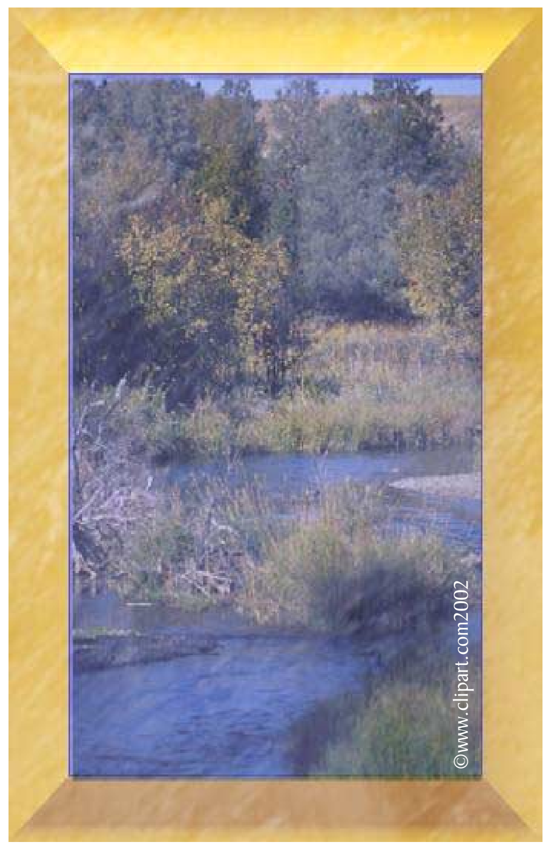
Organic Matters

ATTRA's *Organic Matters* Series

Protecting Water Quality on Organic Farms

By Barbara Bellows
NCAT Agriculture Specialist
October 2002



Abstract: *Organic farming involves many practices that protect against nutrient leaching, water runoff, and soil erosion. Water quality protection is greatest when organic practices are implemented using a "systems approach" rather than simply following a general list of approved practices. By understanding the biological, chemical, and climatic processes occurring in each field, organic farmers can implement practices that both enhance production and protect water quality. When organic practices are implemented in a more piecemeal and less sustainable manner, they can cause environmental impacts similar to those found on conventional farms. Environmental problems most commonly found on organic farms result from mismanaging manure applications or soil incorporation of green-manure crops, and from improper storage of manure or compost. This publication discusses practices that protect and practices that fail to protect water quality. Farmers can use the guidelines provided here to modify management to suit their soil, climate, and farming conditions.*

ATTRA's Organic Matters publication series was created to speed the flow of technical information on current topics to organic farmers, researchers, and others involved in organic production. Support in initiating this series has been provided by the Organic Farming Research Foundation, the USDA's Agricultural Marketing Service, and the Kerr Center for Sustainable Agriculture.

ATTRA is the national sustainable agriculture information service, operated by the National Center for Appropriate Technology through a grant from the Rural Business-Cooperative Service, U.S. Department of Agriculture. These organizations do not recommend or endorse products, companies, or individuals. NCAT has offices in Fayetteville, Arkansas (P.O. Box 3657, Fayetteville, AR 72702), Butte, Montana, and Davis, California.

Table of Contents

Introduction

Rather than relying on synthetic fertilizers and pesticides, organic farms protect the environment by building soil organic matter and mimicking natural systems. Research studies have demonstrated that compared to conventional farms, organically farmed soils tend to have:

- Less nitrogen leaching (McIsaac and Cooke, 2000; Solberg, 1995)
- Better nutrient holding ability (Wander et al., 1994)
- More efficient biological nutrient cycling (Drinkwater et al., 1998; Wander et al., 1994)
- Less runoff and erosion (Stolze et al., 2000)

However, without proper management, organic farming practices can create the same environmental problems as conventional farming practices. Potential environmental concerns associated with organic production are related primarily to:

- The transition period from conventional to organic farming practices
- Unmanaged applications of manure
- Improper timing of green manure plowdown
- Improper storage of manure or compost materials

The Final Rule of the National Organic Program (2000), seeking to ensure that organic cropping systems protect the environment, includes the following language:

- The producer must manage crop nutrients and soil fertility through rotations, cover crops, and the application of plant and animal materials.
- The producer must select and implement tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion.
- The producer must manage plant and animal materials to maintain or improve soil organic matter content in a manner that does not contribute to contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances.

Overview of Organic Practices that Protect Water Quality

Systems-based organic production practices conserve nutrients, protect water quality, and maintain biological diversity by a combination of the following:

- **Increasing soil organic matter** by returning organic materials to the soil and choosing practices that support a biologically active humus complex.
- **Composting** animal manure and other organic residues to form a more uniform and chemically stable fertilizer material.
- **Timing** the release of nutrients from organic-matter mineralization to coincide with the times when plants are actively growing and taking up nutrients.
- **Using crop rotations** for nitrogen fixation and to recycle nutrients from the soil profile, increase soil tilth through root growth, and provide a diversity of crop residues.
- **Using intercropping practices** to diversify crops in the field, enhance soil fertility, increase the efficiency of nutrient use, and decrease pest pressures.
- **Planting catch crops** or cover crops to recover nutrients that may otherwise leach into the subsoil.
- **Using conservation practices** that reduce the potential for water runoff and wind and water erosion.
- **Providing buffers or filter areas** between cropping areas and water bodies to protect against nutrient and sediment movement into lakes and streams.
- **Managing and monitoring irrigation** practices to enhance nutrient uptake, decrease leaching of nutrients, and minimize root and stem diseases.
- **Controlling pest populations** through cultural practices, enhanced pest-predator balances, and the use of biodegradable pesticides that have low toxicity to beneficial insects, fish, birds, and mammals.

The keys to both effective crop production and water quality protection are high levels of soil organic matter and an active community of soil organisms. Adding manure, legumes, and other plant residues to the soil stimulates the growth and multiplication of soil organisms. As these organisms decompose the plant and animal residues, they rapidly release nutrients from young, succulent, and fresh organic materials. They retain within their bodies the nutrients they need to grow, and excrete materials that are difficult to decompose. These components of organic materials that resist decomposition become stabilized in the soil as humus.

As populations of soil organisms increase, the amounts of nutrients held within their bodies or stabilized as humus also increases. Soil organisms hold nutrients in a form that is relatively available for crop uptake but is still protected against leaching, runoff, and erosion (Drinkwater et al., 1998; van der Werff et al., 1995; Wander et al., 1994). It is important to note that climate and soil conditions determine how rapidly populations of soil organisms increase and how effective they are in mineralizing or holding nutrients in their biomass. Thus, organic production practices are most effective in promoting both high yields and water quality protection when they are flexibly developed in response to local conditions. Problems may arise when general organic management concepts are implemented in a prescriptive manner that does not account for the local context.

How Organic Farms Sometimes Fail to Protect Water Quality

Sustainable, well-managed organic farms do not focus on a single crop, but involve a diversity of crops that represent multiple nutrient utilization strategies, water uptake requirements, and pest preferences. Carefully planned crop rotations and intercropping systems guard against nutrient movement into waterways by recycling and conserving nutrients within the plant-soil system. To ensure that an integrated approach is followed, the Canadian Standard for Organic Agriculture (CGSB 1999:6.3.1, cited in Wallace, 2001) recommends that "crop rotations be as varied as possible and include green manures, deep-rooted plants, legumes and / or rotation pastures that include legumes."

Many organic growers strive for this ideal integration of production practices with natural processes. But on some farms, economic pressures, labor shortages, incomplete knowledge of how to integrate new crops or cropping practices into existing operations, unexpected weather conditions, pest pressure from surrounding farms, or other factors result in the implementation of farming practices that meet the definition of "organic" but lack certain characteristics of sustainability. When this happens, the systems approach to organic production may weaken to the point where environmental impacts are similar to those found on conventional farms.

As mentioned above, good organic management does not mean simply following a general list of approved practices. Instead, management decisions must be made in the context of local climate and soil conditions. Five environmental problems that may be associated with the merely prescriptive implementation of either conventional or organic cropping practices are:

- Nutrient leaching and runoff
- Soil erosion
- Pathogen transport into water bodies
- Pesticide leaching or runoff
- Heavy-metal accumulation in soil

In the remainder of this publication, we will examine the biological, chemical, and physical factors that influence each of these environmental problems. Based on this information, you are provided with lists of both *practices to be avoided* and *positive practices* to guide your management decisions. Ecological impacts are discussed throughout to guide adaptation of organic production practices to fit specific soil and weather conditions.

However, before discussing how certified organic production practices can best be managed to enhance water quality protection, let's examine the period of *transition* from conventional to organic practices, since this production stage has the highest potential for environmental risks.

Transitioning from Conventional to Organic Agricultural Practices

Conventional farming practices rely on inputs to treat production problems such as nutrient deficiencies or pest infestations, while organic farming practices enhance crop production by using a systems-based approach that seeks to mimic natural processes. Because of differences in how these two agricultural systems function, production and environmental problems can arise during the transition phase between farming conventionally and establishing organic certification. During this period, before natural balances in nutrient cycles and pest-predator relationships have become established, organic production practices may not function effectively. At the same time, transitional farmers are not allowed to use many of the conventional inputs that previously provided their crops with rapid nutrient inputs or pest controls. Resource degradation or contamination problems may also arise during the transition period as the farmer learns new management practices.

Factors that can present environmental concerns for farmers transitioning to organic practices include:

- Low soil fertility levels and low levels of organic matter in the soil
- Small populations of soil microorganisms available for the decomposition and temporary immobilization of manure and organic residues added to the soil
- Poor soil quality that favors runoff and erosion rather than water infiltration
- Pest populations that far outnumber predator populations
- Incomplete information or mistaken assumptions on the part of the farmer regarding organic cropping practices

Low soil fertility and incomplete natural cycles**.** Land that has been farmed using conventional agricultural practices often has poorer soil tilth, less active biological flora, and less "active" organic matter than soil that has been managed using organic farming practices for several years (Edwards, 1999). Such soils have a limited ability to supply nutrients for crop production. They also may have low populations of soil organisms because of the residual effects of prior applications of pesticides or fertilizers with high acid or salt contents (Sullivan, 1999). In an attempt to produce high yields, transitional farmers may apply large amounts of manure or legume residues. However, the time required for soil organisms to release nutrients from organic matter depends on the succulence of the material and the number and diversity of organisms involved in decomposition, as well as on soil and weather conditions. These organic nutrient sources may not decompose in time to promote healthy and productive crop growth, but instead mineralize their nutrients into a form that is biologically inactive with a high potential for nutrient loss through runoff or leaching.

Over time, well-managed organic farming practices increase soil organic matter, enhance soil tilth and aggregation, and increase the retention of soil carbon and nitrogen within the biomass of soil organisms (Drinkwater et al., 1998; Ryan, 1999). Organic farming practices also bring weed and other pest communities into a dynamic, low-level balance within the cropping system.

Farmers having incomplete information about organic practices. Beginning or transitioning organic farmers may not realize the amount of nutrients removed from the soil when crops are harvested or understand the need to balance nutrient removals with nutrient applications. They also may not realize how low the concentration of nutrients contained in manure or compost is compared to that contained in a similar quantity of synthetic fertilizer. Farmers operating under the misconception that organic farming systems require few or no outside inputs risk degrading their soil and obtaining low and declining crop yields (Conacher and Conacher, 1998). Conversely, farmers who either apply excessive amounts of nutrients or make applications without understanding nutrient cycles or plant needs may create conditions conducive to nutrient runoff. Nutrient imbalances in the soil can also occur when manure or other organic materials contain nutrient concentrations that are different from those needed for crop production.

