximum daily load standards. A 1985–97 survey of ground water sites in nearly half of the state's 100 high-priority basins (sites in the Ambient and Field Station Network) showed that 10 percent of ground water samples taken exceeded allowable nitrate rates. Twenty-five percent of the samples also showed turbidity rates above standards.

More locally, the U.S. Environmental Protection Agency (EPA) identified agriculture as a potential pollution source in 13 of 58 impaired water sites in the Schuylkill watershed and 9 of 26 impaired sites in the Lehigh watershed (EPA 2000, www.epa.gov/iwi/303d/02040106_303d.html). Agricultural runoff in the Mid-Atlantic states can exert significant potential impact in at least half the state of Pennsylvania.

RESIDENTIAL USE AND QUALITY OF GROUND WATER IN PENNSYLVANIA

Pennsylvania's rural agricultural areas have faced another challenge: tremendous population growth. Eight of Pennsylvania's 10 most productive farming counties also accommodate the fastest-growing populations.

Water is a valuable resource for all these residents. Pennsylvanians use at least 1 billion gallons of ground water each day, with about half of that amount consumed as drinking water. Other uses of ground water in the state include industry, mining, and commerce.

Nationally, Pennsylvania ranks second in total number of wells. In 1990, southeastern Pennsylvania used the most ground water, led by Montgomery County and followed by Berks, Lehigh, Lancaster, and Bucks counties. Southeastern Pennsylvania also has the highest number of on-lot septic systems per square mile. These high numbers of wells for drinking water and on-lot septic systems for sewage disposal increase the likelihood of water pollution (ERS 2003).

Quality of ground water varies with location. Naturally occurring water quality problems include high concentrations of calcium, dissolved solids, iron, manganese, or hydrogen sulfide. Human activities may also reduce water quality. Nonagricultural sources of pollution include improperly maintained septic systems; nitrates and bacteria from sewage; improper disposal of household chemicals; improperly installed wells and casings; highway salt; leaking storage, chemical, and fuel tanks; landfill seepage; chemical spills; and many others.

Industrial, residential, and agricultural sources of contamination should be considered together in order to develop comprehensive and sustainable water resource management programs (Fleeger, 1999; Makuch and Ward 1986).

Some of Pennsylvania's most productive farming counties also accommodate the fastest-growing populations.

THE RODALE INSTITUTE®
Long-Term Trials

Concerns about the impact of conventional agricultural practices on human and environmental health prompted The Rodale Institute® to initiate long-term research and demonstration projects on regenerative/organic agricultural techniques.

The Rodale Institute Farming Systems Trial® was designed to demonstrate that regenerative agricultural practices can achieve and maintain high crop yields and improve soil health while reducing ground water pollution and greenhouse gas emissions. Three distinct farming systems were developed to evaluate different crop and soil management strategies and practices. Studies of carbon and nitrogen balances showed that good management of soil organic matter led to improved soil health, sustained high crop yields, and positive impact on the surrounding environment, including ground water reserves.

The Compost Utilization Trial was established by The Rodale Institute to develop best management practices for field scale compost use. Applications of five types of locally produced compost, raw dairy manure, and synthetic mineral fertilizer were compared. The various materials were applied to achieve the same rate of available nitrogen for crop plants. The chosen treatments utilized resources that are readily available to farmers in the Mid-Atlantic region.

These two trials have shown that nitrate leaching can be as much as two times greater when conventional farming methods are used as compared with organic practices. They have also shown that water infiltrates into organically managed soils at more than twice the rate of conventionally managed soils. Increased percolation of water into organically managed soil reduces surface water runoff, soil erosion, and silting of surface waters associated with conventional corn and soybean row crop agriculture.

Pesticide use in conventional corn production gave rise to positive tests for atrazine and metolachlor in water samples gathered from lysimeters (see page 15). Atrazine concentrations consistently exceeded levels that have been shown to cause amphibian abnormalities (0.1 ppb). In experimental areas where atrazine was applied two years in a row, concentrations occasionally exceeded the EPA drinking water limit (3 ppb) for the pesticide.

Results from these long-term comparative trials document and deepen our understanding of the ways in which regenerative/organic agricultural practices improve the sustainability of food systems in Pennsylvania and of how they positively affect water quality and the environment.

Temperature and turning requirements are monitored in compost as part of the organic certification process.

Understanding Biogeochemical and Water Cycles

Before taking a closer look at the research results from The Rodale Institute's long-term trials, it is important to understand biogeochemical and water cycles and their relationship to agriculture.

BIOGEOCHEMICAL CYCLES

Most living organisms, including people and plants, require water and nutrients in order to live, grow, and reproduce. Both water and nutrients, such as carbon, oxygen, nitrogen, and phosphorus, are made available by a complex combination of biological, geological, and chemical processes called biogeochemical cycles. Contaminants, such as pesticides and excess nutrients, can also enter into these cycles, usually carried by water.

Both agriculture and the quality of our water are powered by biogeochemical cycles. At the same time, agriculture uses more water and adds more contaminants to that water than most other sectors of society. Conventional agricultural food production, which currently accounts for 98 percent of our food supply, relies heavily on irrigation, pesticides, and synthetic fertilizers.

Recognition and understanding of the connection between agricultural practices and biogeochemical cycles is vital to the future quality and safety of our water, food supply, and environment. When pesticides and excess nutrients escape from agriculture into the Earth's water cycle, they often exit the cycle in the water that flows from our faucets.

THE WATER CYCLE

The water cycle (Fig. 1), also known as the hydrologic cycle, collects, purifies, and distributes the Earth's water supply. Saltwater accounts for 99.5 percent of our global water resource; only 0.5 percent of our total water supply is fresh water. Water makes up a large portion of most plants and animals. A child's body is approximately 75 percent water, and an adult's is about 50 to 65 percent water. Most vegetable plants require about 1 inch of water each week in order to produce a good crop, and an acre of clay loam soil, to a depth of 6

Recognition and understanding of the connection between agricultural practices and biogeochemical cycles is vital to the future quality and safety of our water, food supply, and environment.

inches, may hold more than 38,000 gallons of water.

While it may appear as if new water is created each time you turn on a tap, water is in fact a finite resource that is continuously recycled. Scientists believe that the amount of water in the world has remained fairly constant for the past 500 million years (Miller 1993).

Agricultural practices can interrupt the water cycle in the following ways:

1. Irrigation can deplete both surface and ground water supplies.

2. Poor management of livestock may lead to nutrient runoff, nutrient pollution, and bacterial or viral contamination of water sources.

3. Clearing vegetation from land often leads to soil erosion and contamination of surface and ground water supplies.

4. Soil tillage for seedbed preparation and weed control may result in increased soil erosion.

5. Adding amendments to crops—including pesticides, supplemental plant nutrients (such as nitrogen and phosphorus), or microbes (such as bacteria and viruses in manure and compost)—has the potential to pollute water via surface runoff, soil erosion, and ground water infiltration.

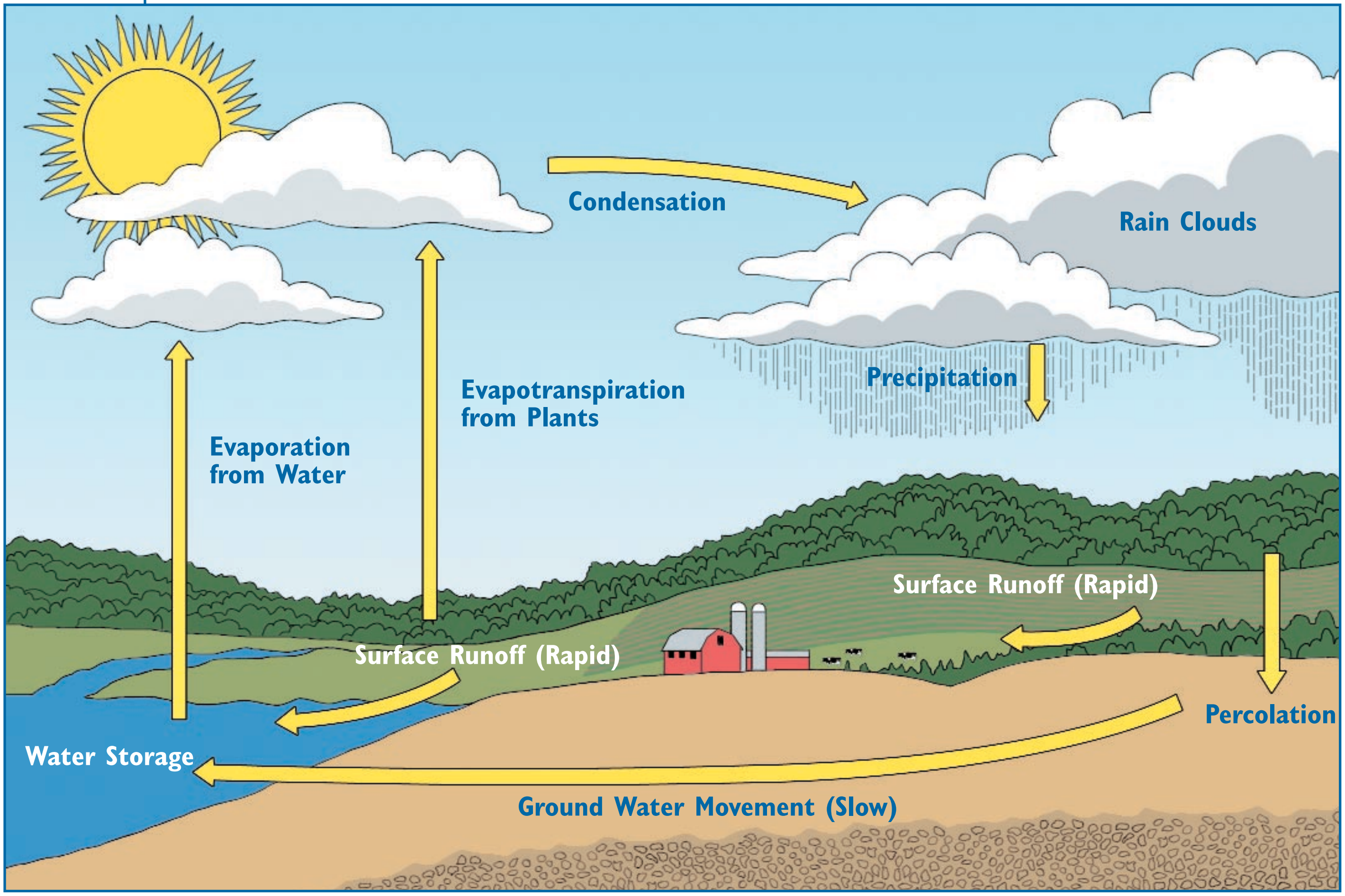


Fig. 1. The water cycle. In this simplified diagram of the water cycle, water moves within the oceans, the atmosphere, the land, and living organisms. It moves by evaporation, plant transpiration, condensation, precipitation, and infiltration. A large portion of water seeps into the soil surface, and some enters the ground water to recharge the supply. A process called run-in transports contaminants directly to ground water through sinkholes, porous or fractured bedrock, or poorly constructed wells. Leaching moves contaminants through the soil with rainwater, melting snow, and/or irrigation water. Water that moves over the soil surface—called runoff—may also transport contaminants with rainwater, melting snow, and/or irrigation water.

