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Soil Management for Small Farms

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Farming West of the Cascades

What Is Soil?

Soil is a natural mixture of weathered rock fragments and organic matter that has formed at the surface of the earth. It is biologically active—a home to countless microorganisms, invertebrates, and plant roots. It varies in depth from a few inches to five or more feet. Soil is roughly 50% pore space, a complex network of pores of varying sizes, much like those in a sponge.

Soil provides nutrients, water, and physical support for plants, and air for plant roots. Soil organisms are nature's prime recyclers, turning dead cells and tissue into nutrients, energy, carbon dioxide, and water to fuel new life.

Soil and Water

Soil Pores, Water, and Productivity

A productive soil can take in and hold water and supply water to plants. A soil's permeability and water holding capacity depend on its network of pores.

- Large pores, or macropores, control the permeability and aeration of a soil. Macropores include earthworm channels and many root channels. They are large enough that water moves through them rapidly by gravity, allowing rainfall and irrigation water to infiltrate into the soil and excess water to drain through the soil.

- Micropores are fine soil pores, typically a fraction of a millimeter in diameter. They are responsible for the water holding capacity of soil. Micropores hold water by capillary forces, like the fine pores in a sponge or towel. Much of the water held in micropores is available to plants, while some is held so tightly that plant roots cannot tap it.

Soil that has a balance of macropores and micropores will provide adequate permeability and water holding capacity for good plant growth. Soils that contain mostly macropores will take in water readily, but they will not hold

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much water. As a result, they need more frequent irrigation. Soils that contain mostly micropores will have good water holding capacity, but they will take longer to dry and warm in the spring. They do not take in water readily, thus rainfall and irrigation water may run off the soil surface.

What Affects the Porosity of Your Soil?

A number of soil properties affect the abundance of macropores and micropores. These include texture, structure, compaction, and organic matter. You can evaluate these properties to understand how they affect the porosity of your soil. The only tools you need are your eyes, your fingers, and a shovel.

Soil texture. Texture describes how coarse or fine a soil is; it depends on the relative amounts of sand, silt, and clay particles in the soil. The coarsest soil particles are sand. They are visible to the eye, and they give soil a gritty feel. Silt particles are smaller than sand, about the size of individual particles of white flour. They give soil a smooth, floury feel. Sand and silt particles look like miniature rocks. Clay particles are the finest, similar in size to tiny bacteria and viruses, and they typically have a flat shape. Soils rich in clay feel very hard when dry, but they are easily shaped and molded when moist.

Although all of these particles seem small, the relative difference in their sizes is quite large. If a typical clay particle were the size of a penny, a sand particle would be as large as a house.

Soil texture affects porosity. Pores between sand particles tend to be large, while pores between silt and clay particles tend to be small. Thus, sandy soils contain mostly macropores, promoting permeability but limiting water holding capacity. Clayey soils contain mostly micropores, creating high water holding capacity but reducing permeability.

Table 1. Soil particle sizes.

Particle	Diameter
Sand	0.05—2 mm
Silt	0.002—0.05 mm
Clay	<0.002 mm

Particle size also affects the surface area in a volume of soil. Surface area is important because surfaces are the most active part of the soil, holding plant nutrients, binding contaminants, and providing a home for microorganisms. Clay particles have a large surface area relative to their volume; a small amount of clay makes a large contribution to the surface area of a soil.

Nearly all soils contain a mixture of particle sizes and a pore network of varying pore sizes. A soil that has roughly equal influence of sand, silt, and clay particles is called a loam. Loams usually make good agricultural and garden soils because they have a balance between macropores and micropores. Loams usually have good water holding capacity and moderate permeability.

A sandy loam is similar to a loam, except that it contains more sand. It feels gritty, yet has enough silt and clay to hold together in your hand. Sandy loams usually have low to moderate water holding capacity and good permeability. Silt loams are richer in silt, and feel smooth rather than gritty. They are pliable when moist, but they are not very sticky. Silt loams usually have high water holding capacity and low to moderate permeability. Clays and clay loams are very hard when dry, and sticky when wet. They can be molded into wires and ribbons when moist. They generally have high water holding capacity and low permeability.

Many soils contain coarse fragments—gravel and rocks. Coarse fragments do not contribute to the productivity of a soil, and they can be a nuisance when tilling. Most agricultural soils have less than 15% coarse fragments in the plow layer.

Soils with many different textures can be suitable for farming, as long as you are aware of the soil's limitations and use appropriate management. Sandy soils need lighter, more frequent irrigation and fertilization, but you can till them earlier in the spring. Clay soils hold more water, but they are harder to till, and they dry more slowly in the spring.

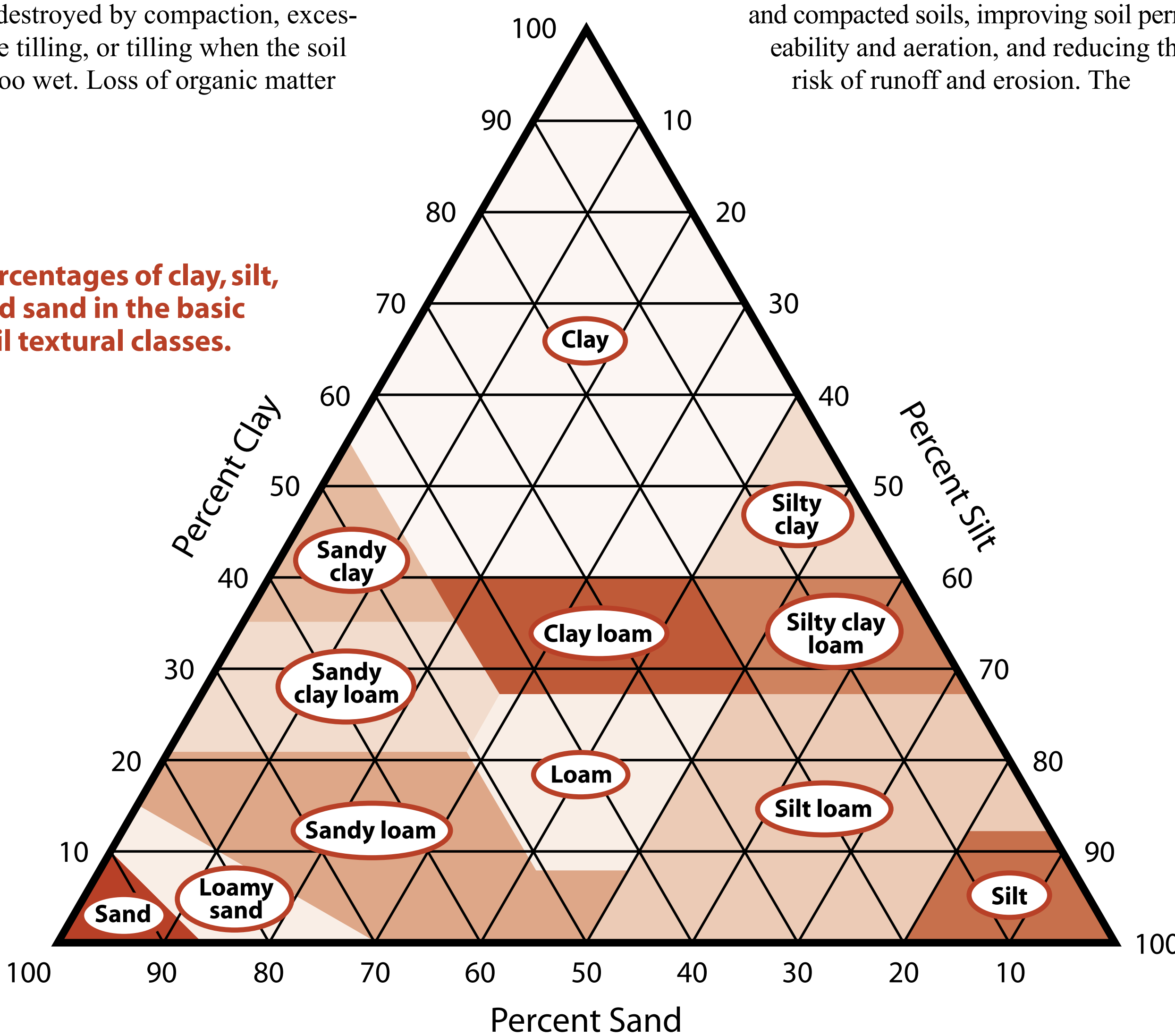
Soil structure. Individual particles of sand, silt, and clay tend to cluster and bind together in soil, forming aggregates called peds. Aggregation is a natural process in soil, caused largely by biological activity, including earthworm burrowing, root growth, and microbial action. Soil organic matter is an important binding agent that stabilizes and strengthens the peds, providing structure to the soil. Dig up a piece of grass sod and examine the soil around the roots. The granules of soil you see hanging onto the grass roots are examples of peds—containing sand, silt, clay, and organic matter.