While additions of manure, compost, plant residues, and other sources of organic matter are critical for maintaining nutrient balances and establishing healthy populations of soil organisms, effective use of these materials requires an understanding of their effect on soil chemistry and soil biology. For example, repeated additions of organic matter can lower the soil pH. This can increase the availability of phosphorus in normally arid soils, which are usually alkaline (Conacher and Conacher, 1998; Nyhuis, 1982). But, on normally neutral or slightly acid soils, this decrease in soil pH will reduce the availability of phosphorus and other plant nutrients and may require farmers to add lime to re-neutralize the soil (Brandi-Dohrn et al., 1997). Also, as we will discuss in more detail later, nutrient availability and the rate of nutrient release differs greatly among different organic materials. Not understanding these differences can result in either unthrifty plants or pollution concerns.

Nutrient Leaching and Runoff

The two agricultural nutrients of particular concern to water quality and human health are nitrate and phosphorus. Nitrate, the common form of nitrogen in soils, is subject to leaching. Unlike potassium, calcium, and magnesium, which are positively charged, nitrate is negatively charged. Positively charged nutrients are able to bind onto most soil particles, including organic matter, because these soil particles have negative charges. Negatively charged nitrate, however, is repelled by negatively charged soil particles. Thus, it is easily transported down through the soil profile and into the groundwater.

Phosphorus is the nutrient of most concern for runoff and erosion losses since this nutrient is "limiting" in fresh-water systems. This means that a modest addition of phosphorus to lakes, rivers, or streams can cause nutrient imbalances that stimulate the growth of algae, which in turn limits the access fish have to nutrients and oxygen.

> Nitrate is subject to leaching. Both phosphorus and nitrate are subject to runoff.

Plants cannot use nutrients from manure or crop materials directly. Instead, these materials need to be broken down, or *decomposed*, by various soil organisms including beetles, earthworms, fungi, bacteria, and nematodes. Activities of soil organisms *mineralize*, or release, nutrients from organic materials into the soil solution. Temperature, moisture, type of organic matter applied, and application methods affect the time required for soil organisms to decompose organic materials and the amount of nutrients mineralized, or released, during decomposition. Conditions favoring the growth of soil organisms and hastening the rate at which they feed on and mineralize organic materials include warm temperatures, moist conditions, a relatively neutral soil pH, moderate fertility levels, and good soil quality. Conversely, cool temperatures and soils that are wet, compacted, or nutrient-poor impede decomposition.

Soil organisms break down fresher, younger, and more succulent materials faster than materials that are older or woodier. The more succulent organic substances contain concentrations of carbon and nitrogen that are similar to the cells of soil organisms and better fit their nutritional needs. Older or woodier materials have a higher concentration of carbon and are difficult for soil organisms to decompose because they contain complex compounds or do not contain sufficient nitrogen to meet the organisms' dietary requirements.

Actively growing plants can take up and use mineralized nutrients from decomposed animal manure, legumes, and crop residue mulches. If plants are not actively growing when nutrients are mineralized or if soil or rainfall conditions do not favor nutrient movement through the soil to plant roots, these nutrients can be transported through the soil by leaching or moved from the field by runoff or erosion.

Leaching

Leaching affects crop growth when nutrients are moved beyond the reach of plant roots. It is of concern to water quality when nutrients are transported into groundwater. Leaching of water and contaminants into groundwater is favored by soils that:

- are saturated
- have a high water table
- have a sandy or gravelly texture
- have cracks caused by soil drying or tunnels formed by animals or earthworms

Various researchers have reported significantly greater nitrate leaching from conventional practices as compared to organic systems. For example, researchers in Illinois looking at nitrogen leaching from tile-drained corn and soybean fields found that accumulation of organic matter and buildup of soil organism populations in organically managed fields resulted in less nitrogen leaching, compared to conventionally managed fields (McIsaac and Cooke, 2000). European studies reported that organic cropping practices reduced nitrate leaching up to 50% compared to conventional practices (Stolze et al., 2000).

Organic cropping systems control nitrate leaching by stabilizing nitrogen in crop plants used in rotations (Stolze et al., 2000). Adding organic matter to the soil stimulates the growth and reproduction of soil organisms, which also retain soil nitrogen in a relatively stable form (Drinkwater et al., 1998). As decomposition processes continue and populations of soil organisms increase, they stabilize mineral nutrients in their bodies and in the soil humus fraction. Effective practices to promote the stabilization of nitrogen in this manner include using a legume and forage grass rotation or using non-leguminous plants as cover crops (Granstedt and L-Baeckstrom, 2000). Wander et al. (1994) reported that high levels of biological activity in cover-cropped fields corresponded with a greater ability of the soil to hold nitrogen against leaching.

Practices to *avoid* to minimize nutrient leaching**.** In both conventional and organic crop production, the risk of nitrogen leaching is greatest when this nutrient is allowed to accumulate in the soil during times when 1) plants are not actively growing and taking it up and 2) water is available to transport it downward through the soil profile. Therefore, farmers should avoid:

- Applying manure or other organic materials at rates in excess of the nitrogen requirements for plant growth
- Adding nutrient inputs that are mineralized when plants are not actively taking up and using nutrients
- Fall or early spring plowing that stimulates nitrogen mineralization from soil organic matter during times when plants are not actively growing
- Repeated additions of manure, compost, or other nutrient sources to soil without monitoring for an excessive buildup of soil fertility
- Repeated years of legume green-manuring without rotation with a non-legume crop or without monitoring for high or excessive levels of soil fertility (Stopes et al., 1996)
- Continuous row-crop production with yearly nitrogen additions from fertilizers or manures without any rotations with a closely rooted grass or forage crop (Randall et al., 1997; Solberg, 1995)
- Excessive irrigation following manure additions or incorporation of a succulent green manure
- Establishing manure or compost piles on soils that have not been cemented or compacted to minimize leaching under the piles

Certain adverse or unexpected weather conditions also favor nitrogen leaching. These conditions include:

- Favorable weather that promotes productive growth and heavy nodulation by legumes, followed by a prolonged drought or untimely frost that causes an early dieback of plants and the release of the nitrogen contained within plant nodules and roots into the soil solution (Stout et al., 2000)
- Manure or organic-matter additions during weather favorable for decomposition, followed by weather conditions that stunt plant growth and decrease nitrogen uptake
- Unexpected heavy rainfall following manure additions

Nutrients and contaminants other than nitrate can leach through cracks or larges pores in the soil profile. Referred to as “preferential flow paths,” these pores are formed when high-clay soils become dry, when plant roots decompose, or when soil organisms such as earthworms leave channels in the soil. The potential for contaminant movement through preferential flow paths is particularly great in areas with:

- High water tables
- Subsurface or "tile" drainage
- Karst geological formations (irregular or rocky limestone formations that have cracks that drain directly to underground streams) (McIsaac and Cooke, 2000; van Es and Geohring, 1993)

To guard against movement of contaminants through preferential flow paths, manure should not be applied to these high-risk areas during times when the ground is saturated or rainfall is likely.

Runoff

Runoff and erosion affect crop growth by removing nutrients from the surface layer of the soil. *Erosion* is the transport of soil and manure *particles* either by water or by wind. The application of manure, compost, or other nutrient sources to the surface of the soil greatly increases the risk that rainwater or wind will move these materials off the field and into nearby drainage-ways or streams. *Runoff* water transports *dissolved* nutrients or other contaminants into drainage ways, streams, or lakes. Nutrients are more readily dissolved by runoff water when they have become concentrated in the surface layer of the soil. This occurs when repeated applications of manure or compost are made without regard to the amount of nutrients already in the soil or to the nutrient needs of growing plants. Dissolved nutrients transported by runoff have a greater impact on algae growth and lake eutrophication than the sediment-bound nutrients transported by erosion (Sharpley et al., 1999).

Unlike nitrate, phosphorus is held by soil particles. Previously, soil scientists believed that soils could bind almost unlimited amounts of phosphorus. Current research clearly indicates that on farms with high rates of manure application (typically livestock operations) or fertilizer applications (typically high-value vegetable farms), the amount of phosphorus in the soil can exceed the ability of soils to bind this nutrient. When this happens, phosphorus not bound by the soil is subject to being dissolved and removed from fields by runoff water.

Phosphorus buildup is most common on livestock farms that do not monitor their use of manure nutrients well and on conventional vegetable fields where excess or "insurance" levels of phosphorus fertilizers are applied. Phosphorus can also build up in organically managed crop fields if manure is applied at rates designed to increase soil organic matter rather than rates calculated to meet crop nutrient needs. For example, an organic crop farmer in New York experienced more than a three-fold increase in the phosphorus concentration in one field as the result of applying animal manure annually at the rate of 6 tons per acre for 21 years (Caldwell, 2001).

Aside from management practices, soil mineralogy and pH determine the capacity of a soil to bind phosphorus. Soils with low pH and high concentrations of aluminum and iron, as well as soils that are neutral to slightly alkaline and have high concentrations of calcium, can absorb high amounts of phosphorus. Soils that are sandy, silty, or have a low organic matter content have a limited ability to absorb and hold phosphorus. Phosphorus that is not bound by soil particles can be transported to surface waters by water runoff.

<u>Practices to *avoid* to minimize nutrient runoff</u>**.** While erosion occurs primarily when soils are bare, nutrient runoff can occur whether the soil surface is bare or has vegetative cover. Crop management practices that can cause nutrient runoff include:

- Repeated additions of manure, compost, or other nutrient sources to soil without monitoring for an excessive buildup of soil fertility

- Addition of manure, compost, or other nutrient sources to the soil surface, without incorporation, followed by a heavy rainfall or excessive irrigation
- Manure or compost additions to ground that is frozen or snow-covered followed by rapid melting
- Manure or compost additions to sloping land without soil incorporation
- Manure or compost piles established on soils that do not have appropriate diversions or filter areas to minimize the contamination of runoff water
- Cropping or applying nutrients up to the edge of rivers, streams, or drainage-ways

Certain land characteristics and adverse weather conditions also favor nutrient runoff and surface water contamination. These include:

- Intense rainstorms and rains of sufficient quantity to saturate the soil
- Sudden melting of snow or ice
- Soils that are compacted at the surface
- Soils that have an internal hardpan
- Sloping land

Positive Management Practices to Minimize Nutrient Leaching and Runoff

To ensure that organic production practices are implemented in a manner that protects the environment, the National Organic Practice Standards (National Organic Program, 2002a) specifically state that raw manure "must be applied in a manner that does not contribute to the contamination of crops, soil, or water by plant nutrients, pathogenic organisms, heavy metals, or residues of prohibited substances." This requirement provides certifying agents the discretion to prohibit questionable practices, such as applying manure to ground that is frozen or too close to water resources.