GROUND WATER

Most water can be classified as either surface water (in streams, rivers, lakes, and oceans) or ground water, which is located in underground rock formations called aquifers. Aquifers are composed of open spaces (pores) between soil grains and rocks, fractures, and other openings within rocks and rock layers that serve as water storage sites. Ground water found within 100 feet of the surface is called shallow ground water. Pennsylvania's soil and bedrock hold about 80 trillion gallons of fresh ground water, comprising almost 97 percent of the state's fresh water supply. Consequently, almost all of Pennsylvania's drinking water comes from ground water.

GROUND WATER MOVEMENT IN PENNSYLVANIA

Ground water flows by the force of gravity from collection areas on hills toward discharge areas in valleys, percolating through subsoil layers to recharge the ground water system. The greatest infiltration and recharging of ground water normally occurs during the spring and fall, when the ground is not frozen, there is sufficient rain, and evaporation and transpiration are low.

The rate at which ground water moves depends on elevation, pressure, rock permeability, and pore space. Compared with surface water, most ground water flows very slowly, on the order of feet per day rather than miles per day. In a sand and gravel aquifer with large pores, water can move 2 to 3 feet per hour, but movement through 1 inch of clay may take up to a year.

PENNSYLVANIA'S WATER BUDGET

Scientists use a water budget to track surface and ground water movement across geographic regions. The movement is measured in inches of water as spread over the surface of the entire state. In Pennsylvania, the average annual precipitation is 42 inches. It is fairly evenly distributed throughout the year but is slightly greater during May, June, and July, the same period during which many agricultural amendments are applied to crops.

About one-half, or 22 inches, of the total precipitation is returned to the atmosphere via evaporation or transpiration. Another 7 inches enters streams directly as runoff. The remaining 13 inches infiltrates the soil surface and becomes ground water.

About 6 inches of stream flow enters Pennsylvania from neighboring states, and 20 inches exits the state each year. For example, Lake Erie brings water to our shore from streams as far away

Water leaving Pennsylvania flows through or past 15 other states and two provinces of Canada before reaching the Atlantic Ocean or the Gulf of Mexico.

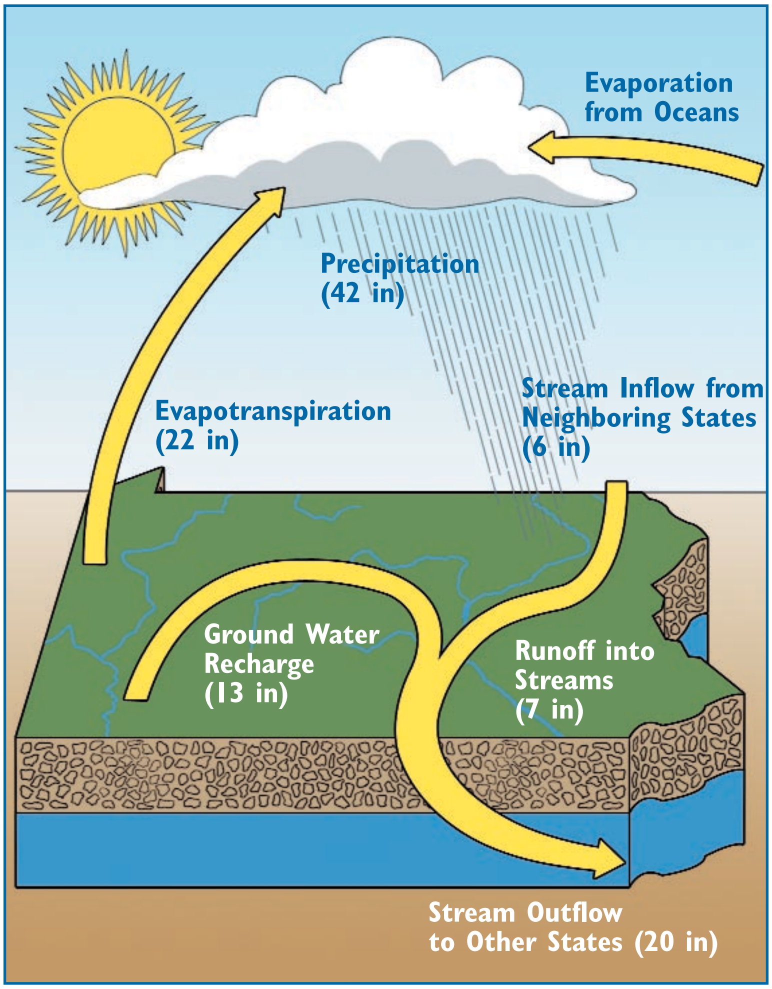


Fig. 2. Annual hydrologic budget for the state of Pennsylvania.

RECENT STUDIES ON WATER QUALITY AND HEALTH

In research conducted by Porter et al. (1999), two species of mice were given water that contained agricultural chemicals, including mixtures of an insecticide (aldicarb), a herbicide (atrazine), and a fertilizer (nitrate), at levels found in drinking water in Wisconsin. When the amendments were consumed individually, negative health effects were minimal or absent in the mice. When amendments were consumed in mixtures, however, health effects were significant. Ingestion of mixtures of pesticides plus nitrate-nitrogen had a negative effect on aggression, body weight, thyroid function, antibody production, and spleen weight. These are important indicators of general health in animals.

as Minnesota (Fig. 2). At the same time, water leaving Pennsylvania flows through or past 15 other states, the District of Columbia, and two provinces of Canada before reaching the Atlantic Ocean or Gulf of Mexico. Contaminants can easily enter or leave the state through this type of water movement (Fleeger 1999; Makuch and Ward 1986).

AGRICULTURE AND THE WATER CYCLE

Pennsylvania farmers are changing. The total number of farms has decreased from 222,000 in 1910 to 59,000 in 2002. The remaining agricultural enterprises are concentrated in the southeast and tend to center on intensive animal production.

Concentrated animal operations are capital-intensive systems that use large scale facilities, imported feeds, and automated technology. These operations are less diversified than traditional land based production, housing thousands of animals instead of only hundreds. More animals produce more manure, and increased manure handling, storage, and land application can result in increased water pollution and production costs.

Concentrated animal production favors corn and soybean row crop production instead of small grains and pasture. As a result, in Pennsylvania, production of small grain crops, such as oats, wheat, and barley, has steadily declined since the 1960s. For example, between 1962 and 2000, the number of acres in oat production decreased by 72%, while acres in corn production increased by 32%. Unfortunately, corn and soybean row crops have a greater potential than small grain crops and pasture for soil erosion, nutrient losses to surface water, pesticide runoff, and ground water contamination by pesticides and nutrients.

Ruminant animals, such as dairy cows, thrive best on forages. Grain-based diets have been shown to negatively impact animal health and nutrition, increasing veterinary costs and reducing the nutritional quality of the meat and milk produced. Adoption of more diversified agriculture systems can restore natural animal behavior, reduce production costs, and increase nutrition while reducing environmental impacts.

Nitrogen, Phosphorus, and Pesticides as Water Contaminants

NITROGEN

Nitrogen is an essential nutrient that crops require in large quantities for proper growth. It helps plants trap energy from sunlight and serves as a fundamental component of proteins and nucleic acids. Consequently, nitrogen fertilizers are applied to cropland in larger amounts than any other plant nutrient.

Most crops receive nitrogen as synthetic fertilizer, about 99 percent of which is created through the Haber-Bosch process. In this method, ammonia is synthesized from hydrogen gas and atmospheric nitrogen. The resulting liquid ammonia can be used directly or further processed into other liquid or solid forms of nitrogen fertilizer, such as ammonium nitrate, urea, and ammonium sulfate. The Haber-Bosch process requires temperatures of 750° to 1250° F and pressures of 200 to 400 atmospheres, demanding large amounts of energy from fossil fuels (usually natural gas) to provide the high heat and pressure. Thus, the price of synthetic fertilizer often fluctuates with the price of natural gas.

Synthetic nitrogen fertilizers make nitrogen available to crops very quickly and for a relatively short period of time. Alternately, natural organic materials (such as composts and manures) release nitrogen over a long period of time because they must be transformed into nitrate (NO_3^-) and ammonium (NH_4^+) ions by soil microbes before plants can use them. Of these organic materials, leguminous green manures and raw animal manures release nitrogen more quickly than composted manures. Therefore, composted manure must be applied at a higher rate than raw manure or legume cover crops to meet the short-term nitrogen demand of the crop.

Nitrogen applications from all sources (synthetic and organic) should always be carefully calculated and applied according to the nitrogen requirements of the crop and the existing nutrient content of the soil. In both conventional and organic agricultural systems, nitrogen can easily be over-applied if crop requirements and soil nutrient status are not assessed. This can reduce the profitability of the crop (especially if nitrogen sources are purchased off the farm) and pollute the surrounding environment and water. Besides being vulnerable to loss to surface and ground water, nitrate can convert into nitrous oxide greenhouse gas when soils are saturated with water and available oxygen is low in soils. This conversion of

Animal manure is the primary agricultural source of nitrogen and phosphorus in water.