In medium- to fine-textured soils, good structure is important because it increases the macroporosity of the soil. The spaces between peds are macropores, improving permeability, drainage, and recharge of air into the soil profile. The pores within peds are predominantly micropores, contributing to the water holding capacity of the soil.

Compaction and loss of structure. Soil structure is fragile and can be damaged or destroyed by compaction, excessive tilling, or tilling when the soil is too wet. Loss of organic matter also weakens structure. Compaction alters the structure of the soil, squeezing macropores into micropores and creating horizontal aggregates that resist root penetration and water flow. You can protect the structure of your soil by avoiding unnecessary traffic on the soil, and by postponing tillage until the soil has become dry enough to till. If you can mold a piece of soil into a wire or worm in your hand, it is too wet for tilling. If the soil crumbles when you try to mold it, it is dry enough to till.

Sometimes a compacted layer or "plow pan" forms just below the depth of tillage. Occasionally, tilling deeper helps break up a plow pan.

Organic matter. Adding organic matter is the best way to improve the plant environment in nearly all soils. Organic matter helps build and stabilize soil structure in fine-textured and compacted soils, improving soil permeability and aeration, and reducing the risk of runoff and erosion. The



Percentages of clay, silt, and sand in the basic soil textural classes.

biological decomposition of organic materials produces natural glues, which bind and strengthen soil aggregates. Organic matter also helps sandy soils hold water and nutrients. Refer to pages 20–22 for information on amending soil with organic matter.

Effect of Porosity on Irrigation

Most areas in the Northwest require summer irrigation for peak crop production. Irrigation is essential on sandy soils. The need for irrigation varies, depending on soil water holding capacity, weather, site aspect, and crop requirements. In most cases, the goal of irrigation is to recharge the available water in the top foot or so of the soil. For a sand, one inch of irrigation water will recharge the water holding capacity. Any more will leach through the root zone, carrying nutrients with it. A silt loam or clay can hold more than 2 inches of water, but you may need to irrigate more slowly than for a sandy soil to avoid runoff.

Site and Landscape Factors

Landscape Position

Landscape position affects the suitability of a site for the production of specific crops. Ridge tops and sideslopes tend to shed water, and soils in these landscape positions are likely to be droughty and subject to erosion. Soils at the bottom of slopes and in low areas collect water, and are likely to be wet late into the spring. Soils on level ground can also be wet during the winter and spring, especially if they have a fine-textured or compacted subsurface layer that restricts the downward movement of water.

Wet Soils

If your soil stays wet in the spring, you will have to delay working the soil and planting. Working wet soil can damage the structure, and planting in cold, wet soil reduces germination. Some plants don't perform well in wet soils. Raspberries, for example, become infected by a root disease in wet soils, lose vigor and may die.

Soil color gives clues to the wetness of a soil. If the subsoil is a brown or reddish color, the soil is usually well drained with few wetness problems. Gray and mottled subsoils are often saturated during the wet season.

If you have wet areas on your farmland, avoid the temptation to till too early in the season, and avoid crops that are sensitive to wet conditions. Mid-season annual crops such as sweet corn, green beans, and squash, and some perennial forages are good choices for wet soils. Blueberries can be a suitable crop on moderately wet soils.

Some farmland has subsurface drainage or ditches that lower the water table and help the soil dry more quickly. If your land has drainage you can maintain and repair it to keep it functioning well. If your land is wet and undrained, you may not be able to install drainage because of wetland regulations. If you have questions about field drainage, check with your local Natural Resources Conservation Service (NRCS) office. You can find it in the government pages of the phone book listed under Federal Government, Department of Agriculture.

Raised beds can improve drainage in marginal situations. The simplest raised beds involve hilling soil in rows during tillage. Raspberry growers frequently hill soil around raspberry plants because the raspberry roots will grow into the more aerated soil in the hilled area, reducing problems with root rot. More sophisticated raised beds can be quite expensive, and usually they are more suitable for gardens than farms. Raised beds may be economical for farmers in some cases; for farmers growing a small area of high value crops under intensive management, installing raised beds may make sense.

Runoff and Erosion

Runoff and soil erosion can be a serious problem on sloping ground. Erosion affects soil quality and crop productivity by reducing the depth of topsoil. Runoff and erosion can also affect water quality when eroded soil or dissolved contaminants run off into surface water. If you are farming sloping ground, follow recommended conservation practices to reduce runoff and erosion. These practices include minimum tillage, cover cropping, contour planting, and strip rotations. The key to these practices is keeping vegetative cover or crop residues on the surface as much as possible to help water soak into the soil rather than run off. Check with your local NRCS office for information on conservation practices that are appropriate for your farm.

Site Aspect

Site aspect has an important effect on crop growth. South- and southwest-facing exposures collect the most sunlight and heat and use the most water. North- and northeast-facing exposures are cooler and retain more water. Low-lying areas can be prone to early and late frosts. South and southwest exposures are a good location for crops grown for early-season markets and crops that need a lot of heat units to ripen. Always consider site aspect when looking to lease or purchase land, or when planning for crop production.

Soil Horizons and Depth

Soil typically has several layers or horizons that were formed by natural weathering processes. Sometimes different layers formed during different geological events.

The surface soil, or topsoil, is the darkest color and contains the most organic matter. It is the most biologically active layer and contains the largest proportion of available nutrients. Topsoils in western Washington range in depth from about 3 inches to 12 inches.

The subsoil contains less organic matter than the topsoil, and it is lighter in color. Its texture can be coarser, finer, or similar to the topsoil. The subsoil provides additional water and nutrients to crops. Deep subsoils with moderate to high water holding capacity greatly increase the ability of deep-rooted crops to survive drought. Well-drained subsoils have uniform brown or reddish colors, while wet subsoils are usually gray, flecked with bright-colored mottles.

Beneath the subsoil is relatively unweathered material called parent material. The parent material in most soils contains few roots and little or no structure. Biological activity is much lower than in the topsoil or subsoil.

Some soils have layers that restrict root growth. In western Washington, the most common restrictive layers are compact "hardpans" in glacial soils, or coarse gravelly layers that hold little water. Other restrictive layers include tight clay horizons and shallow bedrock. Soils with shallow root zones will have less available water and fewer nutrients than a similar soil with a deeper root zone.

Soils of Western Washington

Most of the agricultural soils in western Washington are in the lowlands, below 1,200 feet elevation. This section describes the major types of lowland soils in western Washington, how they were formed, and their suitability for agriculture.

Alluvial Soils

The alluvial soils in the major river valleys throughout western Washington are by far the best farmlands in the area. These soils were formed by repeated flooding cycles that have occurred since the most recent glacial retreat about 15,000 years ago. The valley soils are deep, level, and nearly free from rocks. Most are sandy loam to silt loam in texture. They have good to excellent water holding capacity, good nutrient holding capacity, and low erosion potential. They are easy to till with light equipment and suitable for a variety of crops. Some areas are wet late into the spring and are not suitable for early crops or crops sensitive to wet soils. Other areas are well drained. Most of the alluvial soils in King and Pierce counties have been lost to development, and development encroaches on alluvial farmland in other counties as well.