Sustainable and organic crop production practices used to control nutrient leaching and runoff include:

- Nutrient management planning
- Careful management of manure and plant-residue additions to the soil
- Crop rotations, cover crops, and catch crops
- Riparian buffers
- Establishing and managing manure and compost piles in ways that prevent the contamination of rainwater that moves through them

Nutrient management planning refers to the balancing of nutrients applied to fields with the nutrients removed from fields. Nutrient management practices balance nutrient inputs into the soil system with nutrient uptake by plants growing in the field. Besides protecting environmental conditions, good nutrient management planning practices are important for obtaining high production and good economic returns. A nutrient management balance sheet should include:

- Soil nutrient content as determined by appropriate soil and plant-tissue analyses
- Nutrient availability from animal manure, compost, or other organic sources that will be applied to fields during the current growing season
- Estimated nutrient release from the mineralization of animal manure or green manure crops applied to or grown on the land during previous growing seasons
- Anticipated nutrient uptake by crop plants growing in the field, adjusted according to yield potential as affected by soil characteristics, weather conditions, crop variety, and management practices

Checklist of Nutrient Management Practices

Activity	Timing
Soil testing	In spring or prior to pre-plant nutrient applications
Manure or compost testing	Prior to field application
Calculating nutrient contributions from prior crop rotations and manure or compost applications	• To determine amount of manure or compost to be applied. • To determine whether a green-manure crop rotation is needed to increase soil nitrogen levels
Appropriate manure or compost application	• In spring, based on soil test results and calculations of nutrient contributions from prior cropping practices • In fall, if followed by a cover crop • Do not apply manure or compost when soil is frozen or saturated or when heavy rains are expected
Nitrate testing	• Just prior to time of maximum nitrogen uptake by plants. If nitrate levels are low, readily available forms of nitrogen should be applied • For fields that obtain nitrogen predominantly from legume rotations, nitrate soil tests can help determine nutrient availability to crops planted in the following year
Plant tissue testing	Take leaf samples at the peak of vegetative growth, prior to flowering
Cover cropping	• Following harvest of the primary crop to provide vegetative coverage over the soil and to take up excess nutrients in the soil • If a late-planted crop will be grown in the spring, early-sown cover crops can be planted to hold nutrients being mineralized in the spring against loss
Record keeping	Ongoing activity, recording practices for each field, including: • Rotations • Manure and compost applications • Soil and manure test results • Crop yields, especially in response to different levels of nutrient additions • Cover cropping practices

Soil and plant-tissue analyses. Nutrients available to crops from a field can be determined by using chemical or biological analyses of soil and plant-tissue samples. Most Cooperative Extension Service offices can provide instruction sheets on how to collect representative and uncontaminated soil and leaf-tissue samples, and will accept and ship these samples to state-approved soil and plant nutrient analysis laboratories. While a few states subsidize the cost of soil and plant tissue analyses, in most states there is a moderate charge for each analysis. You can also work directly with either conventional or alternative private testing facilities. Private "conventional" laboratories measure soil organic matter, phosphorus, potassium, calcium, magnesium, cation exchange capacity, and pH in their standard analyses. Assessments of micronutrients and heavy metal contaminants are available at an additional charge. As we shall discuss later, assessments of heavy-metal contaminants—copper, arsenic, zinc—may be important if you have been using manure from certain types of conventional animal production operations since these metals may be components of animal feeds or bedding materials.

"Alternative" soil and plant analysis laboratories provide a variety of assessments that may be of particular interest to organic crop producers, including nutrient analyses of composts and analyses of the populations and diversity of microorganisms in the soil. Other alternative labs provide analyses similar to those of conventional labs except that they give nutrient recommendations in rates associated with commonly used organic inputs, such as composts and manure, whereas conventional labs typically recommend rates associated with synthetic fertilizers. Increasingly, however, conventional labs are able to provide organic recommendations on request. See the ATTRA publication *Alternative Soil Testing Laboratories* for contact information and types of analyses provided by alternative labs.

When using information from a soil or plant-tissue analysis, you need to take into account how the lab developed the recommendations provided. Labs associated with state Land Grant Universities usually base their recommendations on conventional plant production research conducted on soils found within the state. Analyses associated with local soil types are particularly important for phosphorus since the availability of this nutrient varies according to soil mineralogy and pH. Therefore, you should use the phosphorus soil test procedures that are recommended for your state.

Private soil testing labs may *not* provide recommendations based on yield experiments conducted on soils in the state. Instead, they often provide recommendations based on the nutrient needs of crops to be produced without consideration of the capacity of the soil to either release or absorb nutrients.

Organic producers may need to modify recommendations provided by soil testing laboratories to reflect:

- The often greater availability of nutrients from an organically managed soil as compared to a conventionally managed soil
- The lower, or more gradual, or long-term nutrient needs of traditional plant varieties compared to hybrid crops, which are typically used as the test crop in fertilizer yield trials conducted to determine fertilizer recommendations

Soil analyses should be conducted just prior to crop planting to guide applications of nutrients before or during the growing season. Plant tissue analyses can be conducted during the early growth stages to guide applications of supplemental foliar fertilizer or additions of readily available forms of nutrients during the growing season (Table 1). Analyses of mature plant tissues can identify deficiencies and help guide nutrient additions for the following growing season.

Nitrogen is difficult to analyze because it readily changes from one compound to another by chemical and biological processes. Especially on organic farms and on conventional livestock farms that use manure as a fertilizer, nitrogen availability will depend on organic matter decomposition and the formation of nitrate from mineralized nitrogen. For producers growing crops on humid eastern or midwestern soils, the pre-sidedress nitrate test provides an assessment of nitrate in soils just prior to the time of greatest nitrogen uptake by plants (Magdoff, 1991). Unfortunately, fertilizer recommendations based on the pre-sidedress nitrogen soil test have so far been developed only for hybrid field and sweet corn, with preliminary recommendations developed for pumpkins and cabbage (Magdoff and van Es, 2000).

A new nitrate soil test, being developed by researchers at the University of Illinois, may provide more reliable results once it's been perfected. It is based on the finding that amino sugars are the most readily decomposed component of soil organic matter. By measuring the amount of amino sugars in the soil, this test can predict the amount of nitrate that soil organisms will mineralize and release into the soil environment (Mulvaney et al., 2001). Thus far, the amino sugar test has been tried only on field corn.

These nitrogen availability tests can help organic producers identify fields that have sufficient or deficient levels of organic nitrogen. If test results indicate that the soil is deficient in nitrate, readily available forms of nitrogen need to be added soon after soil testing to meet plant nitrogen needs. Since manure, composts, and plant residues must undergo decomposition before becoming available for uptake, applications at the time of plant need may not be mineralized in time to be available for crop growth. Instead, they may mineralize after plant uptake has ceased, releasing mineralized nitrate that is susceptible to leaching. Readily available forms of nitrogen that can be added at this time are listed in Table 1.

Table 1. Organic Sources of Nutrients

	Percent composition				
Nitrogen source	**Total N**	**P_2O_5**	**K_2O**	**C:N ratio**	**Availability**
Bloodmeal	8-13	2	1	3:1	Rapid
Bonemeal	1-4	18-34	3:1		
Cottonseed meal	6	3	1	7:1	Medium
Fish meal	9	4-6		2.5-5:1	Rapid
Alfalfa meal	2.5	0.3	2		Medium
Soybean meal	7	1.5	2	6:1	
Poultry manure	3	3		12-15:1	Rapid (depends on bedding)
Poultry litter pellets	4	2	2	6:1	Rapid
Poulty compost	5	3	2		Rapid
Cow manure	1		1		Rapid (if fresh)

Sources: University of Maine, 1998; Rynk, 1992; Gershuny and Smillie, 1995; Ag-Org P/L, 2001.

Nitrogen soil testing is less problematic in the more arid soils of the western U.S., where tests that sample soils to a depth of 2 feet can be conducted just prior to the cropping season (not at the end of the previous cropping season). For a detailed discussion of soil test procedures and variations in soil test recommendations see *Building Soils for Better Crops* (Magdoff and van Es, 2000).

Nutrients from animal manure and compost applied in the current year. Since manure and compost contain a high percentage of water, the amounts of nutrients in these materials are relatively small compared to synthetic fertilizers. The nutrient content of manure samples can vary widely depending on the length and type of storage, the type of bedding (if any) mixed with the manure, and the type of feed consumed by the animals. It also varies according to the type of animal producing the manure. A comparison of nutrient contents of various types of manure is provided in Table 2. Remember that the animals' diet, how the manure was managed and collected, and the age of the manure will also affect nutrient content and availability. For example, animals fed nutrient supplements will tend to have high concentrations of those supplemented nutrients in their manure. Manure that is mixed with wood or paper bedding will have a higher concentration of carbon and thus be mineralized more slowly than manure that is not mixed with bedding. Fresh manure will have more available nitrogen and will decompose more rapidly than old manure.

To accurately apply manure according to the assessed nutrient deficiencies of your soil and the nutrient needs of your crop plants, take at least three replicate samples of the manure or compost that you will be using and have these samples tested by an approved nutrient analysis laboratory. Many Cooperative Extension offices can provide you with instructions and sampling containers for manure collection. They may also be able to submit the manure samples to appropriate laboratories for you. If your Cooperative Extension office does not provide this service, you can refer to the Minnesota Department of Agriculture web page (http://www.mda.state.mn.us/appd/manurelabs.htm) to identify commercial laboratories that conduct manure testing. These laboratories should also be able to determine (for an additional fee) the amount of heavy metals present in manure samples submitted.

For contact information of laboratories that conduct nutrient analyses of composts, refer to the ATTRA publication *Alternative Soil Testing Laboratories* (Diver, 2001). For more information on how to calculate appropriate amounts of manure and compost to be used in organic production systems, refer to the ATTRA publication *Manures for Organic Crop Production* (Kuepper, 2000).

Table 2. Manure Nutrients

	Pounds nutrients/ton of manure			
	N	P_2O_5	K_2O	C:N ratio
Beef				24:1
scraped from paved surface	11-14	7-9	10-13	
scraped from dirt feedlot	21-26	14-16	20-23	
Dairy				11-30:1
scraped from paved surface	10	3-6	6-9	
with bedding	9	3	6	
Poultry				
broiler house litter	72	78	46	10-14:1
stockpiled litter	36	80	34	
layer-deep pit	38	56	30	3-10:1
layer-undercage	26	31	20	
Swine				9-19:1
fresh	12	9	6-9	
with bedding	11	6	10	
Horse (fresh)	12	6	12	22:50:1
Rabbit (fresh)	24	23	13	14:1
Sheep				13-20:1
fresh	21	10	20	
with bedding	18	7	20	
Goat (fresh)	22	12	18	
mature compost	15-30	5-10	30	20:1

Note: Nutrient contents listed are general averages. For appropriate nutrient planning, have manure samples analyzed by a certified laboratory prior to calculating application rates.

Sources: Wallace, 2001; Zublena et al., 1991; Minnesota Department of Agriculture, 1995; Rynk, 1992; Gershuny and Smillie, 1995.

Nutrient availability from previously applied compost, manure, or legumes. Calculations for nutrient balances should account for the release of nutrients, over time, from various sources of organic matter in the soil. For example, under *humid temperate conditions*, soil organisms decompose and mineralize about one-third of the nutrients contained in manure within the year in which the materials were applied. Another 12% of the plant nutrients is released in the year after application, and 5% is released in the third year. Leguminous green-manure crops can supply almost all of the nitrogen needs of crops grown in the field the following year, and about half the nitrogen needs of crops grown two years after legumes have been incorporated into the soil (Klausner, 1995).

Table 3. Nitrogen Contributions from Legumes

Legume	N lbs/acre
Alfalfa	267
Sweetclover	223
Fava beans	267
Hairy vetch	90-200
Subterranean clover	75-200
Field peas	178
Cowpeas	100-150
Lentils	134
Soybeans	134
Crimson clover	70-130
Chickpeas	108
Dry beans	62

Sources: Wallace, 2001; Bowman et al., 1998

Decomposition rates will be different in other regions of the U.S. In hot climates, mineralization may proceed more rapidly because of the more rapid growth of soil organisms. In contrast, nutrient contributions from legumes grown in arid temperate regions will become available more slowly because arid conditions limit both the growth and production of green-manure plants and the decomposition activities of soil organisms. Remember, in arid regions, you can take soil samples just prior to the growing season to determine the availability of nitrogen from incorporated legumes or other green-manure plants. Typical amounts of nutrients available from green-manure crops are provided in Table 3.

Anticipated nutrient uptake by crop plants. The amount of nutrients a plant will need for productive growth depends on the species and variety, the soil and weather conditions, and the producer's management practices. Table 4 compares the nutrient uptake needs of different crop plants. Generally, nutrient uptake is distributed more evenly over the cropping season for traditional crop varieties than for hybrid varieties. When plants are subject to stress conditions such as drought, cold weather, or waterlogging, they will use lesser amounts of nutrients. Unfortunately, producers are rarely able to predict the impact of future weather conditions on plant growth at the time when they are applying fertilizers or manure to their soils. As a result, many farmers apply nutrients at rates that plants can use under favorable growing conditions. If conditions are not favorable, plants will be unable to use all the nutrients applied and these unused nutrients may leach or run off.