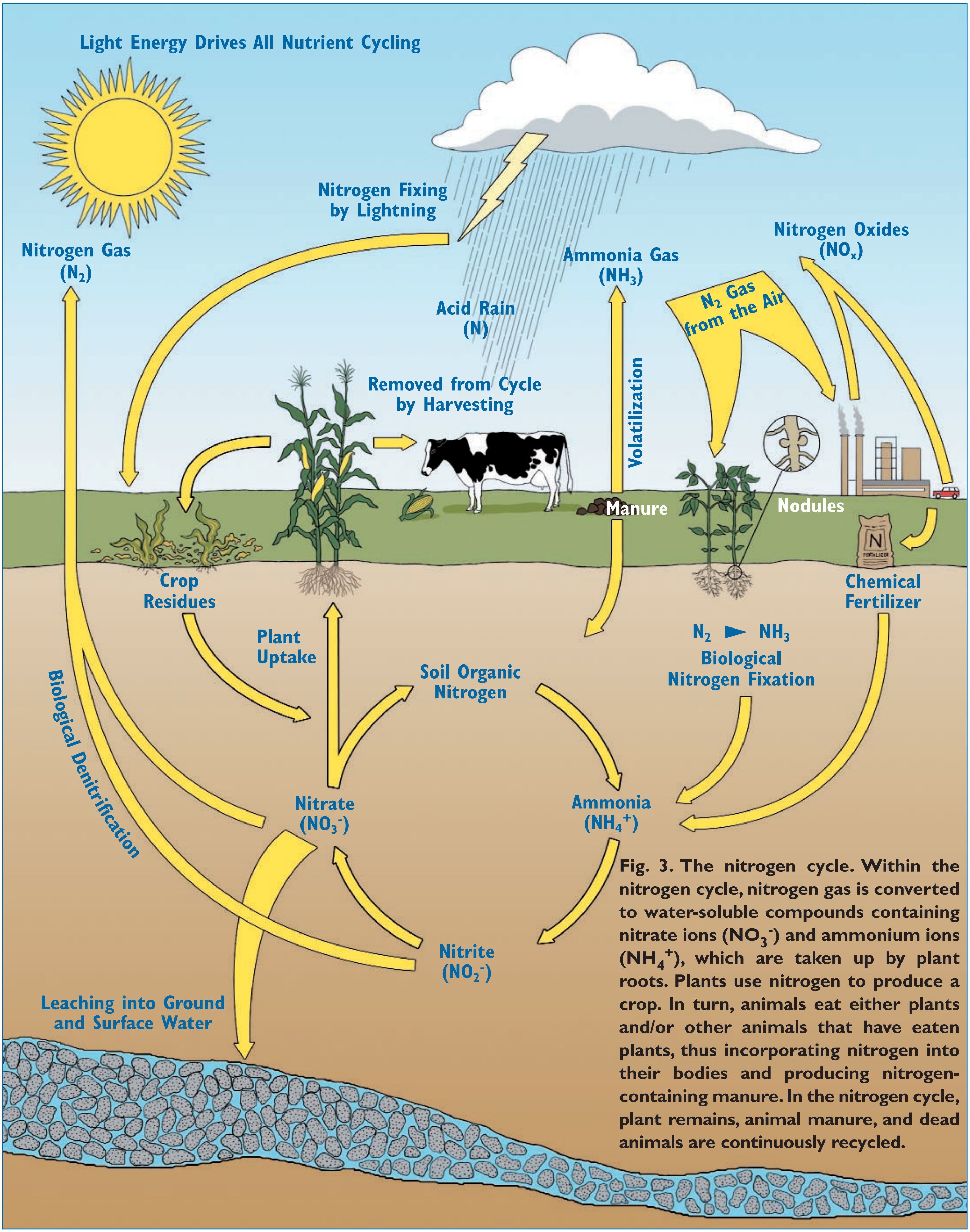


Fig. 3. The nitrogen cycle. Within the nitrogen cycle, nitrogen gas is converted to water-soluble compounds containing nitrate ions (NO_3^-) and ammonium ions (NH_4^+), which are taken up by plant roots. Plants use nitrogen to produce a crop. In turn, animals eat either plants and/or other animals that have eaten plants, thus incorporating nitrogen into their bodies and producing nitrogen-containing manure. In the nitrogen cycle, plant remains, animal manure, and dead animals are continuously recycled.

nitrate to nitrous oxide gas, called denitrification, is another important source of soil nitrogen losses and can contribute to alteration of the atmosphere. (For more information, see "Nitrogen and Phosphorus Contamination" on page 13.)

Only about 50 percent of the nitrogen applied as synthetic fertilizer is absorbed and used by crop plants. As the nitrate content of soil rises, loss of nitrate to surface and ground water can accelerate, especially when fields are subjected to heavy precipitation and/or irrigation. Soils that are high in organic matter, however, retain greater amounts of nitrogen without leaching it to ground and surface water. Landscapes with permanent plant cover also tend to reduce leaching of nitrates and other nutrients.

Calculations for chemical nitrogen fertilizer applications are based on historic yield goals for soils in the region where the crop is grown. For corn, for example, a pound of nitrogen per acre is applied for each bushel of corn harvest expected (i.e., 130 pounds of nitrogen is applied for a yield goal of 130 bushels of corn per acre). It is important to note, however, that these calculations are only estimates, and actual crop growth and yield are greatly influenced by weather during the growing season, which is difficult to predict.

Application rates for composts and raw manures can also be calculated using the same guidelines, based on a nutrient analysis of the manure or compost. The availability of nitrogen from these organic sources (quantity and time of release through mineralization) can be more difficult to predict and control, however, because mineralization is a biological process governed by the environmental conditions in the soil, the presence of the appropriate soil organisms, and the composition of the nitrogen-containing material.

The advantage of organic sources is that they release their nitrogen slowly, making the nutrient available to the crop throughout the growing season, while synthetic sources can be exhausted within a few days or weeks after being applied. Organic sources are also more effective in building nitrogen content in the soil.

RECENT STUDIES ON WATER QUALITY AND HEALTH

Guillette et al. (1998) conducted a comparative study of development in four- and five-year-old children from two distinct areas of Mexico. The first group lived in an agricultural valley and was frequently exposed to pesticides. The second group lived in a nearby nonagricultural region and was not exposed to pesticides. Due to the neighboring geographic regions, the children shared similar genetic backgrounds, diets, water, mineral nutrition, cultural patterns, and social behavior. When the two groups were compared, no difference was found in physical growth patterns, but the children who were exposed to pesticides demonstrated decreased stamina, gross and fine eye-hand coordination, 30-minute memory, and the ability to draw a person.

Nitrogen contribution from leguminous green manures depends on the amount of green matter (biomass) produced by the crop. Biomass production varies from year to year, based on weather and other growing conditions. Thus, adjusting the time when the legume is plowed into the soil, mowed, rolled, or killed chemically can regulate legume nitrogen inputs. This practice controls the amount of biomass that is incorporated into the soil, limiting its nitrogen release. Legume-based nitrogen inputs can also be controlled by planting a smaller amount of legume seed mixed with a grassy cover crop, such as winter rye, resulting in biomass that is lower in nitrogen content. Grassy cover crops can also immobilize soluble nitrogen.

In both conventional and organic agricultural systems, excess nitrogen that is not taken up by plants is vulnerable to leaching into ground water. Even the best, most careful management techniques can result in nitrogen loss due to extreme weather. Heavy rains can wash nitrogen away before plants are able to utilize it. Also, in drought years, the stunted growth of primary crops leaves unused nitrogen in the soil to leach during fall, winter, and spring (Fig. 3).

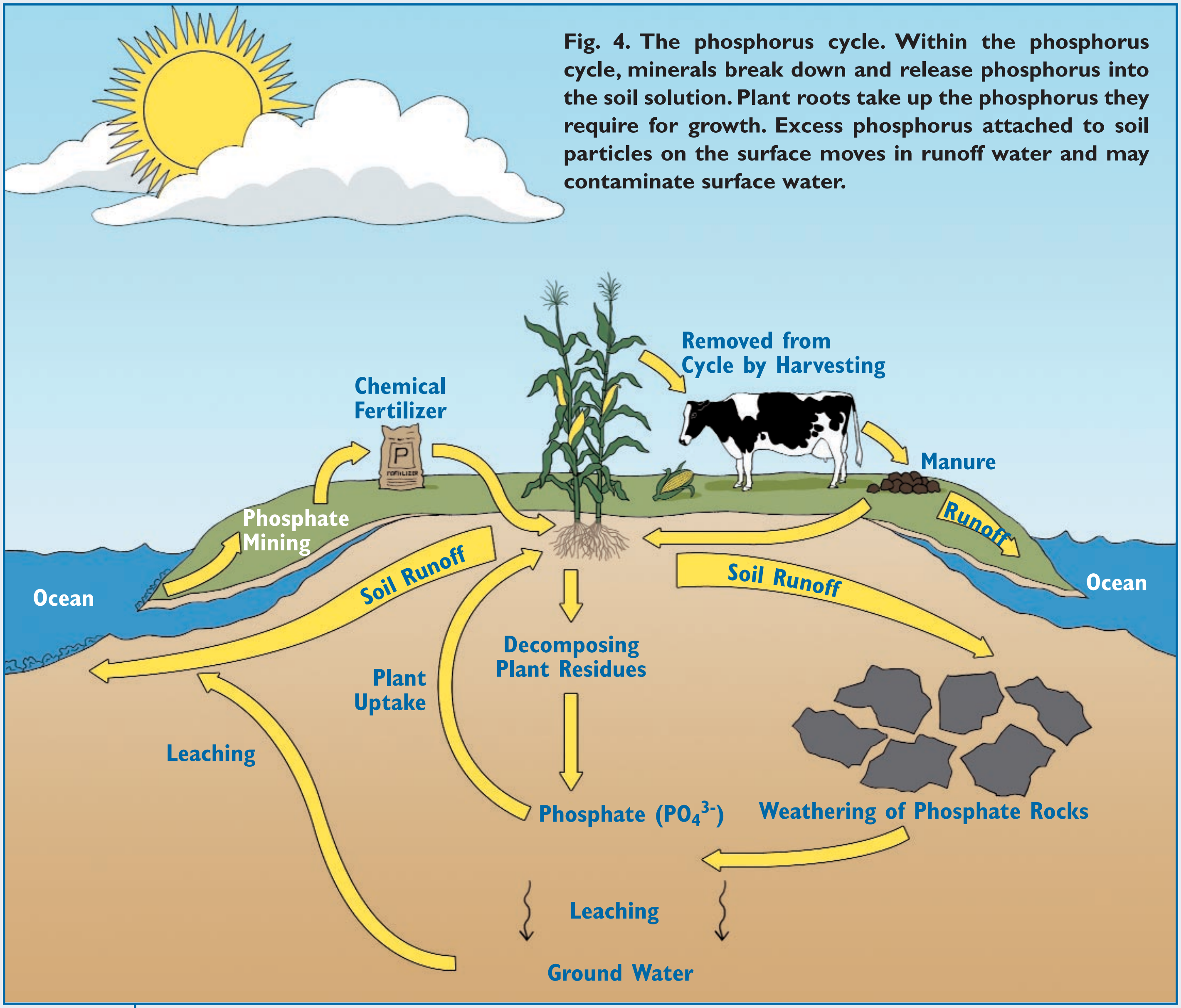


Fig. 4. The phosphorus cycle. Within the phosphorus cycle, minerals break down and release phosphorus into the soil solution. Plant roots take up the phosphorus they require for growth. Excess phosphorus attached to soil particles on the surface moves in runoff water and may contaminate surface water.

PHOSPHORUS

Phosphorus is another nutrient that is essential to plant growth and development, working in concert with nitrogen to facilitate the plant's use of energy captured from sunlight. Phosphorus stimulates root growth, aids in the distribution of energy within plants, assists in protein synthesis, and helps to promote seed development. Root branching and formation of root hairs increase through the plant's effort to find and tap soil-bound sources of phosphorus. Based on its stimulation of healthy root development, phosphorus is vital for supporting the early plant growth and maintaining plant vigor throughout the growing season.

Most phosphate fertilizer is derived from mined phosphate rock deposits. Nearly all phosphate rock is sedimentary material, deposited on the ocean floor and then uplifted onto landmasses over millions of years. When the rock is mined for use as fertilizer, it is "upgraded" by removing impurities and then ground into fine particles called rock phosphate. Rock phosphate can be applied directly to the soil in this form, but nowadays it is usually treated with sulfuric acid to make it more soluble (super phosphate).

Organic phosphorus sources include decaying

NITROGEN AND PHOSPHORUS CONTAMINATION

Nitrogen and phosphorus are two major contaminants of surface and ground water in Pennsylvania. In 2001, the state's farmers applied 130,000,000 pounds of nitrogen to 98 percent of corn acreage (Less 2001; USDA 2002) and about 56,000,000 pounds of phosphorus to 79 percent of corn acreage. In southeastern Pennsylvania, animal manure is the primary agricultural source of both nitrogen and phosphorus contamination in water. In particular, concentrated animal feeding operations and livestock pastured near streams are important sources of nitrogen contamination. Not surprisingly, some of the highest levels of nitrogen occur in streams and ground water in agricultural areas, according to a 1999 U.S. Geological Survey (USGS) report.