Glacial Soils

Most of the other soils in the Puget Sound area formed from glacial materials on low plateaus. The glacial soils developed from three main types of glacial material: till, outwash, and lacustrine (lakebed) deposits.

Glacial till is material left behind by glacial ice. Soils developed from till typically have a sandy loam to loam texture, containing more than 15% gravel and rocks. These soils are usually 18 to 36 inches deep and are underlain by a "hardpan" that consists of very dense and cemented till that was compacted by the weight of the glacial ice sheet. The dense layer restricts root growth and water movement, and it is too thick and too compact to break up. Glacial till soils have a moderate water holding capacity. They are frequently sloping and somewhat rocky, and low areas tend to be wet. Organic matter levels are generally low. Despite these limitations they are suitable for pastures and moderately productive for row crops. Organic matter, conservation tillage, and careful water and nutrient management will make these soils more productive.

Glacial outwash was deposited by glacial meltwater streams. Outwash soils are found throughout the Puget Sound area and in some parts of southwest Washington. Outwash soils are usually coarse textured—sandy or gravelly. In Whatcom County, the outwash has a cap of silty material about a foot thick that was deposited by wind. Some sandy outwash soils are moderately productive and are good soils for early crops and crops needing well-drained conditions. Careful irrigation management and nutrient management are essential to successful crop production. Gravelly outwash soils are too droughty for farming. Outwash soils with a silty cap hold more water than other outwash soils, and they naturally contain higher levels of organic matter. They vary in drainage, and are suitable for a variety of crops.

Lacustrine soils formed in material deposited at the bottom of ancient glacial lakes. They typically have a silt loam texture in the surface horizon, and silt loam to clay loam texture in the subsoil. They have a high water holding capacity and can be productive under good management. Limitations include wetness late into spring, and risk of runoff and erosion on sloping ground. They can be hard when dry.

Volcanic Soils

Areas of eastern King and Pierce counties have soils developed from volcanic mudflow materials. These soils are level with a black, loamy topsoil and a dense, rocky subsoil. Most mudflow soils have restricted drainage, and are wet during the winter and spring. They are well suited to pastures and acceptable for mid-season row crops. They are too wet for early crops or crops that require good drainage.

Volcanic ash and sediments dominate some soils in Lewis and Cowlitz counties. Suitability for farming varies, depending on slope and texture.

Weathered Soils of Southwest Washington

Most areas south of Olympia were not covered by glacial ice 15,000 years ago, and the soils are quite different from soils in the Puget Sound area. They tend to be older, more weathered, and higher in clay content than the glacial soils. They generally have fewer coarse fragments and a more stable structure. They formed in sediments from old terraces, ancient glacial material, and upland material. Most of these soils range in texture from loam to clay, and are found on a variety of slopes. Gently sloping soils on well-drained landscapes are productive agricultural soils when good conservation practices are used. Maintaining organic matter and soil structure are essential in the finer textured soils. Wetter and more sloping soils are better suited for pasture than row crops.

Evaluating Soils

Evaluating the soil is an important part of choosing farmland. If you are planning to buy or lease farmland, learn as much about the soils as you can, keeping the following in mind: soil texture, structure, compaction, depth, drainage and wetness, landscape position, and site aspect. All these will affect site productivity and suitability for different crops. Don't limit your investigation to the topsoil. Dig or probe to a depth of three feet in a few spots to determine the depth and properties of the underlying soil.

Soil surveys are a tool you can use to identify potential farmland or learn more about land you already lease or own. Each county has a soil survey that contains maps showing locations of different soil types and descriptions of each soil type. Because each soil type can have a range of properties and because several soil types often are mixed together on the landscape, the soil survey map does not necessarily match what you find on a piece of land. Use the survey as a guide for understanding soils in an area, but walk and dig on a piece of land to confirm what the soil is like there.

You can request a copy of a soil survey at your local NRCS office. Some surveys are out of print, but you can visit the NRCS office to look at one of their copies.

Soil Organisms

Soil abounds with life. Besides plant roots, earthworms, insects, and other creatures that we can see, soil is home to an abundant and diverse population of microorganisms. A single gram of topsoil (about one quarter of a teaspoon) may contain a billion microorganisms (Table 2). Microorganisms are most abundant in the rhizosphere—the thin layer of soil surrounding plant roots.

The main function of soil organisms is to decompose the remains of plants and other organisms, releasing energy, nutrients, and carbon dioxide, and creating soil organic matter. Organisms at all levels, from tiny bacteria to insects and earthworms, take part in this food web. Mammals such as moles and voles are also part of the food web, feeding on insects and earthworms.

Table 2. Approximate abundance of microorganisms in agricultural topsoil.

Organism	Number per gram (dry weight basis)
Bacteria	100 million to 1 billion
Actinomycetes	10 million to 100 million
Fungi	100 thousand to 1 million
Algae	10 thousand to 100 thousand
Protozoa	10 thousand to 100 thousand
Nematodes	10 to 100

Some soil organisms play other beneficial roles as well. Mycorrhizae are fungi that infect plant roots and increase the roots' ability to take up nutrients from the soil. Rhizobia bacteria are responsible for nitrogen fixation. Earthworms mix large volumes of soil and create macropore channels that improve permeability and aeration.

Not all soil organisms are beneficial to agriculture. Some are pathogens, causing a variety of diseases, such as root rot of raspberries and scab on potatoes.

The activity of soil organisms depends on soil moisture and temperature. Microorganisms are most active between 70° and 100°F, while earthworms are most active and abundant at about 50°F. Most organisms prefer moist soil. Because organic matter is at the base of the soil food web, soils with more organic matter tend to have more organisms. Just about any activity affects the population and diversity of soil organisms—including tillage, the use of fertilizers, manures, and pesticides, and choice of crop rotations. The relationships between farming practices, microbial populations, and soil quality are complex and often poorly understood. Amending soils with organic matter, returning crop residues to the soil, and rotating plantings are practices that tend to increase the number and diversity of beneficial organisms.

Nutrient Management, Fertilizers, and Manures

Soil supplies 13 essential plant nutrients (Table 3). Each nutrient plays one or more specific roles in the function of the plant. Nitrogen, for example, is part of the structure of molecules of chlorophyll, amino acids, proteins, DNA, and many plant hormones. It plays a vital role in nearly all aspects of the growth and development of the plant, and plants need large amounts of nitrogen to grow well. By contrast, molybdenum is involved in the function of a few enzymes, and plants need only tiny amounts. Molybdenum is nonetheless essential, and plants do not grow well in a soil that is deficient in molybdenum.

Nutrients are classified as primary nutrients, secondary nutrients, and micronutrients, based on the amounts of them plants need (Table 3). When the soil nutrient supply is deficient, farmers use fertilizers to provide the additional nutrients needed for healthy plant growth.

Nutrient Deficiencies

The most common nutrient deficiencies are for the primary nutrients, N, P, and K. Nearly all agricultural soils lack enough available N for ideal plant growth. Sulfur deficiencies are common in western Washington, and calcium and magnesium may be deficient in acid soils. Except for boron and zinc, growers in this region seldom encounter micronutrient deficiencies. Boron deficiencies occur in western Washington, particularly in root crops, brassica crops, and caneberries, such as raspberry. Zinc deficiency is most often associated with high pH soils, especially on tree fruit. Plants with nutrient deficiencies sometimes have characteristic symptoms; they also grow more slowly, yield less, and are less healthy than plants with adequate levels of nutrients.

Excess Nutrients

Excess nutrients can be a problem for plants and the environment. Excesses usually result from applying too much of a nutrient, or applying it at the wrong time. Too much boron is toxic to plants. Too much nitrogen can lead to excessive production of foliage (increasing the risk of disease and wind damage), delayed flowering and fruiting, and delayed dormancy. Extra available nitrogen left in the soil at the end of the growing season can leach into groundwater, degrading the quality of drinking water. Excess levels of nitrogen most often occur on soils where large amounts of manure have been used. The key

Table 3. Essential plant nutrients. Plants obtain these elements from soil, fertilizers, crop residues, and other amendments. Plants also require carbon, hydrogen, and oxygen, which they derive from water and air.