Table 4. Nitrogen Needs of Crop Plants

Crop	N lbs/acre
Grains	100-150
Wheat	100-250
Small grains	20-40
Potatoes	120-160
Leafy vegetables	120
Root crops	80

Sources: Gershuny and Smillie, 1995; Lichthardt and Jacobsen, 1991

<u>Careful management of manure and plant residue additions to the soil</u>. Following the decomposition of manure and plant residues by mineralizing soil organisms, mineralized plant nutrients released into the soil solution may be:

- Taken up by plant roots and used in plant growth
- Stabilized or held chemically by minerals or organic matter in the soil
- Immobilized or incorporated into the bodies of soil organisms

- Transported by water either downward through the soil (leaching) or over the surface of the soil (runoff)

Timing nutrient mineralization to coincide with plant nutrient uptake. Crop plants use nutrients from the decomposition of organic materials most efficiently when nutrient mineralization occurs during the time when they are actively growing and taking up nutrients. If organic materials are added late or decomposition occurs slowly (because of weather conditions or the type of organic matter added to the soil), nutrient mineralization will continue after plant nutrient uptake has ceased or become negligible (Sainju and Singh, 1997; Brandi-Dohrn et al., 1997; McCracken et al., 1994; Pang and Letey, 2000). These nutrients have a high potential for loss through leaching or runoff. For example, when manure or succulent organic residues are added to the soil in the fall, some of the nutrients will be mineralized in the fall, and some in the spring prior to crop emergence. Nitrogen mineralized prior to plant uptake can leach into the groundwater, while mineralized phosphorus can be transported by runoff water. As we will discuss in more detail later, a cover crop planted in the fall or early spring can take up and hold decomposed nutrients until it is killed and incorporated before planting of the main crop.

Conversely, the addition of woody or old plant residues to the soil, either just before planting or while plants are actively growing, will cause soil organisms to extract nutrients from the soil in order to have a balanced diet while they decompose these high-carbon residues. The resulting lack of available soil nutrients can stunt plant growth. Even the addition of nutrient-rich, succulent organic residues can slow plant growth and enhance nutrient leaching and runoff risks if these materials are not added in time for soil organisms to decompose them and make their nutrients available for use during the period of active nutrient uptake by plants.

Weather conditions can greatly affect the synchrony between mineralization of organic materials and plant growth. Cold weather slows down the activities of soil organisms. Producers who grow early-season crops in the northern U.S. often apply readily available forms of phosphorus in order to stimulate seed germination and seedling growth since soil organisms that solubilize mineral phosphorus or mineralize organic phosphorus are not active in cold weather. This can enhance the potential for phosphorus runoff, once the weather warms up, if the amount of mineralizable phosphorus in the soil is high.

Legume management. Legumes used as green manures can be a source of leached nitrogen, particularly in humid temperate regions, if unfavorable environmental conditions, such as a prolonged drought or untimely frost, cause plants to die back early in the growing season (Stout et al., 2000). As legumes die back, nitrogen contained within their nodules and roots is released to the soil solution. Agronomic systems in arid regions usually do not experience this problem since legumes are typically incorporated (or in conventional systems, killed back with herbicides) early in the growing season so as not to deplete soil moisture critically needed by the main crop.

Nitrate leaching from legume nodules can also occur if a high-nitrogen-fixing legume is rotated with a crop that has a low nitrogen demand (Stolze et al., 2000) or if legumes are planted for two years in a row (Stopes et al., 1996). In either case, the amount of nitrogen produced by the legume is in excess of that used for crop growth. Rotating legumes with non-leguminous crops, particularly grass-based forages, can effectively enhance soil organic matter as the forage crops will promote stabilization of nutrients in the bodies of soil organisms and in the soil humic fraction (Granstedt and L-Baeckstom, 2000).

Use of high-yielding varieties in organic production systems. The mismatch between nutrient mineralization and plant nutrient needs is especially great when organic materials are used to fertilize "high yielding" or hybrid crop varieties. These varieties were developed to be grown with synthetic nitrogen fertilizers, which can dependably provide high levels of readily available nitrogen. The selection of many hybrid varieties was based on their capacity to exhibit a high response in growth and production to increases in available nitrogen. As Pang and Letey (2000) state in their discussion of nitrogen availability to organically grown crops:

> One might make the case that N was exclusively supplied from organic forms prior to the availability of commercial sources and farming could revert back to those systems. One major difference is the development of high yielding crops, such as hybrid corn, which have a high N demand for a short time, which is a feature that is not readily compatible with organic farming.

Use of traditional seed varieties may decrease this mismatch between nutrient mineralization from organic matter and crop uptake needs. These crop varieties evolved in systems that relied primarily, if not exclusively, on organic nutrient sources. Thus, their nutrient uptake needs are less extreme, less focused on a particular stage in the growth cycle, and more uniform across the growing season, similar to the nutrient releases from organic matter decomposition.

Figure 1. Comparison Between the Mineralization Rates of Organic Materials and Nutrient Uptake by Crop Plants

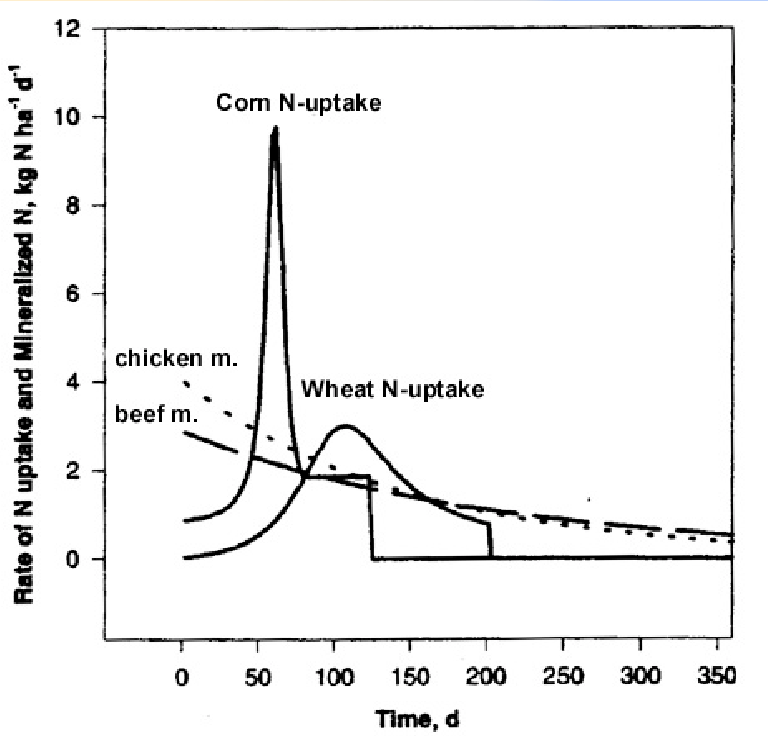


Fig. 1. Representative rates of mineralized N for chicken and beef manures and N-uptake rates by corn and wheat.

Pang and Letey, 2000, Soil Science Society of America Journal, reprinted with permission

Long-term benefits of organic management. Over time, organic farming practices promote the formation of soil humus and the accumulation of nutrient reserves in the bodies of soil organisms and in the readily decomposable form of soil organic matter (Ryan, 1999; Wander et al., 1994). As communities of soil organisms become larger and more diverse, the decomposition of added organic matter will be enhanced, as will the ability of this biological community to temporarily store mineralized nutrients (Drinkwater et al., 1998). As the ability of soils to store nutrients increases, crop nutrient demands will be met from a combination of applied and stored nutrient sources.

Careful management of the types of organic residues added to the soil can also control nutrient mineralization and immobilization processes. In the fall, you can either apply carbon-rich organic materials to the soil or leave woody crop residues on the soil. Soil organisms decomposing these materials will use excess soil nutrients to meet their nutrient demands. Nutrients immobilized in the bodies of soil organisms can be made available to crops in the spring by adding a nitrogen-rich form of organic matter to the soil shortly before the onset of the growing season. This will stimulate the decomposition of the high-carbon material and the mineralization or release of nutrients held in the bodies of soil organisms. Remember that climate conditions affect the time needed for either immobilization or mineralization processes to occur. In cold or arid climates, these processes will be much slower than in warm humid climates.

Readily available forms of nutrients can be applied to crops to meet high nutrient demands or to stimulate mineralization of nitrogen-poor organic materials. Table 1 lists the nitrogen, phosphorus, and potassium available from various organic materials. Concentrated sources of nutrients can be sidedressed, distributed through a drip irrigation system, or provided as a foliar application (Gaskell et al., 2000). These nutrient sources and application methods are expensive; careful monitoring of nutrient additions in relation to plant uptake needs can save money, enhance plant production, and reduce the risks of nutrient leaching and runoff. Use of these readily available nutrients without proper management can increase the potential for nutrient leaching and runoff.

Crop rotations, cover crops, and catch crops. Crop rotations enhance the efficiency of nutrient use and nutrient cycling since plants vary in their nutrient requirements, in their ability to extract nutrients from the soil, and in their access to different soil depths. For example, legumes do not require nitrogen additions since they are able to transform atmospheric nitrogen into a plant-available form, but they do require high levels of phosphorus. Plants with taproots can extract nutrients that have leached deep into the soil. Plants with more fibrous roots can better extract nutrients mineralized from decomposing plant and animal materials in the surface soil. Combining plants with different nutrient needs and root systems in a field, as intercrops or in a cropping sequence, can increase the efficiency of nutrient use and decrease the potential for nutrient leaching or runoff.

Cover crops and catch crops are used in rotations at the end of a growing season or during a secondary growing season. The primary role of cover crops is to reduce erosion potential by providing a vegetative cover on the soil surface. Keeping growing crops on the ground and active roots in the soil enhances soil organisms' growth and nutrient uptake. This reduces the potential for nitrogen leaching (Wander et al., 1994) while maintaining nutrients in a form available for uptake and growth by crop plants (Drinkwater et al., 1998; van der Werff et al., 1995).

Depending on need, cover crops can be selected to provide secondary benefits such as nitrogen fixation, allelopathic control of plant pests, or nutrient scavenging. Care should be taken when selecting cover and catch crops to ensure that these plants do not have allelopathic impacts or serve as secondary hosts for pests or diseases that affect the primary crop. In arid areas, rotation crops can limit the amount of stored soil water available to the primary crop (Wallace, 2001, Wyland et al., 1996) if they are not managed, in part, for water conservation.

Crops that are effective in nutrient scavenging or taking up excess nutrients are referred to as catch crops. Catch crops can be harvested to remove and reduce the amount of excess nutrients in the field or they can be plowed under to return the nutrients within these plants to the soil for uptake by the primary crop. Depending on your cropping system, catch crops can be planted as a:

- Secondary fall-seeded crop
- Winter-sown spring crop
- Secondary crop in the spring prior to planting the main crop
- Main crop in the spring
- Intercrop or secondary crop that is either broadcast or seeded between rows of the main crop or mixed in the drill with the main crop

Catch crops effective in controlling nitrogen leaching include brassicas like mustard, rape, radish, and turnip, as well as other crops that establish quickly and develop a root system during the relatively low temperatures of the fall or early spring seasons (Sainju and Singh, 1997). Researchers in both Oregon (Brandi-Dohrn et al., 1997) and Georgia (McCracken et al., 1994) found winter rye and ryegrass to be the most effective cover crops tested for the control of nitrogen leaching. Field crops that have high nitrogen demands also serve as effective catch crops. These crops include corn, rape, mustard, and wheat (especially spring wheat and hard wheat varieties).