Nutrient contamination of water resources poses a threat to both local and regional health. For example, agriculture throughout the Chesapeake Bay watershed—which includes Pennsylvania, Delaware, Maryland, New York, West Virginia, Virginia, and the District of Columbia—accounts for 40 percent of nitrogen pollution to the bay (Chesapeake Bay Foundation 2003). Nonagricultural sources, such as septic and sewage treatment plant leakage and fallout from the atmosphere, contribute to nitrogen and phosphorus contamination, too (USDA 2001). Other nonagricultural uses of nutrients, including use on golf courses and home landscapes, are less significant sources of pollution (EPA (3) 2002; USGS 1999).

When nitrogen or phosphorus pollutes surface waters such as the Chesapeake Bay, algae grow at an accelerated rate. Excessive algae, or algal blooms, cloud surface waters and prevent sunlight from reaching native underwater grasses. In addition, algal blooms rob water of oxygen, leading to fish kills, clogged water pipelines, and diminished use of surface waters for recreation (Chesapeake Bay Foundation 2003; USDA 2001).

Nitrates in drinking water may cause serious illness or death. In compliance with the Safe Drinking Water Act, the U.S. Environmental Protection Agency (EPA) has established a Maximum Contaminant Level (MCL) of 10 ppm of nitrates in drinking water. The MCL for nitrites is 1 ppm. Infants and the elderly are particularly susceptible to methemoglobinemia (blue baby syndrome), a disease in which high nitrate levels in the body prevent the transport of sufficient oxygen through the bloodstream. In all individuals, long-term exposure to nitrates and nitrites at levels above the MCLs may cause increased urination, increased starchy deposits in the kidneys, and hemorrhaging of the spleen. Livestock may also suffer from exposure to high levels of nitrates and nitrites in drinking water.

MCLs have not been established for dissolved phosphorus in streams or ground water, nor for total phosphorus or total nitrogen in streams. However, the EPA has established a desired goal of 0.1 milligram per liter (mg/L) of total phosphorus to prevent nuisance plant growth in streams and other flowing waters that do not discharge directly to lakes or impoundments (USGS 1999). Animal manures tend to have high concentrations of phosphorus, and misapplication of manure can overly enrich soils surrounding intensive animal operations.

manure, plant residues, and other organic matter in the soil. A small amount of phosphorus also comes from weathering and erosion of phosphate rocks in the soil.

Phosphorus must dissolve in the soil water before plants can use it in the phosphate form. Unlike nitrogen, which can be abundant in the soil water, dissolved phosphorus quickly binds to soil particles. Because of this characteristic, it is not very mobile in the soil. In fact, a plant may not be able to access and use phosphorus that is located as little as 1/4 inch away from its roots. For the same reason, phosphorus is not easily leached with drainage water. Massive amounts can be lost, however, when soil particles are carried away across the soil surface with runoff water. Sediment runoff is the most serious source of phosphate contamination in waterways.

Long-term additions of phosphate fertilizers and manure result in a buildup of soil phosphorus, adding to the potential for losses through erosion and runoff. Therefore, as with applications of nitrogen, all farmers must calibrate their phosphorus applications according to their crop requirements, in conjunction with annual soil tests.

Mycorrhizal soil fungi, which tend to be more plentiful and active in organically managed soils, help to mobilize phosphorus through their symbiotic growth and development with the plant roots. Roots and their associated mycorrhizae can explore more than 1,000 times more soil area than non-mycorrhizal roots, increasing their ability to absorb phosphorus. Due to the presence of these fungi, organic systems generally do not need to incorporate additional phosphate fertilizers (Fig. 4).

PESTICIDES

Pesticides are another major agricultural contaminant that can affect water quality. The term *pesticide* applies to insecticides, herbicides, fungicides, and antimicrobials. They are used in conventional chemical agricultural systems to kill or disrupt weeds, insects, fungi, and bacteria. Due to their mobility and solubility in water, pesticides can also negatively affect non-target organisms, including wildlife and humans, as they accumulate in the soil and leach into ground and surface water surrounding farmlands on which they are applied. (These effects are described more fully in Appendix B.)

Pesticide leaching and contamination can be eliminated entirely in areas around organic and sustainable farms where pesticides are not applied. However, agricultural systems that continue to use pesticides can also reduce their negative impact on the environment through good management practices, such as timely and minimal application only when the target pest is present at thresholds that result in economic damage to the crop plants.

Exposure to pesticides may lead to a complex array of health problems in people and animals, affecting the nervous, immune, endocrine, and reproductive systems. Effects can include asthma, early onset of menstruation, chemical sensitivities, and behavioral changes, such as increased aggression, attention deficit disorder, and hyperactivity disorders in children. Exposure to pesticides may also cause tumors, cancer, genetic mutations, or birth defects. Health effects vary with the pesticide product, dose, and method of exposure (orally, by inhalation, or through skin contact).

Effects of agricultural chemicals on aquatic organisms can be observed in many agricultural areas, although the EPA has not set herbicide contamination regulations to protect aquatic life.

Pesticides commonly used in Pennsylvania agriculture have been found in drinking water, sometimes at levels above regulatory thresholds.

Long-Term Field Trial Results

The Rodale Institute Farming Systems Trial® (FST) was started in 1981 and is an ongoing 12-acre field experiment that compares conventional and organic corn and soybean production systems. The research results include information on yields, economic returns, and environmental data from three systems (Petersen et al. 1999). In 1993, investigators initiated a related experiment, the Compost Utilization Trial (CUT) designed to assess the long-term effects of composts, manure, and conventional fertilizer on crop performance, soil quality, farm economics, and the environment. The objective was to learn more about how farmers can use compost in regenerative cropping systems (Reider et al. 2000). (See "Highlights from the Rodale Institute Farming Systems Trial® and Compost Utilization Trial" on page 18 for a summary of results.)

In addition to the primary objectives, the FST and CUT experiments have yielded useful information on the impact of agricultural practices on water quality. Lysimeters, devices that collect water that moves through the root zone, were installed in FST and CUT to collect water samples, or leachate, for analysis (Fig. 5). From 1991 to 2003, samples were collected 15 to 20 times annually (year-round) from the lysimeters.

FINDINGS FROM THE RODALE INSTITUTE FARMING SYSTEMS TRIAL®

Water samples were evaluated for concentrations of nitrate-nitrogen, soluble phosphorus, and four herbicides in three farming systems (Fig. 6):

1. Manure-based organic system (MNR). This system simulated a mixed farming operation including both crops and livestock. In this system, manure from the livestock operation and legume crops were primary sources of crop nutrients. The five-year rotation included corn grain, soybeans, corn silage, wheat, and red clover/alfalfa hay.

2. Legume-based organic system (LEG). In the "cash-grain" rotation, corn, soybeans, and wheat were grown as the primary income source, and a leguminous green manure provided nitro-

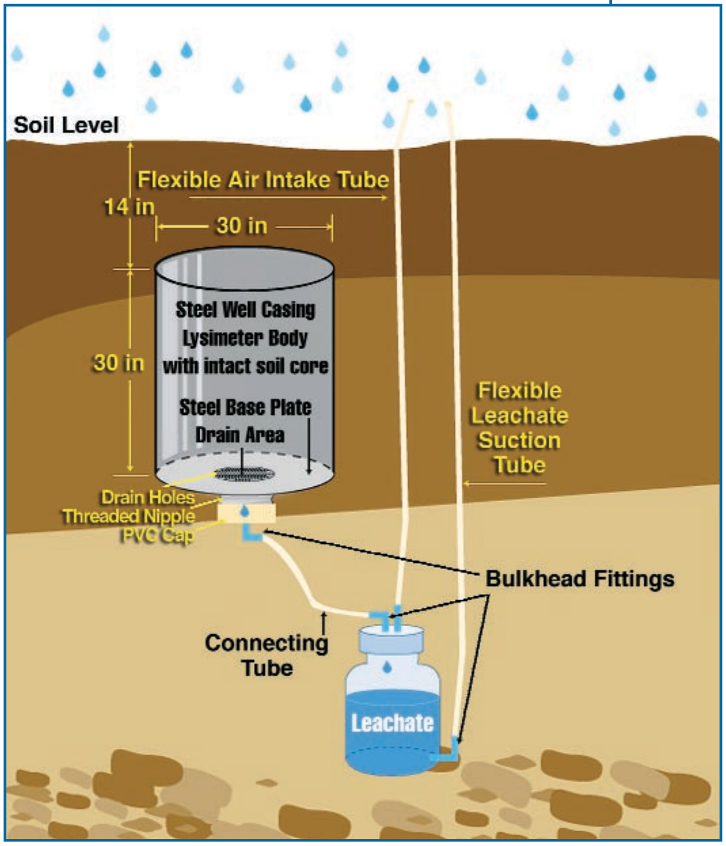


Fig. 5. Intact soil core lysimeter design. In FST and CUT, lysimeters were used to collect water from soil below the rooting depth of crops. A lysimeter resembles a large, underground, steel flowerpot with a hole in the bottom for collecting water—called leachate—that has drained away from the crop planted above it. During installation, soil layers inside the pot remained undisturbed. The soil surface area of each lysimeter was 5 square feet; soil depth was 44 inches (Moyer et al. 1996).

gen without any reliance on animal manure. The system featured a diversified rotation. In both organic systems, no synthetic fertilizers or pesticides were used. Instead, cultivation and crop rotation were used to control weeds, and on-farm biological processes released crop nutrients from legumes and manure.

3. Conventional system (CONV). This system represented a conventional corn-soybean row crop rotation that depended on synthetic fertilizers and herbicides for nitrogen and weed control. Fertilizers and pesticides were applied according to current recommendations of the Penn State Cooperative Extension Service. Cover crops were not part of the rotation.

FST Nitrates

Overall, nitrate-nitrogen concentrations in the FST leachate varied throughout the year (between 0 and 28 ppm). Concentrations were usually highest in June and July, shortly after fertilizer applications or plow-down of manures. Increased soil microbial activity during the growing season may also have contributed to losses of nitrate in all of the systems.

Water leachate samples from the CONV system most frequently exceeded the legal limit of 10 ppm for nitrate concentration in drinking water. Twenty percent of the CONV samples were above 10 ppm, while 16 percent of the samples from the LEG system and only 10 percent of the samples from the MNR system exceeded this limit.

Over the 12-year period of monitoring (1991–2002), all three systems leached 14 to 16.5 pounds of nitrate-nitrogen per acre per year. This rate was low when compared with results from similar experiments in which nitrate-nitrogen leaching was between 27 and 130 pounds per acre per year (Fox et al. 2001, Power et al. 2001). When measuring these losses as a percentage of the nitrogen originally applied to fertilize the field, the LEG system lost the most nitrate-nitrogen (32 percent). The MNR and CONV systems both lost about 20 percent of the applied nitrogen.