Name	Chemical Symbol	Plant-Available Ions in Soil Water	Solubility
Primary Nutrients			
Nitrogen	N	NH_4^+, NO_3^-, NO_2^-	high
Phosphorus	P	$HPO_4^=$, $H_2PO_4^-$	very low
Potassium	K	K^+	low
Secondary Nutrients			
Sulfur	S	$SO_4^=$	high
Calcium	Ca	Ca^{++}	low
Magnesium	Mg	Mg^{++}	low
Micronutrients			
Zinc	Zn	Zn^{++}	very low
Iron	Fe	Fe^{++}, Fe^{+++}	very low
Copper	Cu	Cu^{++}, Cu^+	very low
Manganese	Mn	Mn^{++}, Mn^{++++}	very low
Boron	B	H_3BO_3	medium
Molybdenum	Mo	$MoO_4^=$	low
Chlorine	Cl	Cl^-	high

to applying fertilizers and manures is to meet plant nutrient needs without creating excesses that can harm plants or the environment.

How Nutrients Become Available to Plants

Plants can only take up nutrients that are dissolved in soil water (in solution). Most nutrients in soil are not in solution; they exist in the soil minerals and organic matter in insoluble forms.

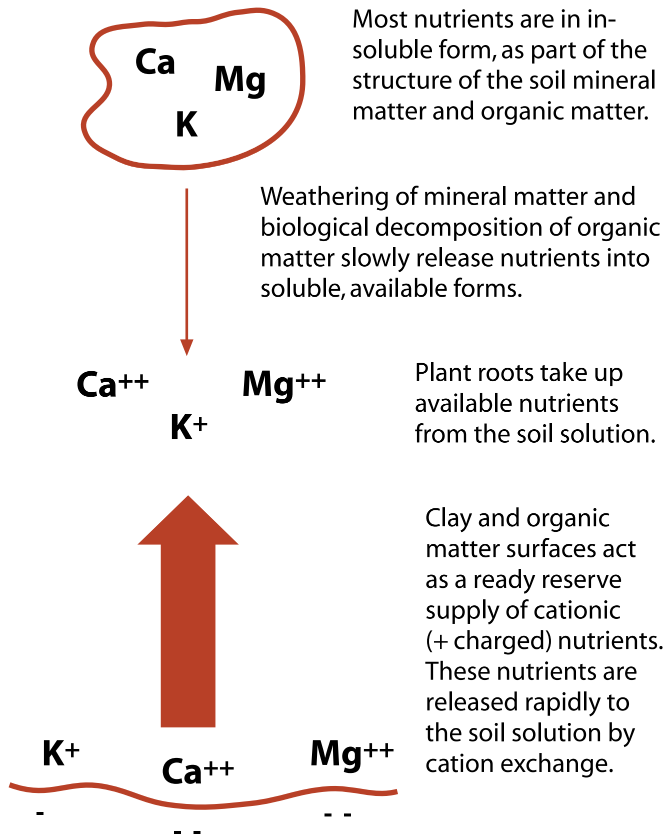
Soil nutrients become available to plants only after they dissolve into soil solution. This occurs by weathering of mineral matter and biological decomposition of organic matter. Weathering of mineral matter is a very slow process, releasing small amounts of nutrients each year. The rate of nutrient release from soil organic matter is somewhat faster, depending on the amount of biological activity in the soil. Nutrient release is fastest when soils are warm and moist, but it is nearly zero when soils are cold or dry. About 1 to 4% of the nutrients in soil organic matter are released in soluble form each year.

Soluble, available nutrients are in ionic form. An ion has either positive or negative charges. Positively-charged ions are cations, and negatively charged ions are anions. Clay particles and soil organic matter have negative charges on their surfaces, and they can attract cations (such as potassium, calcium, and magnesium). The clay and organic matter surfaces hold nutrient cations in a ready reserve form that can be released rapidly into soil solution to replace nutrients taken up by plant roots. This reserve supply of nutrients contributes to the fertility of a soil. The capacity of a soil to hold cations is called its cation exchange capacity, or CEC.

Nitrogen and Phosphorus

Nitrogen and phosphorus present the greatest nutrient management challenges on most farms. Plants need large amounts of both nutrients, but excess levels of either nutrient increase the risk of water quality problems. Understanding the availability and cycling of these nutrients can help growers become better nutrient managers.

The nitrogen cycle. Most nitrogen in soil is in the organic matter in forms such as humus and proteins. This organic nitrogen is not available to plants. As the soil warms in the spring, soil microbes begin



Unavailable and available forms of plant nutrients.

Table 4. Common forms of nitrogen in soil.

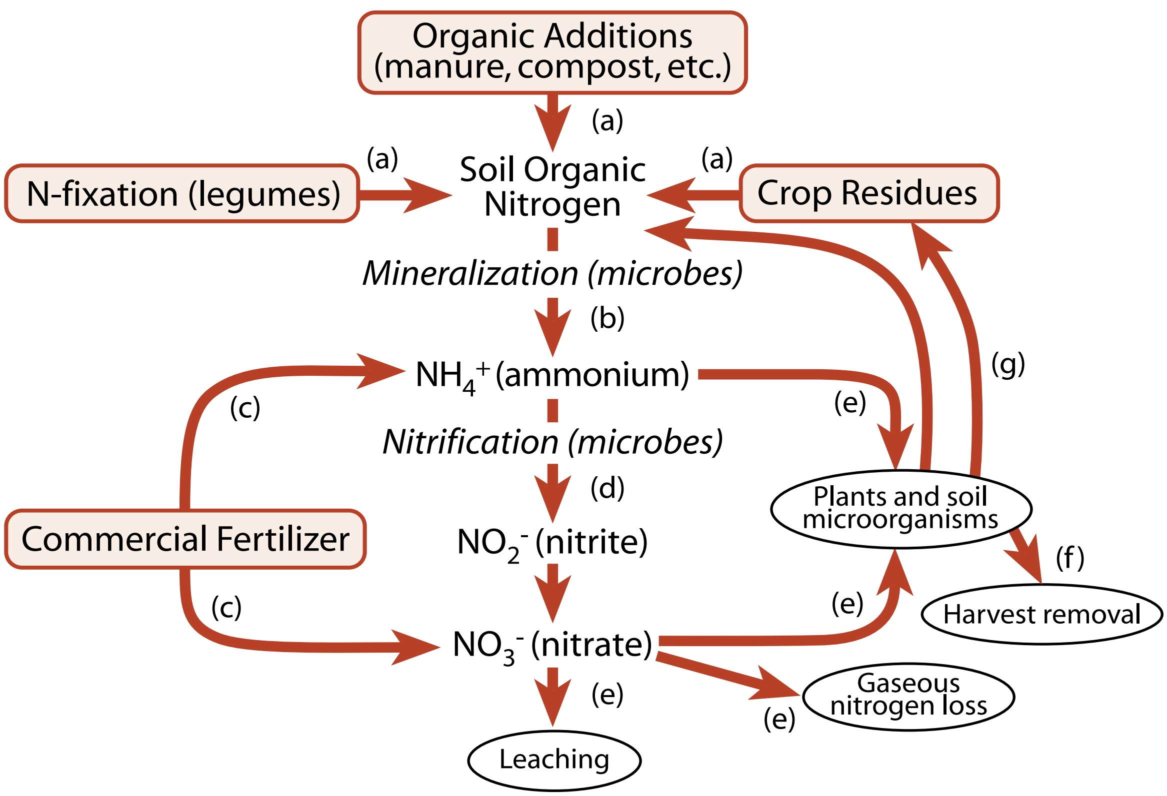
Organic N	Main form in soil. Found in organic matter in forms such as proteins, lignin, amino acids, and humus. Not available to plants. Mineralized to ammonium by soil microorganisms.
Ammonium N (NH_4^+)	Soluble form. Available to plants. Converted to nitrate by soil microorganisms.
Nitrate N (NO_3^-)	Soluble form. Available to plants. Can be lost by leaching. Converted to gases in wet soils.
Atmospheric N (N_2)	Comprises about 80% of soil atmosphere. Source of N for N-fixing plants. Not used by other plants.

to decompose organic matter, releasing some of the nitrogen as ammonium (NH_4^+). Ammonium is a soluble ion that is available to plants and soil microbes. When the soil is warm, a group of microbes called nitrifiers convert the ammonium to nitrate (NO_3^-). Nitrate is also soluble and available to plants. The ammonium and nitrate ions released from soil organic matter are the same as ammonium or nitrate contained in processed fertilizers.