As concerns over phosphorus leaching and nutrient imbalances from manure use increase, researchers and producers are looking for cover crops and rotation crops that have the ability to take up high concentrations of phosphorus (especially on neutral pH and sandy or loamy soils that do not have a strong ability to absorb phosphorus). Legumes are effective rotation or cover crops for reducing phosphorus levels. These plants do not require nitrogen additions from manure because of their ability to fix atmospheric nitrogen, but this process does require high-energy inputs that are provided by phosphorus-containing compounds. Other heavy users of phosphorus include tall fescue, coastal burmudagrass, field corn, grain sorghum, sudan grass, buckwheat, and brassicas including rape (Mitchell, Jr., 1990, Lyman and Sarrantonio, 1993).

While these crops are growing, they can reduce the potential for phosphorus movement into surface waters by reducing soil erosion and by incorporating phosphorus into their plant cells. When these crops die back or are incorporated into the soil, however, decomposition will release phosphorus back into the soil solution where it can then be transported by runoff water into lakes and streams (Sharpley et al., 1995). To reduce the potential for phosphorus runoff, the phosphorus-scavenging crops need to be removed from the field. This is in contrast with nitrogen-scavenging catch crops, which typically are used to hold nitrogen within the field in a form not subject to leaching, then

Table 5. Nitrogen-scavenging Cover Crops

	lbs. N/acre	Comments
Annual ryegrass	43-60	weed suppression adds organic matter
Barley	32	weed suppression subsoil aeration
Oats	77	weed suppression adds organic matter
Rye	50-100	weed suppression adds organic matter
Wheat	40	weed suppression adds organic matter
Sorghum sudangrass	225	weed suppression subsoil aeration
Tansy phacelia	57 root 106 plant	weed suppression
Oilradish	58 root 400 bioma	weed suppression subsoil aeration
Mustard	35 root	weed suppression
Buckwheat	30	phosphorus scavenger weed suppression

Sources: Bowman et al., 1998; Wallace, 2001; University of California SAREP, n.d.

plowed back into the soil so that this nitrogen can be mineralized and used for crop production. Table 4 provides a list of nitrogen- and phosphorus-scavenging plants.

Riparian buffers are vegetative areas maintained on either side of rivers or streams. They serve as a final protection against the movement of contaminants from fields into waterways. A combination of deep-rooted grasses or sedges with water-tolerant trees and shrubs helps hold streambanks in place while also trapping sediments and recycling nutrients transported from fields to riparian areas by runoff or erosion. Soil organisms, sustained by organic residues from these riparian plants, decrease nitrogen additions to waterways by transforming nitrate into ammonium gas through denitrification, degrading pesticides and other contaminants, and decreasing populations of human and animal pathogens in the soil. Maintaining the effectiveness of these buffers requires that good nutrient management and soil conservation practices are implemented across the field. This prevents buffer areas from becoming overloaded with nutrients, sediments, or other contaminants.

Protecting manure and compost piles against runoff and leaching. Storage and composting of animal manure in improperly prepared areas can result in leaching of nutrients into groundwater and runoff of nutrients into surface waters (Stolze et al., 2000). To preserve the quality of composts, manure, and other compost feedstocks as well as to protect water quality, the following compost or manure management guidelines should be used (Rynk, 1992):

- Permanent areas for manure or compost storage should have an impermeable concrete floor with a slope that allows runoff or leachates to flow into a collection or filter area.
- Short-term storage areas should be established on soils that have been compacted or that have had a clay liner installed, in order to minimize permeability.
- Roofs or plastic tarps over nutrient piles protect them from becoming saturated. The composting process depends on maintaining aerobic conditions within the pile so that the maximum number of the right type of microorganisms will be involved in the process. If the pile becomes saturated, pore spaces that formerly held air become filled with water. As a result, conditions within the pile become anaerobic, leading to the proliferation of bacteria that form methane, sulfides, and ammonium. Anaerobic decomposition is much slower, less complete, and more odor-producing than aerobic decomposition.
- Maintain collection or filter areas downslope from the pile. As mentioned previously, any runoff from nutrient piles will be a concentrated source of nutrients, and potentially of pathogens. Measures should be installed to prevent this material from flowing directly into lakes, rivers, or streams. A collection tank installed below the surface of the concrete pad can be used to collect runoff from the pile. The material in this tank can be pumped, mixed with raw manure, and applied to crop fields (since this material is highly concentrated, it should be diluted with manure or water prior to application to minimize risks of stunting plants by "nutrient burn"). A filter area is usually a vegetated area laid out on a shallow slope in a manner that encourages infiltration and microbial processes of runoff materials. Unfortunately, in areas with cold winters, vegetative filter areas have minimal ability to capture and treat runoff wastes during cold weather when vegetation is not growing and the ground may

be frozen or snow-covered. A bark-bed filtration system has been tested in these areas for the treatment of waste materials from milk houses. This system is more effective throughout the year since it contains a bed of tree bark or other high-carbon materials on which colonies of microorganisms become established. The combination of highly absorbent materials and diverse microbial populations allows this system to continue functioning during the winter months (Wright and Graves, 1998).

Soil Erosion

Soil erosion is the transport of soil particles by wind or water. Because these forces most easily move lightweight particles, erosion removes more topsoil, reactive clays, and organic matter than other soil components. Thus, it degrades soil by removing its most fertile components. Soil erosion can also damage surrounding fields and contaminate adjacent water bodies.

Soil erosion by wind can shred or smother growing crops, expose seedling roots in the fields from which the soil is being stripped, and bury seedlings and crops in fields where eroded soil is re-deposited. Wind erosion can also deposit piles of compacted soil on fields.

Soil erosion by water can form rills and gullies in surrounding fields, deposit sediments in ditches, and damage the quality of streams and rivers. Sediments transported by erosion carry attached nutrients, pathogens, and other contaminants. These sediments affect fish habitat by making water cloudy, by altering water temperature, and by becoming embedded in streambank areas used for feeding and breeding. Nutrients transported by sediments can cause algae blooms, degradation of fish habitat, and eutrophication. Pathogens attached to sediments degrade the quality of water for animal and human consumption and increase purification costs if lakes fed by contaminated streams are used as a source of drinking water.

The major land-management factors that control both wind and water erosion are the amount of plant or residue covering the surface of the soil and the amount of aggregation of soil particles.

Practices that Encourage Erosion

To minimize soil erosion and the movement of nutrients attached to soil particles, avoid the following practices:

- Harvest or land-preparation practices that remove plant residues from the soil surface and leave the soil bare during times when rainfall or snowmelt is likely
- Cropping practices that do not use mulches or cover crops and leave the soil bare between rows, especially when plants are young and their leaves do not cover this between-row area
- Practices that cause soil compaction, such as driving equipment onto fields, tilling fields when the soil is wet, or not maintaining an adequate amount of organic matter in the soil
- Use of shallow soil or soil with a high water table that rapidly becomes saturated and then favors runoff or erosion

Positive Practices that Minimize Erosion

To protect land against the forces of erosion, use practices that:

- Maintain a cover of growing plants or residues over the soil surface at all times
- Decrease the potential for water to flow off the land and increase the potential for water to infiltrate the soil
- Increase soil organic matter, soil tilth, and water infiltration

Practices that provide a vegetative cover over the soil surface. When soils have little or no vegetative cover, the forces of wind or water can pick up the exposed soil particles. Raindrops falling on bare soil spray out and disperse fine soil particles. These particles become embedded in nearby soils to form surface crusts or are carried away by the force of flowing water. Winds pry up soil particles and carry them as dust clouds that can be deposited on nearby fields, in rivers, on roadways, or in residential areas.

Conservation tillage, mulching, cover cropping, intercropping, and other practices that maintain a complete cover of vegetation or residues over the soil surface minimize the potential for erosion. Vegetation and residue cover protect the soil surface and minimize soil splatter from the impact of raindrops. Rain that slowly filters or seeps through residues or vegetation to the soil surface have decreased momentum and are more likely to be absorbed by the soil, whereas raindrops that strike a bare soil surface will likely encounter a crust and run off the soil surface as water erosion. Vegetation over the soil surface also decreases wind erosion, by protecting the soil from being detached and moved by wind.

Various cover-cropping and intercropping practices were discussed above in relation to nutrient leaching and runoff control practices. Unfortunately, most of the research and practical experience with conservation tillage comes from conventional systems that use herbicides as a key component of the practice. The potential for using conservation tillage practices in organic production is discussed in detail in the ATTRA publication *Pursuing Conservation Tillage Systems for Organic Crop Production* (Kuepper, 2001).

Soil conservation practices. Cover-cropping and conservation-tillage systems enhance water infiltration and minimize contact of wind and water with the soil surface, thereby decreasing the potential for these forces to transport soil particles. Other soil conservation practices capture water or reduce wind speed as eroded soil is being transported. Soil conservation practices that serve this function include:

- Planting crops on a contour, often involving strip cropping with a forage crop or other non-row crop that provides complete groundcover
- Establishing vegetative buffers upslope or upwind from cropped fields to absorb water flowing into and wind blowing across the fields
- Establishing vegetative buffers downslope or downwind from cropped fields or adjacent to rivers or streams to protect these surface waters from erosion coming off the fields
- Establishing catchment areas or creating or preserving wetlands to capture excess and potentially contaminated water leaving fields (Biological and chemical reactions in catchments and wetlands purify water by capturing nutrients, degrading toxins, and decreasing populations of pathogens)

Practices that improve soil tilth and aggregation. Organic-matter build-up enhances soil tilth and aggregation. Good soil tilth encourages water infiltration, thereby decreasing the amount of water available for runoff and erosion (Karlen and Stott, 1994). *Soil aggregation* refers to soil particles that are held together in small soft clumps by microbial gels, fine root hairs, and organic matter. Because these soil clumps are larger and heavier than individual soil particles, they are less susceptible to being moved by wind and water erosion. In addition to protecting soil against erosion, good soil tilth and aggregation enhance root growth and the ability of plants to take up nutrients from the soil solution.

Crop production practices that favor the build-up of organic matter and the formation of soil aggregates include:

- Appropriate use of animal manures as fertilizers and soil amendments
- Crop rotations involving pasture grasses or other plants that have a fine root system
- Crop rotations that include slowly decomposing, non-leguminous plants that will increase the amount of humus in the soil
- Cropping practices that maintain a healthy environment throughout the year for the growth and reproduction of soil organisms involved in the formation of gels that bind soil aggregates

Pathogens

Pathogens (disease-causing microorganisms) are often found in manure. The organisms of most concern to human health are *E. coli*, *Cryptosporidium*, and *Giardia* (Stehman et al., 1996; IFST, 2001). These organisms cause gastrointestinal problems in people who consume contaminated food or water, posing the greatest threat to young children, the elderly, and people whose immune systems are compromised.

Municipal purification systems chlorinate water to kill *E. coli* and protect the safety of drinking water. However, *Cryptosporidium* and *Giardia* form resistant resting stages (oocysts and cysts, respectively) that are not killed through primary water treatment processes such as chlorination. Sand filters are required to remove these parasites from water.

Application of fresh manure to growing crops or shortly before planting can contaminate these crops with pathogens. Water from rivers or streams used for crop irrigation can also contaminate plants with pathogens if livestock production operations or septic systems upstream are not properly managed and have allowed fresh waste to flow into the water. Poor sanitary practices by farm workers during crop production and harvesting can also cause produce to become contaminated with pathogens.

Practices to Avoid

To minimize pathogen contamination of food and water, you and your neighbors should avoid:

- Animal production practices that do not properly protect young animals from getting ill or passing infections to other animals in the herd
- Lack of biosecurity practices that minimize the potential for movement of pathogens onto the farm—these include ensuring that visitors, veterinarians, technical advisors, and neighbors do not carry pathogen-containing manure from other farms onto your farm by wearing contaminated boots or clothing or driving vehicles that carry contaminated manure
- Applying fresh manure to crops just before or during the growing season
- Using improper manure storage or composting practices that allow rainwater to become contaminated
- Using improperly or incompletely composted materials for crop production
- Poor sanitary practices by farm workers when they are handling edible crop parts during production or harvesting

Positive Practices

Rigorously monitoring compost piles, protecting manure and compost piles from rainfall, and applying composts and manure according to standards will minimize or eliminate the risk of crop contamination by pathogens.