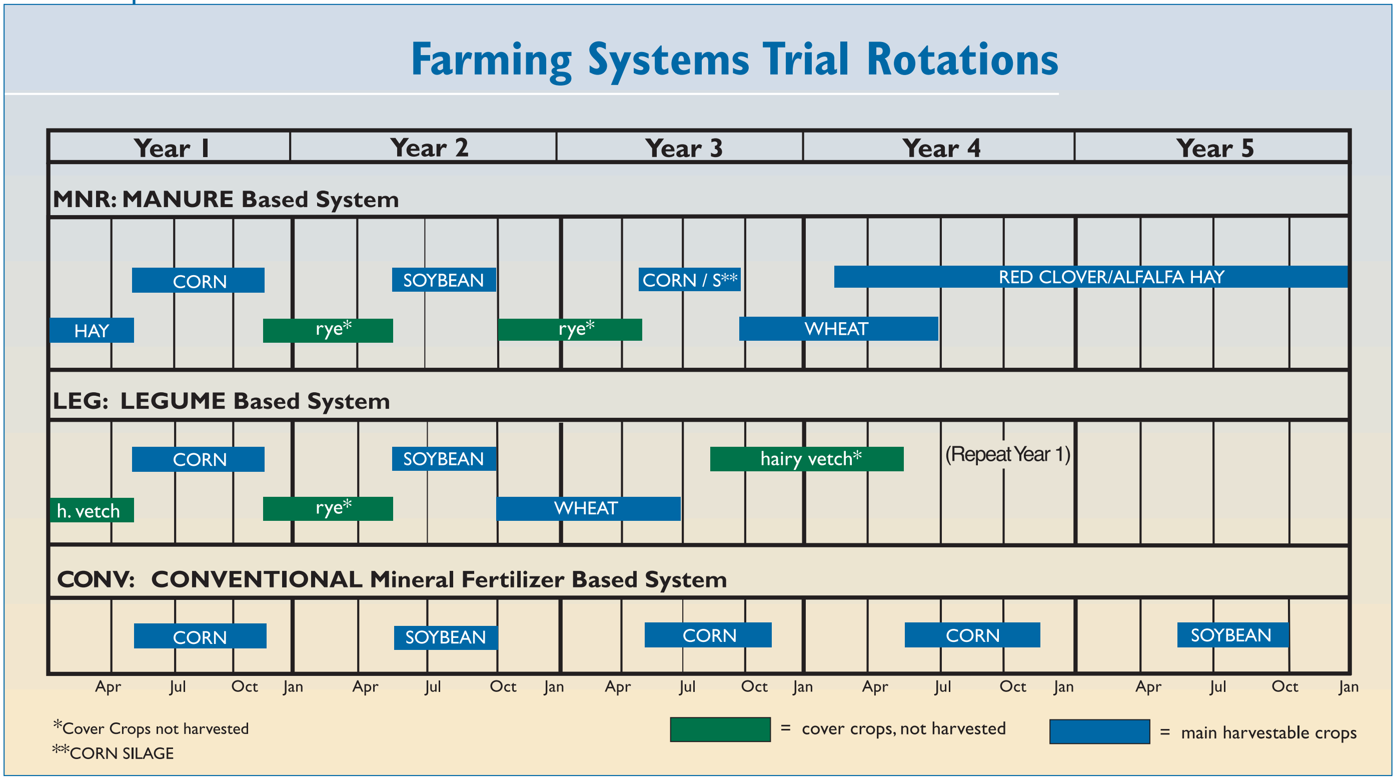


Fig. 6. Crop rotation of The Rodale Institute Farming Systems Trial®, Kutztown, PA.

However, the high nitrate leaching rate in the LEG system was not steady over the entire period of the study; instead, it occurred episodically during a few years of extreme weather. For example, in 1995 and 1999, the hairy vetch green manure supplied approximately twice as much nitrogen as needed for the subsequent corn crop, making excess nitrogen in the soil available for leaching. In 1999, the heavy nitrogen input was followed by a drought that stunted crop growth and decreased the crops' demand for nitrogen. In both years, these nitrogen-rich soils were also subjected to unusually heavy fall and winter rainfall that leached the excess nitrogen into the lower soil layers (Fig. 7).

FST Phosphates

Leachate samples from 2002 were analyzed for ortho-phosphate, the water-soluble part of phosphates. Concentrations of ortho-phosphate in the FST leachate were generally very low (around 0.03 ppm), and total losses were less than 0.1 pound per acre per year. The MNR system lost the largest amount of ortho-phosphate, followed by the LEG and CONV systems, which were not statistically different from each other.

The differences in phosphate losses may be explained by the systematic application of phosphate-containing manure to the MNR system. The LEG system received no phosphate additions, and the CONV system received only small amounts as starter fertilizer for corn.

FST Pesticides

During the project period, the following herbicides were applied to the conventional plots: atrazine, metolachlor, and pendimethalin to corn crops and metolachlor and metribuzin to soybean crops.

From 2001 to 2003, atrazine and metolachlor were detected in water leachate samples collected in the CONV system but were absent in samples collected from both organic systems (Fig. 8). Metribuzin and pendimethalin always fell below the detection limit of the analysis equipment.

In the CONV system, atrazine concentration in all water samples exceeded the level (0.1 ppb) that has been shown to produce adverse effects in amphibians (Hayes et al. 2002).

In the CONV corn-after-corn plots, where

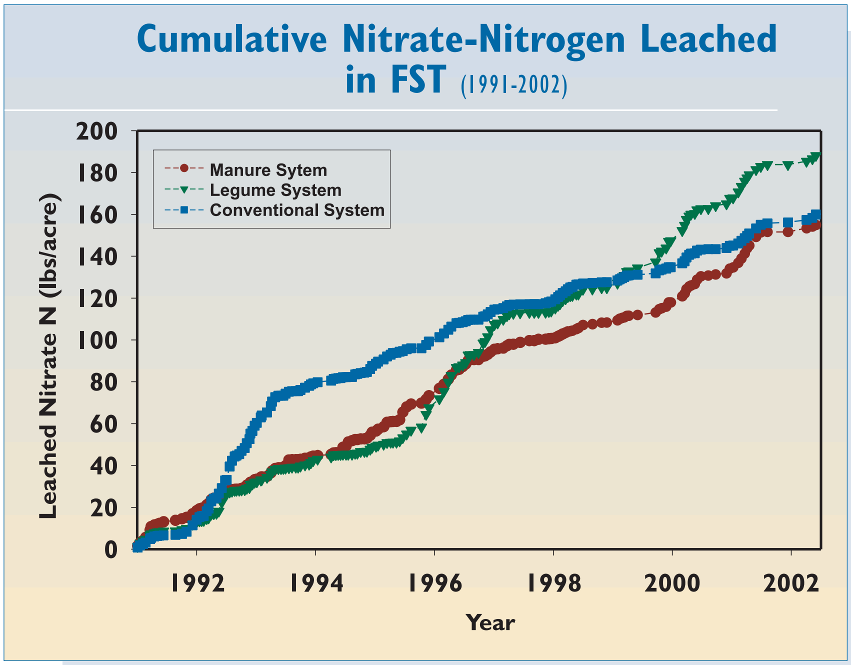


Fig. 7. Nitrate leachate from The Rodale Institute Farming Systems Trial®, 1991-2002. Over the 12-year period of monitoring, all three systems of FST had similar losses of nitrate-nitrogen. The LEG system had higher leaching rates in years of extreme weather, when high nitrogen inputs in the spring were followed by dry summers and heavy rains in the fall and winter.

HIGHLIGHTS FROM THE RODALE INSTITUTE FARMING SYSTEMS TRIAL® AND THE COMPOST UTILIZATION TRIAL

1. Organic amendments and soil management practices are as viable and effective as conventional chemical fertilizers for promoting crop growth and yield. Cover crops, composts, and raw manure can produce yields competitive with those of synthetic mineral fertilizer. In FST and CUT, organic and conventional systems produced similar grain yields, equivalent to or greater than local county yield averages.

2. Crops in organic systems exhibited less drought stress. In drought years, corn and soybean crops grown under organic management produced significantly higher yields than crops grown with chemical inputs. These findings may be attributed to the higher carbon content of organically managed soils, which allows the soil to better absorb and retain water.

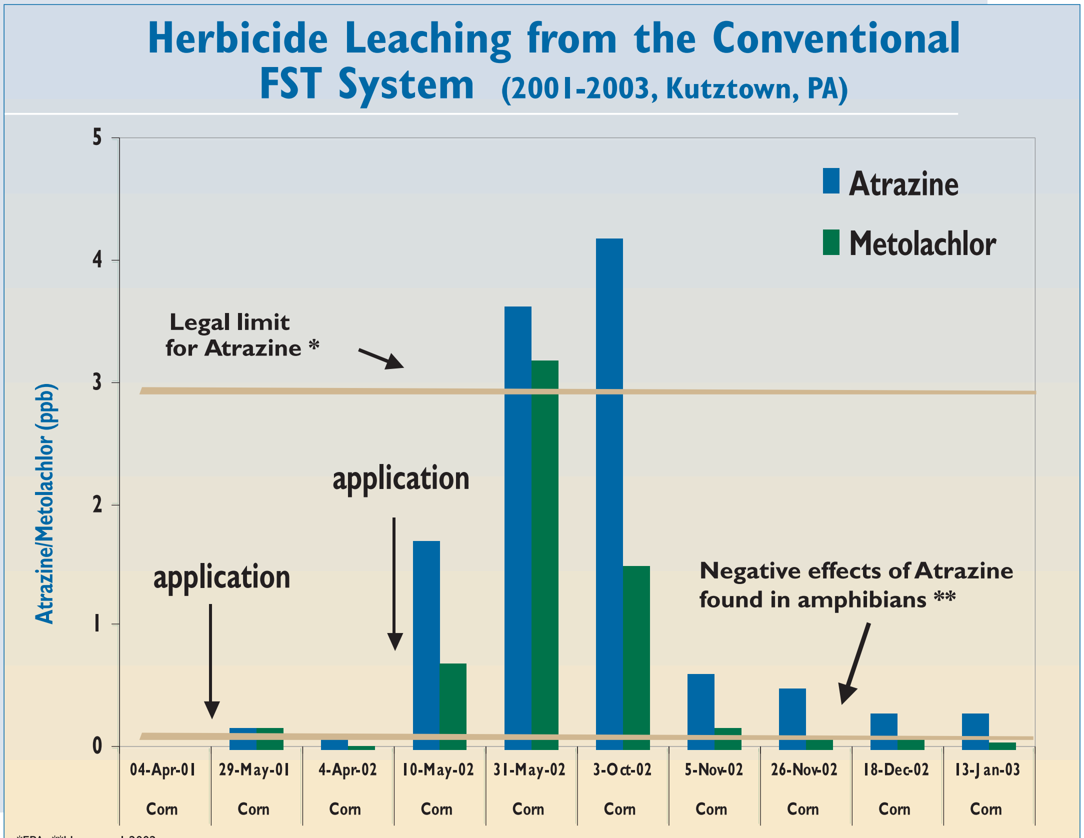
3. Organic management helped to improve biological and physical properties of soil. Soil carbon and nitrogen levels increased notably in the organic systems, while they changed little or decreased in the chemical systems. Other key indicators of soil quality, such as water infiltration and microbial diversity and activity, were enhanced in the organic systems. Improved soil biological and physical properties are associated with reduced runoff, greater water retention, and greater soil aggregate stability.

4. Organic systems were economically superior. Even without organic price premiums, the organic grain rotation produced net returns per acre comparable to those of the conventional grain rotation. However, about 33 percent more labor was required for the organic system. When the extra labor was included, a 6 percent organic price premium would be necessary to make the system competitive. Since organic grain price premiums currently run about 40 to 267 percent higher than those of chemically grown grain, actual profits from the organic systems were significantly greater.

5. Organic systems were more energy efficient. They typically used about 37 percent less energy than the chemical system.

6. Over-application of crop nutrients can be a problem in all agricultural systems. For example, excessive legume cover crops, compost, manure, or chemical fertilizer inputs can increase soil nitrogen content, leading to leaching and nitrate contamination of water. All agricultural systems must monitor soil nutrient status, input levels, and crop nutrient requirements.