Because nitrate has a negative charge, it is not held to the surfaces of clay or organic matter, and it can be lost readily by leaching. Nitrate remaining in the soil at the end of the growing season will leach during the fall and winter, and it may leach to groundwater where it becomes a contaminant. In soils that become saturated during the wet season, soil microbes convert nitrate to nitrogen gases, which diffuse back into the atmosphere.

Ammonium and nitrate taken up by plants become organic forms in the plant tissue. When plant residues are returned to the soil, they decompose, slowly releasing nitrogen into available forms and completing the cycle.

The nitrogen cycle is a leaky one, with losses to leaching and to the atmosphere. Harvesting crops removes more nitrogen. To maintain an adequate nitrogen supply, nitrogen must be added back into the system through fixation or fertilization. Nitrogen fixation is a natural process involving certain plants and *Rhizobia* bacteria. The *Rhizobia* form nodules in the plant roots; through these nodules they are able to supply atmospheric nitrogen (N_2) from the soil air to the host plant. Legumes such as peas, beans, alfalfa, clover, and scotch broom are common nitrogen-fixers. Alder trees also fix nitrogen. When tissue from N-fixing plants decomposes, the fixed nitrogen becomes



Nitrogen cycle: (a) Legumes, soil organic matter, crop residues and organic additions (manures, composts, etc.) are sources of organic N. (b) Organic N is mineralized into ammonium (NH_4^+) by soil microbes. (c) Commercial fertilizer supplies N as ammonium or nitrate (NO_3^-). (d) Microbes nitrify ammonium to nitrite and then nitrate. (e) Plants, microorganisms, leaching below the root zone, and release of gaseous N to the atmosphere remove N from the root zone soil solution. (f) Crop harvest removes N stored in plants. (g) Nitrogen present in both crop residues and soil microorganisms becomes a part of the soil organic N content.

available to other plants. Farmers use legumes as cover crops or in crop rotations to supply nitrogen to future crops. About one half of the nitrogen in a legume cover crop will become available to the following crop.

Buying feed to raise animals brings nitrogen onto the farm in the feed. The animals cycle a portion of the feed nitrogen to the soil through their manure. Manure is a good source of nitrogen for crops and pastures, but adding excessive amounts of manure leads to over-fertilization, increasing the risk of harm to crops and water quality. For more information on using manure, see pages 13–16 and *Fertilizing with Manure*, PNW0533, part of the Farming West of the Cascades series available from Washington State University Cooperative Extension.

Phosphorus. Available forms of phosphorus are released from the mineral and organic fractions of the soil through the weathering and decomposition processes described on page 9. Unlike nitrogen, the available forms of phosphorus have limited solubility, and they revert to insoluble forms in the soil.

In the spring, when soils are still cool, organic matter decomposition is slow, and little phosphorus is available for plants. It is especially difficult for seedlings or transplants to obtain phosphorus early in the season because their limited root system compounds the effect of low availability. The plants often have a purplish tinge associated with phosphorus deficiency. Many crops respond to phosphorus-rich starter fertilizer placed near the seed or transplants to help overcome early deficiencies. Most plants outgrow the deficiencies as the season continues, because phosphorus availability increases in warmer soils, and root systems grow larger and become more able to tap available phosphorus.

Phosphorus levels can be quite high in soils with a history of manure application, although you may still see some signs of early season phosphorus deficiency in these soils. The risk of water quality problems from excess phosphorus is higher in soils with high phosphorus levels. Phosphorus can be a problem in surface water, where it can lead to the excessive growth of aquatic plants. In the Northwest, lakes are usually the most sensitive to phosphorus. Phosphorus can enter surface water in runoff, in eroded sediments, or through shallow groundwater. The environmental risk depends on the capacity of the soil to hold phosphorus in unavailable forms, the amount of phosphorus added to the soil, the amount of runoff and erosion, and the sensitivity of surface water to phosphorus.

Understanding Fertilizers

Fertilizers supplement the native nutrient supply of the soil. They are essential to good plant growth when soil nutrient supply is inadequate. You can use processed fertilizers, organic fertilizers, or a combination of the two.

Comparing processed and organic fertilizers. Processed fertilizers are manufactured or refined from natural ingredients to make them more concentrated and more available to plants. Typically they are processed into soluble, ionic forms that will be immediately available to plants.

Organic fertilizers are natural materials that have undergone little or no processing. They include both biological (plant and animal) and mineral materials (Table 5). Organic fertilizers release nutrients through natural processes in the soil, including chemical weathering of mineral materials, and biological decomposition of organic matter. The released nutrients are available to plants in a water-soluble form. These soluble forms of nutrients are the same as those supplied by processed fertilizers.

Compared with processed fertilizers, organic fertilizers usually contain smaller amounts of nutrients, and they release nutrients more slowly. You need to apply larger amounts of organic fertilizers, but their effects last longer. Organic fertilizers contain a variety of nutrients, but the amounts are not always balanced according to plant needs.

Using organic fertilizers recycles materials that otherwise would be discarded as waste. Production of processed fertilizers, on the other hand, can create waste and use substantial amounts of energy.

Slow release of nutrients. Organic fertilizers are slow-release fertilizers because their nutrients become available to plants during the course of the growing season through the nutrient cycling process described above. The rate of release of nutrients from organic materials depends on the activity of soil microorganisms, just as it does for soil organic matter. Tempera-

Table 5. Comparing organic and processed fertilizers.

	Organic fertilizers	Processed fertilizers
Source	Natural materials; little or no processing	Manufactured or extracted from natural materials, often undergoing extensive processing
Examples	Manure, cottonseed meal, rock phosphate, fish by-products, ground limestone	Ammonium sulfate, processed urea, potassium chloride
Nutrient Availability	Usually slow-release; nutrients are released by biological and chemical processes in soil	Nutrients usually are immediately available to plants
Nutrient Concentration	Usually low concentration	Usually high concentration

ture and moisture conditions that favor plant growth also favor the release of nutrients from organic fertilizers.

Some organic fertilizers contain immediately available nutrients as well as slow-release nutrients. These materials can supply nutrients to plants both early in the season and later. Fresh manure and fish emulsions are examples of organic fertilizers containing available nutrients as well as slow-release ones. As manure ages, the most readily available fraction is lost into the air or leached into the soil, leaving slow-release material in the aged manure.

Some material in organic fertilizers decays so slowly that the nutrients do not become available the first season after application. Repeated application of organic fertilizers builds up a pool of material that releases nutrients very slowly. In the long run, this will decrease the amount of fertilizer needed each year.

Fertilizer Labels

The labels on fertilizer containers tell the amount of each of the three primary nutrients in the fertilizer, expressed as a percent of total fertilizer weight: Nitrogen (N) is always listed first, phosphorus (P) second, and potassium (K) third. Historically, fertilizer labels have not listed the amount of phosphorus as P, but as units of P_2O_5.[1] This convention is still used today for fertilizer labels and recommendations, even though there is no practical reason for doing so, except that people are accustomed to it. Similarly, fertilizer labels list potassium as K_2O. For example, a bag of fertilizer labeled 5-10-10 contains 5% nitrogen expressed as N, 10% phosphorus expressed as P_2O_5, and 10% potassium expressed as K_2O. This information is the called the fertilizer analysis.