The National Organic Standards (National Organic Program, 2002b) require that composting of plant and animal materials occurs at temperatures high enough to kill most pathogenic organisms found in manure. Guidelines provided by the National Organic Standards specify that:

- Compost material must have an initial C:N ratio of between 25:1 and 40:1

  and

- A temperature between 131° F and 170° F must be maintained for 3 days using an in-vessel or static aerated pile system

  or

- A temperature between 131°F and 170°F must be maintained for 15 days using a windrow composting system, during which period the materials must be turned a minimum of five times.

The National Organic Standards (National Organic Program, 2000) seek to minimize pathogen contamination of fresh produce by stipulating when manure can be added to fields. These standards require that when raw manure is used as a nutrient source, it is:

- Soil-incorporated "not less than 120 days before harvest of a crop whose edible portion is in contact with the soil or soil particles"

or

- Soil-incorporated "90 days prior to harvest for a crop whose edible portion does not have such contact."

The National Organic Standards do not restrict the timing of manure applications for crops not intended for human consumption (e.g., animal feeds, fiber, or biofuel crops), nor is there a restriction on the timing of applications of fully composted materials. However, organic certifying agents can prohibit growers from applying manure to frozen ground or too close to water—practices that present a high risk for pathogen and nutrient runoff from fields, resulting in water contamination (National Organic Program, 2002b).

<u>Conflicts between protecting against pathogens and minimizing leaching and runoff risks.</u> Unfortunately, practices designed to protect against food contamination by pathogens may be contradictory to practices designed to protect against leaching and runoff. For example, if you are planning on growing cool-season greens in the early spring for harvest around the start of the farmers' market season in early May, you will need to apply raw manure no later than the end of December. Realistically, manure should be incorporated into the soil in the fall following harvest. To prevent nutrient leaching and runoff, you should plant a cover crop that can capture and hold mineralizing nutrients from manure applications until they are needed for crop production in the spring. Unfortunately, achieving a balance between nutrient holding by cover crops in the fall and winter and nutrient release from these same crops in the spring can be difficult. Growing crops need readily available nutrients for productive crop growth while decomposition and mineralization of nutrients in cover crops is slow in the spring because cold weather slows microbial activity. Applications of readily available nutrient sources may be necessary to overcome this lag in nutrient release.

For pest and pathogen control, organic production methods rely primarily on preventive mea-

Pesticides

sures such as use of pest-resistant varieties, cultural control methods, and practices that enhance balances between pests and predators. Pesticides are used as a last resort, and are mostly limited to biologically derived substances with low mammalian toxicity. However, some botanical pesticides are toxic to non-target organisms. Rotenone is toxic to fish and pyrethrum kills beneficial as well as disease-causing insects (Conacher and Conacher, 1998). Diatomaceous earth controls insect pests because of its irritant, physically-disruptive properties —but it can also be a strong irritant of human lung tissue if not handled with care. Even plant nutrients and substances with relatively low toxicity can become contaminants if applied at excessive rates, close to water sources, or during times when heavy rainfall or flooding is expected. Copper sulfate is permitted as a pesticide on the NOP National List of Allowed and Prohibited Substances (National Organic Program, 2002b), with the stipulation that this "substance must be used in a manner that minimizes accumulation of copper in the soil." Although necessary for crop production as a micronutrient, copper becomes phytotoxic even at slightly elevated levels.

Positive Practices

Crop production practices that minimize environmental contamination and ecological disruption by pesticides include:

- Integrated pest management (IPM) practices that control pest and disease incidence through the use of crop rotations, good sanitary measures, disease-resistant varieties, predatory insect and nematode species, and the targeted application of least-toxic pesticides. For further information see the ATTRA publication *Biointensive Integrated Pest Management* (Dufour, 2001).

- Farmscaping practices that provide habitat for species that are predators of plant pests. For further information see the ATTRA publication *Farmscaping to Enhance Biological Control* (Dufour, 2000).

Heavy Metals

The term *heavy metals* refers to lead, cadmium, arsenic, copper, zinc, and iron. While the last three elements are required for plant growth in small amounts, buildup of these elements in the soil environment can be phytotoxic (Mikkelsen, 2000) as well as damaging to the growth of soil organisms. Use of copper sulfate as a pesticide can result in the accumulation of copper in the soil. Animal manure can be a source of various other metals. The National Organic Standards (National Organic Program, 2002b) prohibit the use of sewage sludge or biosolids because these products tend to have high concentrations of heavy metals.

Arsenic for many years has been the standard treatment for lumber to protect it against rotting and insect damage. However, public concern regarding the leaching of this toxic substance into groundwater has resulted in federal regulations prohibiting the sale of arsenic-treated lumber starting in 2003. The National Organic Standards (National Organics Program, 2002b) prohibit the use of treated lumber in the construction of compost bins, within a cropped field, or for livestock fencing. For information on other options see the ATTRA publication *Organic Alternatives to Treated Lumber* (Gegner, 2002).

Manure from non-organic livestock operations may contain antibiotics or heavy metals. Copper and zinc are used as trace-mineral supplements and additives in feed for various animals; arsenic is a feed additive for poultry (Mikkelsen, 2000). While not a heavy metal, boric acid is a potentially toxic element and can contaminate soils when boric-acid-treated recycled paper is used as bedding material by the poultry industry (Wilkinson, 1997). Plants can take up these elements, causing phytoxicity and lowering the food quality of harvested products.

While the National Organic Program Final Rule (National Organic Program, 2002) does not prohibit use of manure from non-organic sources, it does permit certifying agents to test soil and manure for residues when "a reasonable concern exists that manure, either raw or as a component of compost, contains sufficient quantities of prohibited materials to violate the organic integrity of the operation." Careful soil management can permit safe food production from fields contaminated with potentially toxic elements. For example, copper and zinc become increasingly available for plant uptake at low soil pH levels. Increasing the soil pH decreases the availability and toxicity of these elements (Mikkelsen, 2000).

Other Environmental Concerns

<u>Irrigation practices</u> can cause soil and water degradation and food contamination if not used carefully. Water from streams that run past animal agricultural operations can be contaminated with nutrients and pathogens if the livestock farm does not use environmentally sound manure management practices. Use of contaminated water in irrigation practices can compromise food safety if this water comes in contact with edible parts of the crop.

Applying irrigation water at inappropriate times or in excessive amounts can promote the leaching or runoff of nitrogen, phosphorus, and other crop nutrients. Irrigation water should be applied in amounts appropriate to the soil type and the growth stage of the crop. It also should not be applied prior to the incorporation of manure or compost into the soil, especially on sloping soils. Monitoring irrigation water and tracking the rate of evapotranspiration are key irrigation management strategies.

Particularly in arid areas, irrigation practices can cause heavy metals, salts, and other contaminants to become concentrated in surface soil. Water added to the soil absorbs minerals, which move upward in the soil profile as water is lost from the soil surface through evaporation. When water evaporates, the absorbed minerals are left on the soil surface. Keeping soils cool and protected against evaporation can conserve water within the soil while minimizing concerns associated with the upward movement of salts and contaminants.

Inappropriate or contaminated soil amendments. Soils can become degraded or unacceptable for organic production if inappropriate or contaminated soil amendments are used. Some amendments that were labeled as organic prior to the National Organic Program may no longer be acceptable since they contain "secret" or inert ingredients or other substances not approved under the new federal standards. While bloodmeal and bonemeal are not currently restricted by the U.S. National Organic Standards, it is interesting to note that the Canadian Standard for Organic Agriculture restricts the use of these materials and requires that they be obtained from organically raised livestock and composted (Wallace, 2001). Concerns are also being raised regarding the use of soybean and canola meal as fertilizers and soil amendments for organic crop production because of the prevalence of genetically engineered soybeans and canola (S. Diver and N. Matheson, personal communications).

For production as well as certification purposes, the farmer should ascertain the source of materials used to produce compost applied to fields. Recently, the pesticides clopyralid and picloram have been traced to various urban composting operations, to hayfields, and to manure from animals grazing on treated hayfields. In the state of Washington, composts containing these pesticides were being provided as soil amendments to backyard gardeners and organic growers. Unfortunately, the pesticides, which are used for weed control on lawns, in pastures, and along utility right-of-ways, are very persistent in the environment and very toxic to plants. These pesticides do not break down during composting, and when ingested by animals, pass into the urine quickly without significant degradation. Small concentrations of these pesticides in composts or straw mulch cause plants to become bushy rather than grow vertically. They also prevent fruit set, and promote abnormal formation of side shoots. Plants most susceptible to toxicity from these products are sunflowers, legumes such as peas and beans, and solanaceous plants such as peppers, tomatoes, and potatoes (Bezdicek et al., 2001; WSDA, 2002).

Plastic. Plastic materials are commonly used in vegetable and fruit production as a mulch, for row covers, and to kill weed seeds and other pests through soil solarization. As a mulch, plastic warms up the soil, allowing for earlier crop production; reduces evaporation, leaching, and waterlogging of soils; deters weed growth; protects against soil compaction; and enhances growth by increasing the concentration of carbon dioxide in the soil (Marr, 1993). Like plastic mulches, plastic row covers allow for earlier crop production, increased yields, enhanced efficiency of water resource use, and decreased weed growth and soil compaction. In addition, plastic row covers can protect against certain insect pests, and buffer plants against cold caused by wind chill (Bachmann and Earles, 2000). Clear plastic laid on the soil prior to planting can increase soil temperatures sufficiently to kill certain weed seeds and plant pests through soil solarization.

The many advantages of plastic use in horticultural production unfortunately come with an environmental price. While plastics reduce leaching and water-logging of covered soils, they also concentrate water that cannot soak through the plastic into the soil. This concentrated water flows off the plastic and forms erosive streams (Durham, 2001). USDA researchers determined that fields mulched with plastic exhibited four times more water runoff and up to 15 times more soil erosion than fields mulched with organic materials (Anon. 1999).

Disposal of plastic mulch poses an additional environmental problem. To prevent semi-degraded plastics from becoming incorporated into the soil, the National Organic Standards require removal of plastic mulches from beds at the end of the production season (National Organic Program, 2002). Mulch removal is tedious and dirty work, and good methods for plastic disposal or recycling are lacking. Soiled plastics cannot currently be recycled economically. Consequently, plastic users are forced to dispose of this material through incineration, burying on the farm, or landfilling. Burning requires costly fuel and labor, emits toxins into the air, and forms an unsightly, difficult-to-handle pile of plastic residues (Rutledge, 2002). Several states require permits for open burning. Burying plastic on the farm may limit future land use and lower the value of your land since plowing or digging into these soils may expose the buried materials. Public landfilling can be costly and is ultimately unsustainable.

Alternatives to plastic mulches include biodegradable paper mulches and living mulch crops. Many paper mulches developed to date are unacceptable since they tear and degrade before the end of the growing season. Other experimental products are cost-prohibitive. However, the USDA Agricultural Research Service (ARS) is currently testing a brown paper coated with vegetable oils and getting positive results (McGraw, 2001).

Living mulches under examination include white clover, perennial rye grass (Peet, 2001), and hairy vetch (McGraw, 2001). Advantages of organic mulches compared to plastic mulches is that they build up organic matter in the soil and may decrease pest populations by providing habitat for beneficial insects (Peet, 2001). For more information on living mulches and how to select appropriate varieties for your climate and cropping systems, see the ATTRA publication *Pursuing Conservation Tillage Systems for Organic Crop Production*.

Summary

Organic farmers protect against contamination of water by using practices that conserve and recycle nutrients within the farming system. Such practices are most effective and sustainable when they are implemented as part of an integrated, systems-based approach.