7. There are many ways to manage crop nutrients in agricultural systems. For example, grass cover crops, composted manure, and proper input adjustment can easily reduce nutrient leaching and runoff in all agricultural systems.



*EPA **Hayes et al. 2002

Fig. 8. Detection of herbicides in The Rodale Institute Farming Systems Trial® during the period 2001–03. Atrazine and metolachlor were detected in leachate samples collected in the conventional system but were absent in samples from both organic systems. In plots where atrazine was applied two years in a row, concentrations always exceeded the level that has been shown to produce adverse effects in amphibians (0.1 ppb) and occasionally exceeded the EPA limit of atrazine in drinking water (3 ppb).

atrazine was applied two years in a row, atrazine concentration in leachate samples occasionally exceeded 3 ppb (the MCL set by the EPA for drinking water), which was higher than in the corn-after-soybean plots.

Metolachlor was also detected as a persistent ground water contaminant in the CONV system at 0.2 to 0.6 ppb, similar to atrazine detections, with occasional peaks of 3 ppb when metolachlor was applied two years in a row in corn-after-corn plots. However, the EPA has not yet established an MCL for metolachlor in public drinking water or in other areas of the environment.

FINDINGS FROM THE COMPOST UTILIZATION TRIAL

Researchers designed CUT to evaluate five types of compost, raw dairy manure, and chemical fertilizer in a three-year crop rotation of corn, vegetables (peppers or potatoes), and wheat (Fig. 9). Water samples were evaluated for nitrate-nitrogen and soluble phosphorus in response to the application of four nutrient sources:

1. Broiler litter and leaf compost. Broiler litter (chicken manure with sawdust bedding) was composted with leaves.

2. Dairy manure and leaf compost. Dairy manure and bedding (straw and/or newspaper) were composted with leaves.

3. Raw dairy manure. Fresh dairy manure and bedding (straw and/or newspaper) were applied without composting.

4. Conventional fertilizer. Synthetic fertilizer (30-30-10 NPK) and liquid nitrogen were applied to corn. Peppers received only liquid nitrogen, and potatoes received liquid nitrogen and phosphorus.

Pesticides were not applied in CUT, so no sampling for pesticides was conducted.

CUT Nitrates

During the nine-year monitoring period (1994–2002), overall nitrate-nitrogen losses were

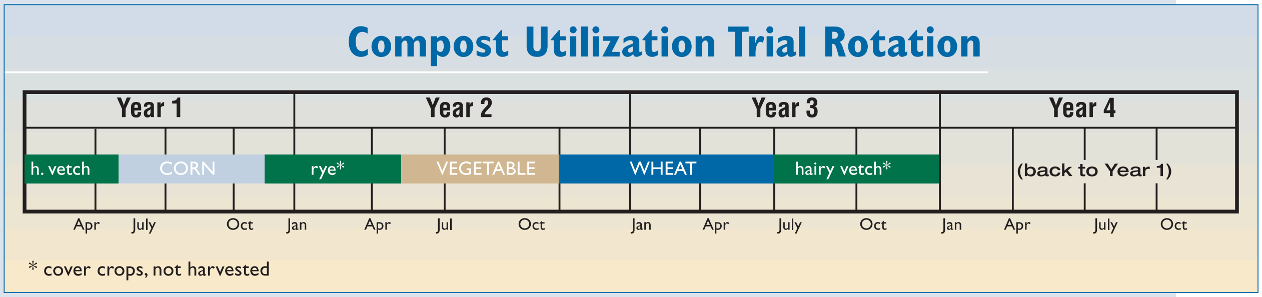


Fig. 9. Crop rotation of the Compost Utilization Trial.

between 4 and 11 pounds per acre per year. Compost treatments lost about 4 percent of the nitrogen that was applied to the crops, while raw manure and conventional fertilizer lost about 9 percent.

From 1994 to 1998, overall nitrate-nitrogen losses were very low (1.6 to 5.3 pounds per acre per year). During those years, raw dairy manure and conventional fertilizer lost the highest amounts of nitrate.

The nitrate-nitrogen leaching rates increased significantly when the crop rotation was changed in 1998. Hairy vetch was introduced before the corn crop in the rotation to replace the other fertilizer amendments (compost, raw manure, or chemical fertilizer) and to serve as a nitrogen source. (The other nitrogen amendments continued to be applied to the vegetable crop in the rotation, and the wheat crop received no nitrogen inputs.) In the following years (1999–2002), the nitrate-nitrogen leaching rate increased 3.5 to 6 times across all the treatments (Fig. 10).

RECENT STUDIES ON WATER QUALITY AND HEALTH

Swan et al. (2003) noted inferior sperm quality in rural men from the Midwest compared with that of men from urban areas. When the sperm of 512 men in Columbia, Missouri, and the urban areas of Minneapolis, New York City, and Los Angeles were evaluated, the Missouri men averaged 113 million motile sperm per sample (a very low count). The counts of the Minneapolis, New York, and Los Angeles men were 201, 192, and 162 million respectively. The researchers hypothesized that agricultural chemicals were to blame. The Columbia area is heavily agricultural, with 57 percent of the land used for farming, while the other study areas support little or no farming.

These results illustrate the importance of assessing and monitoring soil nutrient content and crop requirements before adding conventional or organic nitrogen inputs, in order to reduce nutrient leaching potential.

CUT Phosphates

As in FST, concentrations of ortho-phosphates in leachate samples collected from CUT in 2002 were very low (0.04 ppm). Total losses were less than 0.1 pound per acre. The raw manure and synthetic fertilizer treatments tended to lose more phosphates than the compost treatments, but these differences were not statistically significant.

CONCLUSIONS FROM FST AND CUT

Buildup of nutrients can cause contamination problems in both organic and synthetic chemical–based agricultural systems. Continuous analysis and adjustment of all nutrient inputs are vital to reduce or eliminate nutrient losses in all agricultural systems.

Each farming system has its own unique management needs. For example, although the legume system in FST has competitive yields and low inputs, management of the legume cover crop needs to be refined to avoid producing excessive available nitrogen, leading to losses to the environment.

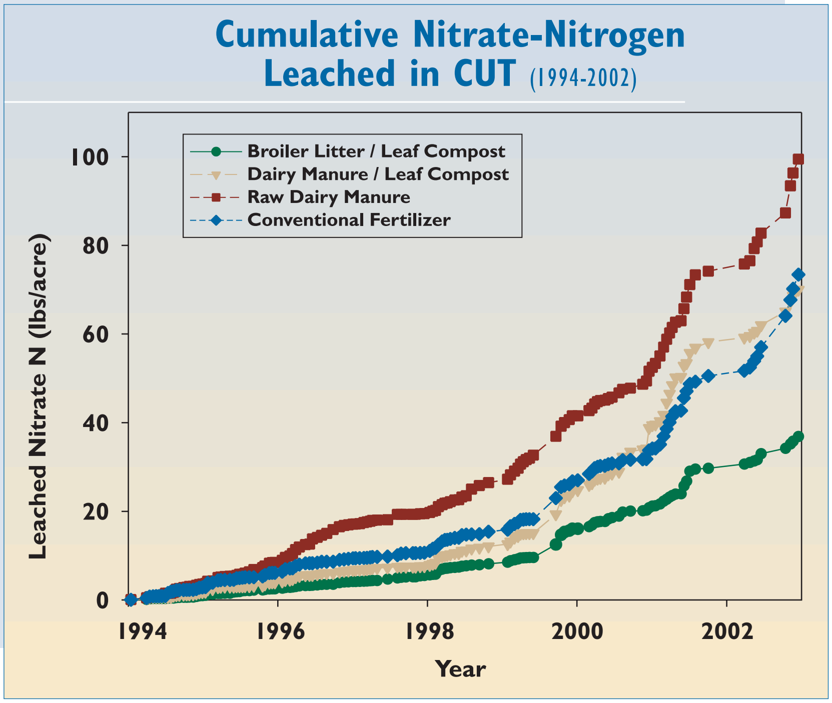
The higher rate of nitrate leaching in FST as compared with CUT is possibly due to differences in the crops grown, types of nutrient inputs, and differences in cover crop management. CUT included more summer and winter cover crops in its rotation than FST, allowing for greater year-round plant use of available nutrients.

Of all the nutrient amendments, compost performed best to reduce leaching of nitrate and phosphate. This may be due, in large part, to the fact that humic materials (which are highly concentrated in compost) provide a gradual release of nitrogen and phosphorus when compared with simple chemical nutrient sources and raw manures. This gradual nutrient release reduces nutrient loss and can promote crop growth longer than other nutrient applications.

In the conventional system, water samples were contaminated with atrazine at levels that are known to affect the health of wildlife and humans. Metolachlor was also present, although contamination risk levels have not yet been established for this chemical. Organic production systems eliminate ground water contamination from pesticides.

Compared to compost, raw manure and synthetic chemical fertilizer provide quick but less sustained nutrient release, increasing nitrate leaching.

Fig. 10. Cumulative nitrate-nitrogen leached in the Compost Utilization Trial during the period 1994–2002. In the trial, losses of nitrate-nitrogen were greatest in response to application of either raw dairy manure or synthetic chemical fertilizer when compared with applications of compost. The plow-down of the hairy vetch cover crop after 1999 increased nitrate-nitrogen losses across all treatments. Overall, leaching rates were low compared to those reported elsewhere.



Farm Management to Improve Water Quality

Farmers can improve the water quality of their farms and surrounding area through sensible farm management based on the results of and experience from our long-term experiments.

MANURE MANAGEMENT

Because manure is a potential source of nutrients and pathogens, farmers must take special precautions to manage it effectively. Guidelines for good management are:

1. Compost manure and other wastes to reduce their volume, stabilize their organic matter, improve their consistency for field application, and reduce nutrient solubility that can lead to losses.

2. Calibrate manure-spreading equipment properly.

3. Spread manure uniformly on fields at the planned rates based on crop needs.

4. Spread manure on fields as close to the time of crop use as possible.

5. Avoid spreading manure during fall and winter unless a cover crop is active.

6. Incorporate manure into the soil as soon as possible after it is spread to avoid volatilization.

7. Use conservation practices such as strip cropping, contour farming, crop residue management, cover crops, cropland terraces, diversions, and grassed waterways on soils with high erosion potential. These practices can effectively reduce the loss of soil and manure nutrients.

8. Take special care when applying manure near environmentally sensitive areas such as streams, lakes, ponds, or sinkholes.

9. Avoid using heavy manure-spreading equipment on wet soil. Manure spreaders have been implicated as a major cause of soil compaction on many farms.

10. Keep good records of manure applications. Records document good management and are valuable in guiding management adjustments and improvements.

RECENT STUDIES ON WATER QUALITY AND HEALTH

At Pennsylvania State University, Kiesecker (Anon 2002) found greater rates of limb deformities in trematode-infected tadpoles of wood frogs that were exposed to the agricultural pesticides atrazine (herbicide) and malathion and esfenvalerate (insecticides) in Pennsylvania. Laboratory experiments showed that the pesticides weakened the immune response of the tadpoles, resulting in more infections and greater likelihood of limb deformities. Kiesecker commented, "We can learn a lot from experiments with amphibians because they are particularly sensitive to environmental changes that appear to be associated with the recent emergence of new diseases and resurgence of old diseases that infect humans. Frogs may be sentinel species that are warning us about the interplay between human-caused environmental change and disease susceptibility. Hopefully, people will listen."