For processed fertilizers the analysis guarantees the amount of available nutrients in the fertilizer. For organic fertilizers the analysis is for the total amount of nutrients rather than available nutrients. The amount of available nutrients will be less than the total, because nutrients in most organic fertilizers are initially unavailable to plants and are released slowly.

Examples of Processed Fertilizers

Nitrogen. The raw material for processed nitrogen fertilizer is nitrogen gas from the atmosphere. The manufacturing process is the chemical equivalent of biological nitrogen fixation, and it requires a substantial amount of fossil fuel energy. Examples of processed nitrogen fertilizers are listed in Table 6.

Phosphorus and potassium. Processed phosphorus fertilizers (Table 7) come from phosphate rock. The rock is treated with acid, releasing the phosphorus into plant-available forms.

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[1] If you need to convert from P to P_2O_5, the conversion is 1lb P = 2.3 lb P_2O_5. For potassium the conversion is 1lb K = 1.2 lb K_2O.

The most common raw material for potassium fertilizers is sylvinite (Table 7), a mixture of sodium chloride and potassium chloride salts. The potassium in sylvinite is already in soluble form, but the sylvinite is treated to remove the sodium salts, making it suitable to use as a fertilizer. Some other potassium fertilizers are potassium sulfate salts, which supply sulfur as well as potassium.

Mixed fertilizers. Mixed fertilizers contain all three primary nutrients blended in varying ratios. Many farmers find these are more convenient to use than fertilizers providing individual nutrients, although they tend to be more expensive. Use soil test results and recommendations from Cooperative Extension publications to determine which ratios best meet your needs.

Common Organic Fertilizers

Animal manure. Manure is a good source of plant nutrients and organic matter, and it is readily available for many growers. Properly managed manure applications recycle nutrients to crops, improve soil quality, and protect water quality. Animal manures vary widely in nutrient content and nutrient availability, depending on the type of animal that produced

Table 6. Examples of processed nitrogen fertilizer materials.

Material	Analysis	Comments
Urea	46-0-0	Rapidly converted to ammonium in soil.
Ammonium sulfate	21-0-0	Also contains 24% available sulfur. Used with acid-loving plants such as blueberries.
Diammonium phosphate	18-46-0	Used in mixed N-P-K fertilizers as a source of nitrogen and phosphorus.
Ammonium nitrate	34-0-0	Contains N in nitrate and ammonium forms.

Table 7. Examples of processed phosphorus and potassium fertilizers.

Material	Typical Analysis	Comments
Triple superphosphate	0-46-0	Concentrated phosphorus fertilizer.
Monoammonium phosphate	11-52-0	Used in mixed fertilizers as a source of nitrogen and phosphorus. Also used as a starter fertilizer.
Diammonium phosphate	18-46-0	Used in mixed fertilizers as a source of nitrogen and phosphorus.
Potassium chloride	0-0-60	Concentrated source of potassium.
Potassium magnesium sulfate	0-0-22	Also contains 11% magnesium and 18% sulfur.
Potassium sulfate	0-0-50	Also contains 18% sulfur.

the manure and the age and handling of the manure. Farmers must be able to understand and reduce that variability to make best agronomic and environmental use of manure.

This section is a brief introduction to using manure as a fertilizer. For details on manure use, including manure testing, determining application rates, and spreader calibration, see *Fertilizing with Manure*, PNW0533.

- *Sources of manure.* You can obtain manure in bulk from manure processors, organic fertilizer dealers, or directly from livestock producers. Manure from processors is often more uniform and will have a guaranteed nutrient analysis. Manure processors often compost manure to destroy pathogens and weed seeds. Manure from livestock producers is usually less expensive, or even free, but it may be more variable in quality and may not have an analysis. If the manure is not composted or well aged, it may contain weed seeds and pathogens. Be sure to read the sidebar on manure safety before using fresh manures.

- *Nutrient content.* Not knowing the nutrient content of manure can lead to large errors in application rate. We strongly advise that you test the manure you plan to use. If you buy manure from a commercial source they should be able to provide you with nutrient test values, and you would not need to do further testing.

  In the absence of test values, use the published values in Table 8 as a starting point. Remember that these are average values and they may not accurately represent your situation.

- *Applying manure*. Manure application rates are usually based on N because N is usually the nutrient needed in the largest quantity for crop growth. Manure is not like commercial fertilizer in that it does not come with a guaranteed N availability. Nitrogen availability from manure varies greatly, depending on the type of animal, type and amount of bedding, and age and storage of manure. There is no simple test to determine N availability for an individual manure sample. Use Table 8 as a guideline for estimating N availability.

  Horse manure or other manures with lots of woody bedding may remove available nitrogen from the soil (N immobilization), rather than supply nitrogen for crop growth. Woody material contains so little N that microorganisms must use soil N to supply their metabolic needs as they break the material down. Expect nitrogen immobilization from manures containing less than 1% N.

  Experiment with manure applications and observe the performance of your crops to fine-tune your application rate. It's better to be conservative with your application rate and add more nutrients if the crops appear deficient.

Table 8. Typical nutrient content, solids content, bulk density, and estimate of nitrogen availability for animal manure at the time of application.

Type	N	P_2O_5	K_2O	Solids	Bulk density	Nitrogen availability
	lb / ton as-is			%	lb/cu yard	%
Broiler with litter	73	63	46	70	900	40–70
Laying hen	37	56	32	40	1400	40–70
Sheep	18	9	24	28	1400	25–50
Beef	12	6	12	23	1400	20–40
Dry stack dairy	9	4	13	35	1400	20–40
Separated dairy solids	5	2	2	19	1100	0–20
Horse	9	6	11	37	1400	0–20

Using Manure Safely

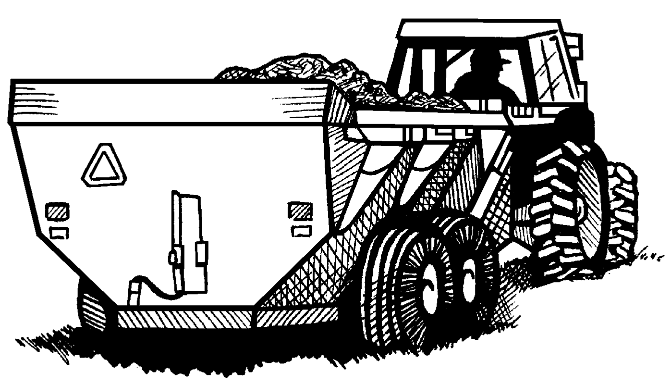
Fresh manure sometimes contains disease-causing pathogens that can contaminate produce. Salmonella bacteria are among the most serious pathogens found in animal manure. Pathogenic strains of *E. coli* bacteria can be present in cattle manure. Manure from swine and carnivores can contain helminths, which are parasitic worms.

These pathogens are not taken up into plant tissue, but they can adhere to soil on plant roots, or on the leaves or fruit of low-growing crops. Cooking destroys pathogens, but raw food carries a risk of pathogen exposure. Although washing and peeling raw produce removes most pathogens, some may remain. The risk from pathogens is greatest for root crops (e.g., carrots and radishes) or leaf crops (e.g., lettuce or spinach), where the edible part touches the soil. The risk is negligible for crops such as sweet corn, which does not come in contact with the soil, or for any crop that is cooked thoroughly.

Avoid using fresh manure where you grow high-risk crops. Composting manure at high temperatures will kill pathogens, but you need careful quality control to make sure that all of the manure reaches conditions for pathogen kill. Refer to the *On-Farm Composting Handbook* for details on composting procedures. Commercial manure composts are composted under conditions to destroy pathogens. Bacterial pathogens die naturally in the environment during a period of weeks or months, and well-aged manure should not contain them. Helminths in swine manure can persist in soil for years, however. High temperature composting will kill helminths.

The best of manure application estimates will not be useful if you don't know how much you're applying once you get into the field. You will need a spreader with capacity matched to the size of your farm, and you will need to calibrate it so that you have confidence in your application rates. See *Fertilizing with Manure*, PNW0533, for details on estimating nutrient availability, application rates, and spreader calibration.