Maintaining nutrient balances within fields while minimizing water flows onto fields from off-farm areas, keeping water within fields, and capturing any water that flows away from fields will conserve nutrients on the farm while protecting the environment.

Using a diversity of plants as rotation crops, cover crops, and intercrops enhances soil quality, facilitates nutrient capture, and helps recycle nutrients that would otherwise be leached through the soil. These crops also provide soil cover, which encourages water infiltration and decreases the potential for nutrient runoff and erosion.

Building up stores of active organic matter and diverse communities of soil organisms will enhance soil storage of nutrient reserves while decreasing the potential for transport of these nutrients to ground or surface waters. Composting organic materials will provide a more uniform nutrient and organic-matter source that is less likely to cause biosecurity risks than fresh manure. During storage, both manure and compost piles should be sited on concrete slabs or soils with a low leaching potential and with collection or treatment areas for contaminated runoff water. By using practices that conserve nutrients in your crop fields, you are also protecting the environmental quality of nearby streams, lakes, and rivers.

Selected Abstracts

Organic crop production manuals

Wallace, J. (ed.) 2001. Organic Field Crop Handbook. Second Edition. Canadian Organic Growers Inc., Ottawa, Ontario, Canada. 292 pages.

> A practical handbook for farmers producing organic field crops. While focusing on production aspects, this handbook gives serious consideration to relationships between organic cropping practices and the environment. An overview chapter on environmental sustainability examines issues of soil management, energy use, water quality, air quality, waste management, and biodiversity. Chapters on crop rotations and green manures examine the relationship between these cropping practices and nutrient leaching, runoff, and erosion. Methods for minimizing the risks of pathogen contamination and food safety concerns are outlined in the chapter on manure management and composting.
>
> One strength of this handbook is its numerous tables. Information contained in these tables includes: nutrient availability from manure, nutrient availability from various green-manure crops, carbon-to-nitrogen ratio of compost materials, matching cover crops with uses, matching cover crops and primary crops, and a trouble-shooting guide for on-farm composting systems.

Literature reviews—Organic farming and the environment

Stolze, M., A. Piorr, A. Haring, and S. Dabbert. 2000. The Environmental Impacts of Organic Farming in Europe. Organic Farming in Europe: Economics and Policy. Volume 6. University of Hohenheim, Stuttgart, Germany. 127 pages.

> This small volume provides a comprehensive overview of European research focused on the relationship between organic production practices and environmental quality. Information reported is based on a survey of specialists in 18 European countries using a structured questionnaire, combined with information collected from a literature search of international databases. The survey was designed to provide a qualitative assessment of the impact of organic farming on the environment and resource use compared with that of conventional farming practices. Besides addressing water quality issues such as nitrate leaching and runoff from compost piles, this review also addresses flora and fauna diversity, energy use, animal health and welfare, and food quality of organically produced foods. Rated on a scale from "much better" to "much worse" (overall) organic farming was rated "the same as" conventional farming systems in about 40 percent of the categories, "better" in 40 percent, and "much better" in 20 percent. Tables and charts, provided in each section, summarize how referenced research studies compared organic agricultural practices with conventional practices for that particular issue.
>
> Besides rating organic against conventional practices, the authors provide, for each specific environmental issue, a description of the issue, followed by a summary of the research conducted, concluding with a summary of how research results can be used in organic crop management decisions. For example, the section on nitrate leaching concludes with a list of management recommendations for organic farmers, such as reducing livestock density, using appropriate animal husbandry practices, limiting the use of liquid manure, using compost that is homogeneous, and increasing green manuring.

Conacher, J. and A. Conacher. 1998. Organic farming and the environment, with particular reference to Australia: A review. Biological Agriculture and Horticulture. Volume 16. p. 145-171.

Although this article focuses on Australian agriculture, most of the information presented is also pertinent to organic farming systems in the U.S. The authors begin with a discussion of environmental benefits commonly attributed to organic farming systems, including improvements in soil structure and porosity, water infiltration and water-holding capacity, nutrient cycling and nutrient retention, and buffering against pest and disease infestations. In reference to Australia (and by extension, to some of the semi-arid regions of the U.S.) the authors stress the ability of organic farming practices to build up soil organic matter reserves to restore hydrological balances and enhance soil structure in saline soils.

According to the authors, potential adverse environmental impacts of organic farming practices include:

- Soil degradation when insufficient amounts of nutrient and organic-matter inputs are applied relative to crop removal
- An increase in soil acidity caused by the leaching of cations with nitrate anions
- Use of fertilizers and amendments from uncertified or unregulated sources
- Nitrate leaching
- Eutrophication
- Heavy-metal concentrations
- Contamination from persistent pesticides applied prior to the conversion of fields from conventional to organic production practices

Recommendations are provided to minimize these environmental risks, along with references to scientific studies that form the basis for the recommendations.

Organic systems and nitrate leaching

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature. Volume 396. p. 262-265.

Nitrogen and carbon losses from organic and conventionally managed fields were analyzed over 15 years. Immobilization of nitrogen by soil organisms and soil organic matter caused nitrogen to accumulate in organically managed fields. Conventional fields had less nitrogen immobilization and more nitrate leaching than the organic plots. Nitrate-leaching was 50% more in the conventionally managed fields compared to the organically managed fields. In addition, organic fields had higher water infiltration rates, higher water holding capacity, reduced soil erosion, and increased soil productivity.

McIsaac, G. and R.A. Cooke. 2000. Evaluation of water quality from alternative cropping systems using a multiple-paired design. University of Illinois at Urbana-Champaign. College of Agriculture, Consumer and Environmental Sciences. Accessed at <http://www.aces.uiuc.edu/~asap/research/stew_farm/home.html>.

Nitrate losses from tile-drained organically managed corn and soybean fields were lower, on average, than those from conventionally managed fields on similar soils.

Nitrate accumulated in soil organic matter and in plant residues. High concentrations of nitrate nitrogen, however, were measured in drainage water from organic fields following the incorporation of green manure into the soil.

McCracken, D.V., M.S. Smith, J. H. Grove, C. T. MacKown, and R.L. Blevins. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. Soil Science Society of America Journal. Volume 58. p. 1476-1483.

Rye was more effective than vetch in preventing nitrate leaching from fields. Early plant development allowed for nitrogen capture during the early spring while the extensive root system of the rye plants efficiently scavenged nitrate from soils. Fall rye was recommended as a cover crop for reducing nitrate leaching during the winter season.

Wander, M.M., S.J. Traina, B.R. Stinner, S.E. Peters. 1994. Organic and conventional management effects on biologically active soil organic matter pools. Soil Science Society of America Journal. Volume 58. p. 1130-1139.

A ten-year comparison of organically and conventionally managed fields showed higher levels of carbon and nitrogen accumulation in the organically managed soils. Cover-cropped soils had organic matter with a high C/N ratio indicative of high organic matter turnover rates and retention of soil organic matter in chemically stabilized forms. Conversely, the conventionally managed soil had the smallest pool of soil organic matter and lowest levels of biological activity. High levels of biological activity in cover-cropped fields corresponded with greater retention of nitrogen by the soil.

Nitrogen availability in organic production systems

Cover crop acreage, Shinbone Valley, Tennessee.

Photo used with permission.

Pang, X.P. and J. Letey. 2000. Organic farming: Challenge of timing nitrogen availability to crop nitrogen requirements. Soil Science Society of America Journal. Volume 64. p. 247-253.

The rates and amounts of nitrogen mineralized from organic materials are not consistent with nutrient needs of hybrid corn and other crops grown under organic production methods. To meet nutrient demands of corn, excessive amounts of manure must be applied. As this manure mineralizes, nitrate not taken up by the crop plants is susceptible to leaching. Hybrid corn varieties have a narrow time period during which they require high nitrogen availability to obtain optimum yields. Nitrogen mineralization occurs too gradually to meet these peak demands, resulting in sub-optimal yields. Mineralization that continues beyond the time of peak nitrogen uptake can release nitrate, which is then subject to leaching. More nitrogen leaches from applications of cattle manure than from poultry litter since cattle manure has a slower mineralization rate. Related studies show that nitrogen leaching was greatest when poor growing conditions resulted in rapid nitrogen mineralization but limited nitrogen uptake by plants. The authors suggested that the lack of synchrony they observed between nitrogen mineralization and nitrogen uptake was due to the use of nitrogen-responsive hybrid varieties of corn. Traditional varieties of corn evolved with systems dependent on organic inputs and do not have the same narrow period of demand for nitrogen exhibited by the hybrid varieties.

Mikkelsen, R.L. 2000. Nutrient management for organic farming: A case study. Journal of Natural Resources and Life Science Education. Volume 29. p. 88-92.

A case study of an organic farming operation raises questions about nutrient management practices, processes used to manage land in organic farming, and potential problems that could arise in the certification of organic farms. The case study describes an organic vegetable farming operation that uses poultry manure as a source of organic matter and nutrients. Unfortunately, the manure additions have resulted in buildups of copper and zinc in the soil because these compounds were used as feed supplements for poultry. The concentrations of these heavy metals in the soil have limited the farmer's ability to grow certain copper-sensitive crops and is causing him problems in trying to keep his organic certification. Questions raised by this case study include:

- What management practices can the farmer use to lessen the impact of this concentration of heavy metals in his soil on crop growth?
- What role should organic certification groups and government agencies have in maintaining soil quality on farms?
- What responsibility should poultry producers have in the production of a litter that has minimal impact on the environment?

Related NCAT/ATTRA Publications

Biointensive Integrated Pest Management
Farmscaping to Enhance Biological Control
Pursuing Conservation Tillage Systems for Organic Crop Production
Manures for Organic Crop Production
Nutrient Cycling In Pastures
Sustainable Soil Management
Organic Alternatives to Treated Lumber

References

Ag-Org P/L. 2001. Ag-Org P/L Organic Fertilizer. Accessed at <http://www.ag-org.com/chemistry.html>.

Bachmann, J. and R. Earles. 2000. Season Extension Techniques for Market Gardeners. NCAT/ATTRA, Fayetteville, AR.

Bezdicek, D., M. Fauci, D. Calwell, R. Finch, and J. Lang. 2001. Persistent herbicides in compost. BioCycle. Vol. 42, No. 7. p. 25–30.

Bowman, G., C. Shirley, and C. Cramer. 1998. Managing Cover Crops Profitably. Second Edition. Sustainable Agriculture Network. Handbook Series Book 3. National Agricultural Library, Beltsville, MD.

Brandi-Dohrn, F.M., R.P. Dick, M. Hess, S.M. Kauffman, D.D. Hemphill, Jr., and J.S. Selker. 1997. Nitrate leaching under a cereal rye cover crop. Journal of Environmental Quality. Vol. 26. p. 181–188.

Caldwell, B. 2001. How can organic vegetable growers increase soil organic matter without overloading the soil with nutrients. Small Farmer's Journal. Vol. 25, No. 3. p. 22–23.

Conacher, J. and A. Conacher. 1998. Organic farming and the environment, with particular reference to Australia: A review. Biological Agriculture and Horticulture. Vol. 16. p. 145–171.

Diver, S. 2001. Alternative Soil Testing Laboratories. NCAT/ATTRA, Fayetteville, AR.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature. Vol. 396. p. 262–265.

Dufour, R. 2001. Biointensive Integrated Pest Management (IPM). NCAT/ATTRA, Fayetteville, AR.

Dufour, R. 2000. Farmscaping to Enhance Biological Control. NCAT/ATTRA, Fayetteville, AR.

Durham, S. 2001. Vegetative Mulch Reduces Pesticide and Soil Losses in Runoff. ARS News and Information. Accessed at: <http://www.ars.usda.gov/is/pr/2001/010402.htm>.

Edwards, C. 1999. Soil Biology Primer. United States Department of Agriculture, Natural Resources Conservation Service, Washington, D.C.