PASTURED ANIMAL MANAGEMENT

As animal production is intensified, care must be taken to prevent pasture activities from contaminating surface waters. Guidelines for good management are:

1. Maintain animals on pasture rather than confined indoors.

2. Do not overstock the pasture, and balance

Restricting access of animals to waterways helps preserve water quality.

livestock numbers with forage supply.

3. Exclude animals from waterways and protect stream banks with fencing.

4. Use pasture pumps (see "Sources of Information on Water Quality and Agriculture" on page 28) to supply pastured animals with water, eliminating their need to access streams and creeks.

5. Match phosphorus in livestock diets to their nutritional requirements in order to reduce surplus phosphorus in manure.

6. Use rotational grazing to increase grazing efficiency, and design grazing systems with multiple pastures and a diversity of forages.

BUILDING HEALTHY SOIL, PREVENTING EROSION, AND KEEPING WATER CLEAN

Healthy soil has a buffering capacity that helps keep water clean. It is promoted by the following management practices:

1. Build and/or maintain levels of soil organic matter that reduce nutrient losses.

2. Avoid soil compaction to maintain proper water filtration through the soil and reduce excessive runoff.

3. Maintain a proper soil nutrient balance by applying nutrients to soil only at times and in amounts required by crops.

4. Reduce soil tillage to maintain crop residue, reduce soil and wind erosion, improve soil texture (tilth), and improve water infiltration.

5. Develop unfarmed grass waterways and forested stream banks to serve as buffers and filters for agricultural runoff.

6. Use contour field designs and strip cropping to reduce erosion and promote healthy crop rotation.

7. Mulch vegetable and fruit crops to improve water infiltration, increase soil moisture retention, reduce runoff, and promote accumulation of soil organic matter.

8. Plant fencerow trees and grasses to reduce the erosive effects of wind, wind-blown soil, and water.

Final Thoughts

Our planet's fresh water supply is a precious and valuable resource. It is also a finite resource, comprising only a small fraction of the Earth's total water supply. No new fresh water is ever created; it is only recycled through the atmosphere and environment. As water rights issues arise in the western United States and other areas, it appears that fresh water is already in short supply in some regions. Even where it is abundant, water can also be easily polluted by agricultural, industrial, and residential use.

In the next 20 years, we will need to supply fresh water and food (produced with that water) to support the lives of an additional billion humans. The arithmetic is alarming. Even more alarming is the fact that agriculture is currently one of the greatest users—and polluters—of our water resources. Residential use of cleaners, lawn chemicals, and septic systems is also a growing and serious source of water pollution.

Individuals must realize that simple decisions we make about the food we eat and the products we use in our homes do have a profound impact on the world's water supply over time. With this perspective, it's clear that we must make efforts to better understand and protect our water resources. Wise agricultural management and residential use can preserve these resources and still supply the food our growing population needs.

Clean water is among Pennsylvania's most important natural resources, and agriculture is among its most important industries. Unfortunately, agriculture has been a major source of water contamination. Fractured limestone bedrock that underlies agricultural regions makes Pennsylvania's ground and surface water particularly vulnerable to contamination. Agricultural amendments, such as pesticides and fertilizers, are especially dangerous to our health once they have entered our water. While pesticides and nutrients play roles in conventional agriculture, they don't belong in our drinking water. To make matters worse, pesticides and nutrients have been found in mixtures in ground water, increasing the risk to human health.

Education is part of the solution. Consumers need to understand the importance and finite nature of our water resources and of the contaminants they may contain. At the same time, federal, state, and local governments must recognize the shortcomings of our water regulatory systems and set goals to improve our resources.

When conventional and organic farmers reduce nutrient contamination by fine-tuning their management of fertilizers, manure, compost, and cover crops, they help to improve our water supply. Avoiding an oversupply of nutrients makes economic sense for both conventional and organic farmers, since it reduces input costs. By practicing organic agriculture, farmers avoid the negative effects of pesticides that presently plague our water and food systems.

Both organic and conventional farmers can get help from many nonprofit, federal, state, and local organizations in order to reduce water pollution. In some cases, financial help is available for improving farm operations' impacts on water resources.

In turn, consumers can support organic agriculture by buying organically grown food. They can also join or form a local watershed protection group.

Keeping water clean while producing healthy food is a goal that everyone can adopt. By doing so, we take an active role in assuring a healthy future for this generation and generations to come.

Appendix A: Regulation of Water Quality

The quality of drinking water is regulated by a complex set of criteria. The U.S. Environmental Protection Agency (EPA) enforces the Safe Drinking Water Act, enacted in 1974, which requires the agency to determine acceptable levels of contaminants in the public drinking water supply. It was developed to protect human health, watersheds, and the environment by regulating many agricultural contaminants, including pesticides, crop nutrients, and microscopic pathogens. The Maximum Contaminant Level (MCL) is the lowest level of contamination that a public water supply can be reasonably required to achieve, given the present technology and resources. All public water supplies must abide by the EPA standards. Some individual states have additional water quality criteria.

The public drinking water system supplies water to 90 percent of Americans. However, the EPA does not oversee private wells that supply water to approximately 42 million people. Most private wells are drawn from ground water, but some households use water from streams or cisterns (USGS 1999).

Some scientists and concerned citizens believe that the EPA has not adequately protected our public and private drinking water supplies. Their concerns are as follows:

- MCLs have been established for few of the chemicals found in water. Many pesticides and their breakdown products have not been evaluated.
- MCLs are frequently based on the economic feasibility of contaminant removal rather than on health criteria.
- Pesticides and nutrients almost always occur as mixtures in the surface and ground water of agricultural and urban areas. For example, several herbicides and fertilizers are frequently applied simultaneously to corn and may contaminate water supplies as a mixture or combine in the aquifer from diverse sources. However, existing water quality criteria typically are based on tests of individual chemicals and do not account for commonly found mixtures or chemical by-products.
- Safety criteria are usually based on a single route of exposure, such as oral, inhalation, or skin contact. However, in most households, people may drink and bathe in contaminated water, thus inhaling, ingesting, and absorbing chemicals by multiple routes simultaneously.
- Safety criteria are usually based on long-term exposure to constant concentrations of contaminants. However, real-world cycles of exposure tend to involve lengthy periods of low concentrations and seasonal pulses of high concentrations.
- Safety criteria often focus on cancer, while other disorders are ignored. Potential effects on the reproductive, nervous, endocrine, and immune systems, as well as on chemically sensitive individuals, are not evaluated. For example, many pesticides are suspected endocrine disrupters, which have the potential to affect reproduction or development of humans and wildlife by interfering with hormones.
- Homeowners may not be aware of possible contamination because private wells are not monitored regularly as is required for large public supply wells. In addition, many homeowners in new residential areas that rely on private wells may not know that chemicals leached from previously farmed land can remain in shallow, slow-moving ground water for decades.
- Since most toxicity tests are based on contamination's effects on rats, mice, dogs, or rabbits, results may vary from human reactions.
- Safety criteria for many aquatic organisms have not been established.
- Few independent studies (those conducted by parties other than pesticide manufacturers) have been conducted on newly registered chemicals, giving the appearance that these chemicals are less hazardous than they really are. In addition, any acknowledged potential safety concerns are questionable due to the inability to obtain long-term independent studies for comparison.

The complexities of contamination and the nature of exposure and its effects require further research.

Appendix B: Pesticides—A Closer Look

The pesticides described here—atrazine, metolachlor, alachlor, and aldicarb—were chosen because they are commonly used in Pennsylvania agriculture, they move readily in water, and they have been found in drinking water, sometimes at levels above regulatory thresholds.

Herbicides are the primary category of agricultural pesticide applied throughout the United States. For example, in Pennsylvania, corn farmers applied 1,536,000 pounds of atrazine and 1,031,000 pounds of metolachlor for weed control in 2001.

Atrazine

Atrazine, a white crystalline compound in the triazine chemical class, has been sold under the trade name Aatrex and others. The herbicide is widely used to control broadleaf and grassy weeds and was estimated to be the most heavily used herbicide in the United States from 1987 to 1989, with its most extensive use on corn in the Midwestern states (EPA 2002).

Atrazine may be released to the environment in wastewater from manufacturing facilities and through field application as an herbicide. It is highly persistent in soil and has been classified as a Restricted Use Product (RUP) due to its potential for ground water contamination. Atrazine and its breakdown products tend to leach into surface and ground water resources. It is the second most common pesticide found in private and community wells in the United States (EPA (1) 2002; Extoxnet).

Under the Safe Drinking Water Act, the U.S. Environmental Protection Agency (EPA) has set a Maximum Contaminant Level (MCL) for atrazine at 3 parts per billion (ppb). However, the herbicide has been found at concentrations above the MCL in ground water in Pennsylvania, Delaware, New York, and much of the Midwest. In a study of Pennsylvania's Lower Susquehanna River Basin, atrazine was detected in 98 percent of the stream samples and 75 percent of the well samples (Lindsey et al. 1999). It has also been detected in 76 percent of rainfall samples taken in Mississippi, Iowa, and Minnesota, indicating its propensity for atmospheric transport (Majewski et al. 2000).

The EPA suspects that atrazine has the potential to cause the following health effects when people are exposed at levels above the MCL for short periods of time: congestion of the heart, lungs, and kidneys; low blood pressure; muscle spasms; weight loss; and damage to the adrenal glands. After a lifetime of exposure above the MCL, atrazine has the potential to cause weight loss, cardiovascular damage, retinal and some muscle degeneration, and cancer. In addition, atrazine is a suspected endocrine disrupter. Its reproductive and developmental toxicity is not completely known.

The EPA is currently reevaluating the allowable levels of atrazine in drinking water and has drafted new criteria for the protection of aquatic life, limiting four-day average exposures to 12 ppb. Several recent research reports have focused on the toxic effects of atrazine on populations of frogs.

Metolachlor

Pure metolachlor, an odorless, off-white to colorless liquid at room temperature, is sold under the trade names Bicep and Dual. It is a broad-spectrum, preemergence herbicide used for weed control on many agricultural crops (primarily corn, soybeans, and sorghum) and on lawns and turf; ornamental plants; trees, shrubs, and vines; rights of way, fencerows, and hedgerows; and in forestry (EPA 2002; Extoxnet).

Currently, metolachlor is not regulated under the Safe Drinking Water Act, but water supply systems are required to sample and analyze for it. Residues have been detected in ground water in 20 states, and samples in 3 states have been found to exceed the lifetime Health Advisory Level (HAL) of 100 ppb. In 5 other states, concentrations in well water exceed 10 percent of the HAL. Metolachlor is one of the top five pesticides found in surface water in the Midwest and was detected in a majority of samples taken from Corn Belt streams, rivers, and reservoirs for several months after application. Because of the detections, the EPA is concerned about the degradation of water quality that occurs in areas where metolachlor is used.

The EPA considers metolachlor to induce cancer under the definition of the Delaney Clause. In addition, it is a suspected endocrine disrupter. Its reproductive and developmental toxicity is not completely known.

On an acute basis, metolachlor is slightly toxic to practically nontoxic to birds, moderately toxic to cold- and warm-water fish, nontoxic to bees, and slightly toxic to aquatic invertebrates. Metolachlor contamination has exceeded safety criteria for some endangered birds, small mammals, and fish.