- *Timing manure applications*. The best time to apply manure to row crops is in the spring before planting. You also can apply manure in the fall, but some of the nutrients will be lost during the winter if you apply manure to bare ground. Environmental risks of leaching and runoff also increase. If you do apply manure in the fall, apply it early, and plant a cover crop to help capture nutrients and prevent runoff. You can apply manure to pastures from late February through mid October in most parts of western Washington, as long as the applications are at moderate rates.



Biosolids. Biosolids are a by-product of wastewater treatment. They are processed wastewater solids that meet federal and state criteria for application to land. A common form of biosolids is a spongy, black substance called "cake." Biosolids cake is about 20 to 25% dry matter and 75 to 80% water. It typically contains about 3 to 6% nitrogen and 2 to 3% phosphorus on a dry weight basis, plus small amounts of potassium and trace elements. Some of the nitrogen in biosolids is immediately available to plants. The rest is released slowly. Most of the biosolids produced in Washington are used to fertilize agricultural and forest crops. Typical agricultural application rates range from 2 to 5 dry tons per acre depending on the nitrogen content of the biosolids and the nitrogen requirement of the crop.

Some commercial and municipal composters use biosolids as an ingredient in making compost. Biosolids composts behave like other composts, slowly releasing nutrients. They are a good source of organic matter and will provide small amounts of nutrients to plants.

There are two classes of biosolids based on pathogen removal. Class A biosolids include biosolids composts and heat-treated biosolids. They are virtually free of pathogens, and are safe to use on any crop.

Class B biosolids are processed to reduce, but not eliminate pathogens. Pathogens remaining in Class B biosolids are similar to those in fresh manure. After land application any remaining pathogens in class B biosolids are killed by exposure to sunlight, drying, soil microorganisms and other environmental factors. To allow time for the pathogens to die off, federal regulations require waiting periods between the application of class B biosolids and the harvest of crops. Waiting periods are longest for crops where the edible part touches the soil (more than 1 year for aboveground crops and more than 3 years for root crops). Because of the length of the waiting periods, it is usually impractical to use Class B biosolids on vegetable crops. The most commonly used crops for Class B biosolids application are grain crops and pastures, which have much shorter waiting periods.

Biosolids contain small amounts of trace elements. Some trace elements are micronutrients (such as zinc, copper, and molybdenum) which can benefit crops. Other trace elements (such as lead and cadmium) have no known beneficial effects. Large amounts of trace elements can be toxic to crops, animals, or humans. Levels of trace elements in biosolids produced in Washington are low compared with federal standards. When growers apply Washington biosolids at rates to meet crop nitrogen requirements, the trace element accumulations in the crop are insignificant.

You can usually obtain biosolids free or at low cost from wastewater treatment plants. In many cases the treatment plant or their contractor will apply the biosolids for you. Even though the risks associated with biosolids use are no greater than risks with manure, the Department of Ecology requires that wastewater treatment operators obtain permits for biosolids application. As a farmer you do not have to apply for a permit, but the permit may affect your farm management. For example, the permit will specify application rates and timing, and application buffers to ditches, streams, and property boundaries.

If you consider using biosolids, ask the following questions:

- Are the biosolids Class A or Class B?
- What is the content of nutrients and trace elements in the biosolids?
- Are they a slurry (more odor) or a solid?
- What site management and waiting period requirements are there?
- When will the biosolids be available, and does the timing fit in with your farm management?
- Who will apply the biosolids and what equipment will they use?
- Will buyers accept crops treated with biosolids? (Some food processors and consumers will not buy vegetable crops fertilized with biosolids, but buyer acceptance is less likely an issue for grain crops.)

Although biosolids behave like organic fertilizers, they are not certified as such, and certified organic farmers should not use biosolids. Their best use is for grain crops and pastures on farms that do not seek organic certification. For more information on biosolids, read the extension bulletin PNW0508, *Fertilizing with Biosolids*.

Commercial organic fertilizers. Many organic by-products and some unprocessed minerals are sold as commercial organic fertilizers. Table 9 shows approximate nutrient contents of some of these materials. Numbers represent total nutrient contents; because most are slow-release fertilizers, not all of the nutrients will be available the same year they are applied. The table shows that each fertilizer contains one main nutrient. The other nutrients are present in smaller amounts. Several companies produce balanced organic fertilizers, a combination of materials blended into a single product that provides all of the primary nutrients.

Choosing organic fertilizers. Choosing organic fertilizers involves tradeoffs in cost and convenience. Farmyard manure is usually inexpensive or free, but it is less convenient than packaged, commercial materials. If you or your neighbors have livestock, it makes both environmental and economic sense to recycle the manure produced by the livestock.

Commercial organic fertilizers can be expensive, but you may choose them where convenience or quick availability of nutrients is important or for small areas of land under intensive production. The cost per pound of nutrients in organic fertilizers varies widely, depending on the type of material, the concentration of nutrients, and the size of the package. Compare costs and nutrient availability when shopping for organic fertilizers.

Estimating How Much Fertilizer to Use

The goal of applying fertilizer is to supply enough nutrients to meet plant needs, without accumulation of excess nutrients that could harm water quality. Farmers should have a regular soil testing program to assess nutrient status and to plan fertilizer applications.

Soil tests. A soil test will give you (1) information on the levels of nutrients in your soil, and (2) a recommendation for how much fertilizer to add each year based on your soil test results and the crops you are growing. You don't need to test each field every year. You can rotate your tests around the farm, testing each field at least once every 2 to 3 years.

Table 9. Total nitrogen, phosphate and potash content typical of some organic fertilizers.

Material	% Nitrogen	% P_2O_5	% K_2O
Cottonseed Meal	6–7	2	1
Blood Meal[1]	12–15	1	1
Alfalfa	2	0.5	2
Bat Guano[1]	10	3	1
Fish Meal[1]	10	4	0
Fish Emulsions[1]	3–5	1	1
Bone Meal	1–4	12–24	0
Rock Phosphate[2]	0	25–30 (only 2–3% available)	0
Greensand	0	0	3–7
Kelp Meal	1	0.1	2–5

[1]These materials contain a substantial amount of quickly available nitrogen that plants can use early in the season.

[2]Very low availability. Useful only in acid soils.

A basic soil test typically includes the following nutrients: phosphorus, potassium, calcium, magnesium, and boron. The test also includes soil pH and a recommendation for lime if needed. Many soil test labs don't test routinely for nitrogen because there is no simple, reliable test for predicting nitrogen availability in soils. The lab will give a nitrogen recommendation, however, based on the crops you are growing and information you provide about the soil (such as whether there is a history of manure applications that would increase soil available nitrogen). Some specialized nitrogen tests are done, such as the pre-sidedress nitrate test for corn (see Oregon State University bulletin EM 8650), but samples for these tests are collected at different times from the basic test.

The best way to take a soil sample is to collect multiple cores (at least 15) from a field, air-dry them, and mix the cores together well. Use a cylindrical soil-sampling probe to get uniform samples. Send about a pint of the dried, mixed sample to the lab. The samples you collect should be from the top foot (0 to 12-inch depth) of your soil. Avoid atypical areas such as the site of an old manure pile, burn pile, or building, or areas that are unusually wet or eroded.

Farmers generally collect different samples for each field, crop, and soil type. If you are growing a large variety of crops on a small acreage, it will not be economical to do a soil test for each crop, and you will want to group crops for soil tests. For more information on sample collection, see Oregon State University Extension Bulletin EC 628, *How To Take a Soil Sample…And Why*, available on the OSU publications web site at http://eesc.orst.edu, or University of Idaho Bulletin 704, *Soil Sampling*, available on the UIdaho web site at http://info.ag.uidaho.edu/. For information on interpreting soil tests see OSU bulletin EC 1478, *Soil Test Interpretation Guide*, available on the OSU web site listed above.