Gaskell, M. J. Mitchell, R. Smith, S.T. Koike, and C. Fouche. 2000. Soil fertility management for organic crops. University of California, Division of Agriculture and Natural Resources. Publication 7249. Accessed at: <http://anrcatalog.ucdavis.edu/merchant.ihtml?pid=3704&step=4>.

Gegner, L. 2002. Organic Alternatives to Treated Lumber. NCAT/ATTRA, Fayetteville, AR.

Gershuny, G. and J. Smillie. 1995. The soul of soil : A guide to ecological soil management. agAcess, Davis, CA.

Granstedt, A. and G. L-Baeckstrom. 2000. Studies of the proceeding crop effect of ley in ecological agriculture. American Journal of Alternative Agriculture. Vol. 15, No. 2. p. 68–78.

IFST Public Affairs and Technical & Legislative Committees. 2001. IFST: Current Hot Topics. Organic Food. Institute of Food Science and Technology (UK). Accessed at: <http://www.ifst.org/hottop24.htm>.

Karlen, D.L. and D.E. Stott. 1994. A framework for evaluating physical and chemical indicators of soil quality. In: J.W. Doran, D.C. Coleman, D.F. Bezdicek, and B.A. Stewart (eds.) Defining Soil Quality for a Sustainable Environment. Soil Science Society of America, Inc., Madison, WI.

Klausner, S. 1995. Nutrient Management: Crop Production and Water Quality. Cornell University. College of Agriculture and Life Sciences, Ithaca, NY.

Kuepper, G. 2000. Manures for Organic Crop Production. NCAT/ATTRA, Fayetteville, AR.

Kuepper, G. 2001. Pursuing Conservation Tillage Systems for Organic Crop Production. NCAT/ATTRA, Fayetteville, AR.

Lichthardt, J.J. and J. Jacobsen. 1991. Fertilizer Guidelines for Montana. Bulletin 104. Montana State University Extension, Bozeman, MT. 42 p.

Lyman, B. and M. Sarrantonio. 1993. Brassicas. Northeast Cover Crop Fact Sheet #17. Soil Health Series. Rodale Institute Research Center, Kutztown, PA.

Magdoff, F. 1991. Understanding the Magdoff Pre-Sidedress Nitrate Test for corn. American Society of Agronomy Journal. Vol. 4, No. 3. p. 297-305.

Magdoff, F., and H. van Es. 2000. Building Soils for Better Crops. Second Edition. Sustainable Agriculture Network, Beltsville, MD.

Marr, C. W. 1993. Plastic mulches for vegetables. Commercial Vegetable Production. Kansas State University Agricultural Experiment Station and Cooperative Extension Service. Accessed at: <http://www.oznet.ksu.edu/library/hort2/samplers/MF1091.asp>.

McCracken, D.V., M.S. Smith, J. H. Grove, C. T. MacKown, and R.L. Blevins. 1994. Nitrate leaching as influenced by cover cropping and nitrogen source. Soil Science Society of America Journal. Vol. 58. p. 1476–1483.

McGraw, L. 2001. Paper mulch coated with vegetable oil offers biodegradable alternative to plastic. ARS News and Information. Accessed at: <http://www.ars.usda.gov/is/pr/2001/010312.htm>.

McIsaac, G. and R.A. Cooke. 2000. Evaluation of water quality from alternative cropping systems using a multiple-paired design. University of Illinois at Urbana-Champaign. College of Agriculture, Consumer and Environmental Sciences. Accessed at: <http://www.aces.uiuc.edu/~asap/research/stew_farm/home.html>.

Mikkelsen, R.L. 2000. Nutrient management for organic farming: A case study. Journal of Natural Resources Life Science Education. Vol. 29. p. 88–92.

Minnesota Department of Agriculture. 1995. Useful Nutrient Management Data. MDA, St. Paul, MN.

Minnesota Department of Agriculture. 2002. Certified Manure Testing Laboratories. Accessed at: <http://www.mda.state.mn.us/appd/manurelabs.htm>.

Mitchell, C.C. Jr. 1990. Nutrient removal by Alabama crops. Alabama Cooperative Extension System. Circular ANR-449. Accessed at: <http://www/aces.edu/department/grain/ANR-449.htm>.

Mulvaney, R.L., S.A. Khan, R.G. Hoeft, and H.M. Brown. 2001. A soil organic nitrogen fraction that reduces the need for nitrogen fertilization. Soil Science Society of America Journal. Vol. 65. p. 1164–1172.

National Organic Program. 2000. Soil fertility and crop nutrient management practice standard, Section 205.203. In: National Organic Program Final Rule. December 21. Accessed at: <http://www.ams.usda.gov/nop/nop2000/nop2/finalrulepages/finalrulemap.htm>.

National Organic Program. 2002a. Production and Handling. Subpart C—Organic Crop, Wild Crop, Livestock, and Handling Requirements. Crop Production. Accessed at: <http://www.ams.usda.gov/nop/nop2000/Final%20Rule/preamble/pre-prodhandling.htm>.

National Organic Program. 2002b. National List of Allowed and Prohibited Substances. Subpart 205.600 Evaluation criteria for allowed and prohibited substances, methods, and ingredients. National Organic Program Final Rule. Accessed at: <http://www.ams.usda.gov/nop/nop2000/Final%20Rule/regtext/reg-natlist.htm>.

Nyhuis, J. 1982. Desert harvest : A guide to vegetable growing in arid lands. Growing Connections, Inc., Tucson, AZ

Pang, X.P. and J. Letey. 2000. Organic farming: Challenge of timing nitrogen availability to crop nitrogen requirements. Soil Science Society of America Journal. Vol. 64. p. 247–253.

Peet, M. 2001. Living mulches. Sustainable Practices for Vegetable Production in the South. Accessed at: <http://www.cals.ncsu.edu/sustainable/peet/cover/l_mulch.html>.

Randall, G.W., D.R. Huggins, M.P. Russelle, D.J. Fuchs, W.W. Nelson, and J.L. Anderson. 1997. Nitrate losses through subsurface tile drainage in conservation reserve program, alfalfa, and row crop systems. Journal of Environmental Quality. Vol. 26. p. 1240–1247.

Rutledge, A.C. 2002. Agricultural plastics—It's good but… Agricultural Extension Service. The University of Tennessee. Accessed at: <http://bioengr.ag.utk.edu/Extension/ExtProg/machinery/Articles/agplastics.htm>.

Ryan, M. 1999. Is an enhanced soil biological community, relative to conventional neighbours, a consistent feature of alternative (organic and biodynamic) agricultural systems? Biological Agriculture and Horticulture. Vol. 17. p. 131–144.

Rynk, R. (ed.) 1992. On-Farm Composting Handbook (NRAES-54). Northeast Regional Agricultural Engineering Service (NRAES), Ithaca, NY.

Sainju, U.M. and B.P. Singh. 1997. Winter cover crops for sustainable agricultural systems: Influence on soil properties, water quality, and crop yields. HortScience. Vol. 32, No. 1. p. 21–28.

Sharpley, A., S.J. Smith, and J.A. Daniel. 1995. Prevention of ground and surface water contamination by new agricultural management systems. In: Clean Water–Clean Environment–21st Century. Team Agriculture—Working to Protect Water Resources. Volume III: Practices, Systems and Adoption. Conference proceedings. March 5–8, 1995, Kansas City, MO.

Sharpley, A.N., T. Daniel, T. Sims, J. Lemunyon, R. Stevens, and R. Parry. 1999. Agricultural Phosphorus and Eutrophication. ARS–149. United States Department of Agriculture/ Agricultural Research Service, Washington, D.C.

Solberg, S.O. 1995. Influence of crops and cultivation management on the nitrogen leaching potential on ecological farms in southeast Norway. Biological Agriculture and Horticulture. Vol. 11, No. 1. p. 115–121.

Stehman, S.M., C. Rossiter, P. McDonough, and S. Wade. 1996. Potential pathogens in manure. In: J.S. Popow (ed.) Animal Agriculture and the Environment: Nutrients, Pathogens, and Community Relations. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

Stolze, M., A. Piorr, A. Haring, and S. Dabbert. 2000. The Environmental Impacts of Organic Farming in Europe. Organic Farming in Europe: Economics and Policy. Vol. 6. University of Hohenheim, Stuttgart, Germany. 127 pages.

Stopes, C., S. Millington, and L. Woodward. 1996. Dry matter and nitrogen accumulation by three leguminous green manure species and the yield of a following wheat crop in an organic production system. Agriculture, Ecosystems and Environment. Vol. 57, No. 2/3. p. 189–196.

Stout, W.L., S.L. Fales, L.D. Muller, R.R. Schnabel, and S.R. Weaver. 2000. Water quality implications of nitrate leaching from intensively grazed pasture swards in the northeast US. Agriculture, Ecosystems, and Environment. Vol. 77. p. 203–210.

Sullivan, P. 1999. Sustainable Soil Management. NCAT/ATTRA, Fayetteville, AR.

University of California - SAREP. No date. Cover crop database. University of California Sustainable Agriculture Research and Education. Accessed at: <http://www.sarep.ucdavis.edu/cgi-bin/ccrop.exe>.

University of Maine. 1998. Home Garden Organic Nutrient Sources. Analytical Laboratory.

Maine Soil Testing Service. Accessed at: <http://anlab.umesci.maine.edu/handout/organ02.HTM>.

van der Werff, P.A., A. Baars, and G.J.M. Oomen. 1995. Nutrient balances and measurement of nitrogen losses on mixed ecological farms on sandy soils in the Netherlands. Biological Agriculture and Horticulture. Vol. 11, No. 1. p.41–50.

van Es, H. and L. Geohring. 1993. Rapid movement of manure to tile drainage lines: Should we be concerned? What's Cropping Up? Vol. 3, No. 4. p. 5, 7.

Wallace, J. (ed.) 2001. Organic Field Crop Handbook. Second Edition. Canadian Organic Growers, Ottawa, Ontario, Canada.

Wander, M.M., S.J. Traina, B.R. Stinner, S.E. Peters. 1994. Organic and conventional management effects on biologically active soil organic matter pools. Soil Science Society of America Journal. Vol. 58. p. 1130–1139.

Wilkinson, S.R. 1997. Response of Tifway 2 bermudagrass to fresh or composted broiler litter containing boric acid-treated paper bedding. Communications in Soil Science and Plant Analysis. Vol. 28, No. 3–5. p. 259–279.

Wright, P.E. and R. E. Graves. 1998. Guidelines for milking center wastewater. DPC?15, NRAES 115. Northeast Regional Agricultural Resource Service, Ithaca, NY.

WSDA. 2002. Clopyralid in compost. Facts. Washington State Department of Agriculture, Olympia, WA. 1 page. Accessed at: <http://www.wa.gov/agr/Clopyralid%20f.pdf>.

Wyland, L.J., L.E. Jackson, W.E. Chaney, K. Klosky, S.T. Koike, and B. Kimple. 1996. Winter cover crops in a vegetable cropping system: Impacts on nitrate leaching, soil water, crop yield, pests and management costs. Agriculture, Ecosystems and Environment. Vol. 59. p. 1–17.

Zublena, J.P., J.V. Baird, and J.P. Lilly. 1991. Soil Facts: Nutrient Content of Fertilizer and Organic Materials. North Carolina Cooperative Extension Service. Accessed at: <http://www.soil.ncsu.edu/publications/Soilfacts/AG-439-18/>.

By Barbara Bellows
NCAT Agriculture Specialist

Edited by Richard Earles
Formatted by Gail Hardy

October 2002

The electronic version of **Protecting Water Quality on Organic Farms** is located at:
HTML
http://www.attra.ncat.org/attra-pub/organicmatters/om-waterquality.html
PDF
http://www.attra.ncat.org/attra-pub/PDF/om-waterquality.pdf

IP214