Alachlor

Alachlor is an odorless white solid in the chemical class chloroacetanilide. It has been sold under the trade names Lasso, Lariat, and others. Alachlor is the second most widely used herbicide in the United States, applied to control annual grasses and broadleaf weeds in crops such as corn, soybeans, and sorghum. It is an RUP (EPA 2002; Extoxnet) that is highly mobile and moderately persistent. Reliable monitoring studies have demonstrated that alachlor, even when used according to label directions, results in significant ground water contamination. It degrades into products that are also very mobile and persistent. The MCL for alachlor has been set at 2 ppb, but the EPA has detected it in ground water at concentrations above the MCL in at least 15 states.

The EPA has found alachlor to cause slight skin and eye irritations when people are exposed to it at levels above the MCL for relatively short periods. With lifetime exposure above the MCL, it has the potential to cause damage to the liver, kidneys, spleen, and nose and eyelid linings. It is also classified as an oncogen. In accordance with the 1996 EPA proposed Guidelines for Carcinogen Risk Assessment, the herbicide was classified as a “likely” human carcinogen at high doses, but “not likely” at low doses.

Alachlor is slightly toxic to mammals, slightly toxic to practically nontoxic to wildfowl, highly to moderately toxic to fish, and nontoxic to bees. It poses a potential risk to terrestrial animals on a chronic basis.

Aldicarb

Aldicarb is a white crystalline solid in the chemical class n-methyl carbamate (commonly referred to as carbamates). It is an RUP and is sold under the trade name Temik. Aldicarb is a systemic insecticide used to control mites, nematodes, and aphids and may be applied directly to soil. It is widely used on cotton, peanut, corn, and soybean crops. In the mid-1980s, misapplications of aldicarb on cucumbers and watermelons led to highly publicized adverse effects in humans. In 1990, the manufacturer announced a voluntary halt on its sale for use on potatoes because of concerns about ground water contamination (Extoxnet).

The proposed MCL for aldicarb is 7 ppb. It is highly toxic and easily degraded by bacteria, light, and reactions with water. As such, it is very soluble and mobile in soil. Aldicarb movement is most critical in sandy or sandy loam soils, and because of its rapid degradation, levels in surface water may be lower than levels in ground water. It has been found at concentrations above the MCL in wells in 12 states and more than 25 countries.

Aldicarb primarily affects the nervous system. As a cholinesterase inhibitor, it can cause a variety of symptoms, including weakness, blurred vision, headache, nausea, tearing, sweating, and tremors. Very high doses can result in death due to paralysis of the respiratory system. In addition, aldicarb is a suspected endocrine disrupter. The complete reproductive and developmental toxicity is not completely known. Aldicarb is very highly toxic to birds, moderately toxic to fish, and nontoxic to bees.

Sources of Information on Water Quality and Agriculture

Alliance for the Chesapeake Bay
www.acb-online.org

Chesapeake Bay Foundation
www.cbf.org/site/PageServer
Directory of 553 regional nonprofit watershed organizations
www.chesapeakebay.net/wshed_directory.htm

Delaware River Basin Commission
www.state.nj.us/drbc/drbc.htm

Delaware Valley Regional Planning Commission
www.dvrpc.org

Natural Resources Defense Council
Endocrine Disruption: An Overview and Resource List
www.nrdc.org/health/effects/bendinx.asp

The Nature Conservancy
http://nature.org

Pasture pumps
Rife Hydraulic Engine Mfg. Co., Inc.
PO Box 95, Nanticoke, PA 18634
Tel 570-740-1100; Fax 570-740-1101
www.riferam.com/pasture/index.htm

Pennsylvania Association of Conservation Districts, Inc.
www.pacd.org/about/default.htm

Pennsylvania Association for Sustainable Agriculture
www.pasafarming.org

Pennsylvania Department of Environmental Protection
www.dep.state.pa.us

Pennsylvania Environmental Council
www.libertynet.org/pecphila

Pennsylvania Nutrient Management Program
http://panutrientmgmt.cas.psu.edu

Pesticide Action Network of North America
www.panna.org

Schuylkill River Greenway Association
www.corecom.com/srga

Schuylkill River Watershed Initiative
www.srwi.org

The Rodale Institute®
www.rodaleinstitute.org/home.html
www.newfarm.org
www.kidsregen.org

U.S. Department of Agriculture
Agricultural Research Service
www.nps.ars.usda.gov/programs

U.S. Environmental Protection Agency
www.epa.gov

U.S. Geological Survey
Water resources of Pennsylvania
http://pa.water.usgs.gov

Glossary

Acute toxicity Any poisonous effect produced within a short period of time, usually 24 to 96 hours following an exposure.

Algae Chlorophyll-bearing nonvascular plants (primarily aquatic) that have no true roots, stems, or leaves. Most algae are microscopic, but some species can be as large as vascular plants.

Aquifer A water-bearing layer of soil, sand, gravel, and/or rock that yields usable quantities of water to a well.

Bedrock Consolidated (solid) rock that underlies soils or other surface materials.

Breakdown product A compound derived by chemical, biological, or physical actions or processes exerted upon the parent compound. The breakdown can be a natural process that generates compounds that can be more or less toxic and/or persistent than the original compound.

Cancer A cellular disease in which heritable, somatic mutations cause undifferentiated, abnormal, and uncontrolled cell growth.

Carcinogen An agent capable of inducing cancer.

Cholinesterase inhibitor Proper functioning of the nervous system requires an enzyme called cholinesterase, which facilitates the transmission of nerve impulses across synapses. Certain insecticides (organophosphates, carbamates, and organochlorine families) disable this enzyme, resulting in symptoms of neurotoxicity, including tremors, nausea, and weakness. These insecticides cause paralysis at low doses and at higher doses may cause death, acting with a similar mechanism in both insects and humans. Exposure to cholinesterase-inhibiting pesticides has been linked to impaired neurological development in fetuses and infants, as well as chronic fatigue syndrome and Parkinson's disease in adults.

Chronic Constant and/or long-lasting.

Concentration The volume or mass of a substance present in a given volume or mass of sample material. Usually expressed as micrograms per liter (water sample) or micrograms per kilogram (sediment or tissue sample).

Contamination Degradation of water quality as compared with original or natural conditions, due to input of foreign substances.

Delaney Clause A section on food additives (Section 409) in the Food, Drug, and Cosmetic Act of 1958, stating that no additive will "be deemed safe if it is found to induce cancer when ingested by man or animal." This clause directs the FDA to reject such food additives. Its language has been interpreted to mean a "zero risk" standard for any cancer-causing food additive, including residues from pesticides found in processed foods.

Denitrification A process by which oxidized forms of nitrogen, such as nitrate (NO_3^-), are reduced to form nitrites, nitrogen oxides, ammonia, or free nitrogen; commonly brought about by the action of denitrifying bacteria and usually resulting in the escape of nitrogen gas to the atmosphere as greenhouse gases.

Developmental toxicity Adverse effects on a developing organism that result from exposure prior to conception (through either parent), during prenatal development, or postnatally until the time of sexual maturity. The major manifestations of this toxicity include death of the developing organism, structural abnormality, altered growth, and functional deficiency.

Drinking water standard, guideline, or criterion The maximum concentration of a compound permitted in a public drinking water supply, designed to protect human health. The standards are U.S. Environmental Protection Agency (EPA) regulations that have no regulatory status but are issued in an advisory capacity.

Endocrine disrupter The endocrine system—also referred to as the hormonal system—is made up of glands, hormones, receptors, and target organs. The systems regulate a wide range of biological processes, including control of blood sugar, growth and function of reproductive systems, regulation of metabolism, brain and nervous system development, and development in all stages of growth. A variety of chemicals can disrupt the endocrine systems of animals, and laboratory studies have generated compelling evidence that endocrine systems of certain fish and wildlife have been adversely affected by chemical contaminants, resulting in developmental abnormalities and reproductive impairment. The relationship between human endocrine diseases and exposure to environmental contaminants is less documented.

Evaporation The physical process by which a liquid or solid substance is transformed to the gaseous state; the opposite of condensation.

Fungicide An agent applied for the purpose of killing a fungal disease.

Glossary—*continued*

Green manure A crop that is grown specifically to improve the soil and/or provide nutrients to primary crops. Green manures (especially non-legumes such as winter rye, *Secale cereale L.*) can also reduce nitrate leaching by capturing and accumulating nitrates during times when primary crops are not actively growing.

Growth regulator An organic compound, either natural or synthetic, that modifies or controls one or more specific physiological processes within a plant. If the compound is produced within the plant, it is called a plant hormone. A plant regulator is defined by the EPA as "any substance or mixture of substances intended, through physiological action, to accelerate or retard the rate of growth or maturation, or otherwise alter the behavior of plants or their produce."

Health Advisory Level (HAL) Issued by the EPA, health advisories provide information on contaminant levels that can cause human health effects and are known or anticipated to occur in drinking water.

Herbicide An agent applied for the purpose of killing undesirable plants (weeds).

Insecticide An agent intended to prevent, destroy, or repel insects.

Leachate Water containing dissolved materials that moves through the soil profile into ground water supplies.

Leaching The movement of dissolved materials from soil or rock to ground water, such as the movement of pesticides or nutrients from the land surface into ground water.

Lysimeter The device used to collect water that passes through the soil in order to determine nutrient and chemical movements in field experimentation.

Maximum Contaminant Level (MCL) The EPA has jurisdiction under the Safe Drinking Water Act to set maximum levels for chemical contaminant concentrations in drinking water. These levels are based on the water system's technological ability and the cost of removing the contaminant and on the potential health problems that may be associated with it.

Mycorrhizal fungi Fungi that form a symbiotic association with the roots of certain plants.

Nitrate (NO_3^-) A nitrogen-containing ion that is very mobile in soil water and is easily absorbed by growing plants or lost to ground or surface water.

Nutrient An element or compound essential for animal and/or plant growth. Common plant nutrients include nitrogen, phosphorus, and potassium, which are the common base of chemical fertilizers.

Oncogen A chemical that may cause tumors.

Pesticide A chemical applied to crops, rights of way, lawns, or residences to control weeds (herbicide), insects (insecticide), fungi (fungicide), nematodes (nematicide), rodents (rodenticide), and other pests.

Phosphate (PO_4^{3-}) A phosphorus-containing ion. Phosphorus is an important plant nutrient that binds to soil particles. It is not easily leached with drainage water but can be lost when soil particles are carried away across the soil surface with runoff water. Runoff is the most serious source of phosphate contamination in waterways.

ppb A unit of concentration expressed as parts per billion (1×10^9).

ppm A unit of concentration expressed as parts per million (1×10^6).

Restricted Use Product (RUP) A pesticide that, because of its extreme toxicity, must be applied only by a certified pesticide applicator or under the direct supervision of a certified applicator.

Runoff Excess water that passes quickly over a surface without being absorbed.

Transpiration The loss of water vapor by plants to the atmosphere. It occurs mainly from the leaves through pores (stomata) whose primary function is gas exchange. The water is displaced in a continuous column of water moving upward from the roots.

Trematode A parasitic flatworm; also called fluke.

Tumor An abnormal, uncontrolled growth of cells.

Volatilization The act or process of vaporizing (to turn into a gas or vapor).

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