Washington State University and Oregon State University no longer test soils, but private labs in both states do. Cooperative Extension county offices have lists of testing labs. If you have not worked with a lab before, call them to make sure they are set up to test and make recommendations for agricultural soils.

Ask the lab:

- Do you routinely test soils for plant nutrients and pH?
- Do you use WSU or OSU test methods and fertilizer guides?
- Do you give recommendations for fertilizer applications?
- Are there forms to complete? What information do you need?
- How should the sample be packaged and sent?
- How much does a test cost?
- How quickly will you send results?

Extension publications. Extension publications are a good source of information on crop nutrient needs. Use them together with soil test results for planning fertilizer applications. Check other bulletins in the Farming West of the Cascades series, or use the WSU publications web site (caheinfo.wsu.edu) or the OSU site (eesc.orst.edu) to find appropriate bulletins.

Fertilizer calculations. Fertilizer recommendations are usually given in pounds of nutrient (such as nitrogen) per acre. You will need to convert the fertilizer recommendations from pounds of nutrient to actual pounds of fertilizer.

Example

You plan to make a mid-season application of 100 lb/acre of nitrogen to your corn crop. You are growing 5 acres of corn, using urea (46-0-0).

1. Divide the amount of nitrogen recommended for 1 acre (100 lb) by the fraction of nitrogen in the fertilizer (46% or .46).

   100 lb N/acre / .46 = 218 lb urea/acre

2. Calculate the total amount of fertilizer needed by multiplying the area of your field by the fertilizer rate calculated in step 1:

   218 lb/acre x 5 acres = 1,090 lb urea

If you are growing crops intensively on a small area of land, the acre-based calculation for each crop may not be convenient. To convert the calculations to units per 1,000 square feet, divide the recommendations per acre by 44.

Example for a Small Area

You are growing carrots and plan to make a nitrogen application of 80 lb N/acre. Your carrot bed covers 2,000 square feet and you are using urea (46-0-0).

1. Divide the amount of nitrogen recommended for 1 acre (80 lb) by the fraction of nitrogen in the fertilizer (46% or .46).

   80 lb N/acre / .46 = 174 lb urea/acre

2. Divide the urea rate by 44 to calculate the amount of urea needed per 1,000 square feet.

   174 lb urea/acre / 44 = 4.0 lb urea/1,000 square feet

3. Calculate the total amount of fertilizer needed by multiplying the area of your field (in 1,000 square foot units) by the fertilizer rate calculated in step 2.

   (4.0 lb urea/1,000 square feet) x 2 = 8.0 lb urea

Tips for Estimating Organic Fertilizer Rates

Estimating how much organic fertilizer to use can be a challenge because you must estimate the availability of the nutrients in the organic fertilizer.

- Organic fertilizers having large proportions of available nutrients (such as bat guano and fish emulsions) can be substituted in direct proportion for processed fertilizers.
- For other commercial organic fertilizers, apply according to their nutrient availability. Composts, rock phosphate, and plant residues generally have lower nutrient availability than more concentrated animal products (bloodmeal, bone meal, and chicken manure). If you use packaged organic fertilizers, the recommendations on the package often are a good guideline for application rates. Check the recommendations against other products to make sure they seem reasonable.
- The nutrient concentration and availability in farmyard manures varies widely depending on the type of manure and its handling. For guidelines for determining appropriate application rates for different types of manures see *Fertilizing with Manure*, PNW0533.

- Whatever fertilizer you use, observe your crops carefully. It is sometimes hard to estimate how much organic fertilizer to use. Lush plant growth and delayed fruiting and flowering are signs of high amounts of available nitrogen, indicating overfertilization. You can experiment with different fertilizer rates in different rows and see if you notice differences. Plan your experiment carefully, so you are confident that any results come from the fertilizer rates, rather than differences in soil, watering, sunlight, or other management.
- Use soil testing to track changes in nutrient availability and modify application rates.

Timing Fertilizer Applications

In most cases, the best time to apply fertilizers is close to the time the plant needs the nutrients. Proper timing of applications reduces the potential for loss of nutrients before they are taken up by the plants. Loss of nutrients is not only inefficient, but the lost nutrients may become contaminants in groundwater or surface water.

Plants need the largest amount of nutrients when they are growing most rapidly—early to midsummer for corn and squash, earlier for spring plantings of lettuce and other greens. Plants also need available nutrients (especially phosphorus) shortly after seeding and transplanting. For a long-season crop such as corn, farmers often add a small amount of fertilizer as a starter at the time of seeding and a larger amount in early summer, just before the period of rapid growth. If the entire application was made in the spring, some of the nutrients (especially nitrogen) could be lost by leaching before the plant was ready to use them.

When using organic fertilizers, a single application is usually adequate because nutrient release occurs throughout the growing season. If you apply organic fertilizers to a crop that matures early, the crop will not take up nutrients that are released from the fertilizer during the late summer and fall. Nitrogen released after crop maturity is likely to leach into groundwater during the winter. Planting cover crops between the rows or immediately after crop harvest can capture some of the nutrients released late in the season by organic fertilizers.

For perennial plants, timing depends on the growth habit of the plant. Blueberries, for example, benefit most from fertilizer applied early in the season at budbreak, while June-bearing strawberries are fertilized after harvest. For crop-specific information on timing fertilizer applications, refer to the appropriate extension bulletins.

Calibrating Fertilizer Spreaders

Depending on the size and type of your operation, the type of spreader you use will vary. If you have a small, intensively managed crop, you may apply fertilizer by hand. For a larger area, a hand-operated whirlybird applicator may work, or you may use a broadcast or band applicator towed behind a tractor. Whatever equipment you use, be sure to calibrate it to apply the appropriate amount of fertilizer.

For tractor-operated applicators you control the rate by adjusting the fertilizer settings.

1. Select a setting that is likely to be close to your desired rate, and place a known weight of fertilizer in the spreader.

2. Measure a known distance (50 or 100 feet is adequate) and drive the spreader over that distance.

3. At the end of the run, weigh the fertilizer remaining in the spreader. The difference between the initial and final weights is the amount spread.

4. Calculate the area spread by multiplying the distance traveled by the width spread. Convert into acres by dividing by 43,560.

5. Divide the weight of fertilizer applied by the application area in acres. This is the application rate in lb/acre.

6. Compare with your target rate.

7. Adjust the settings as needed and repeat the process until you are within 10% of the desired fertilizer rate.

8. Record the settings for future use.

Example

1. You need to apply urea at a rate of 218 lb/acre. Your spreader width is 5 feet, and the length of your test run is 100 feet. You apply to the test area and use 2.1 lb of urea.

2. The area spread is 5 ft x 100 ft = 500 square feet

3. The area spread (in acres) is 500 / 43560 = 0.0115 acre

4. The application rate in lb/acre is 2.1 / 0.0115 = 183 lb/acre

5. The difference from the target rate is 218 - 183 = 35 lb /acre

6. This is more than 10% below the target so you will need to open the settings and test again.

You can adapt the above method to work with hand-operated whirlybird spreaders. It may be more convenient to calculate on the basis of 1,000 square foot units rather than acre units. You can adjust rates with whirlybird spreaders by changing the settings or changing your walking speed.

You can also calibrate a spreader by placing it on blocks so that the wheels can spin freely. Place fertilizer in the spreader, and place a tarp beneath the spreader. Turn the wheels, counting the number of turns. Determine the distance traveled by multiplying the circumference of the wheel by the number of turns. Weigh the fertilizer on the tarp, and continue with the above calculation. For calibrating manure spreaders see *Fertilizing with Manure*, PNW0533.

If you change fertilizer formulation or application rate, you will need to recalibrate the spreader for the new conditions.

Adding Organic Matter

Organic matter builds and stabilizes soil structure, improving the porosity, infiltration, and drainage of the soil, and reducing erosion. It holds water and nutrients for plants and soil organisms. Organic matter also is a long-term, slow-release storehouse of nitrogen, phosphorus, and sulfur.

The value of organic amendments varies, depending on their nitrogen content, or more specifically on their carbon to nitrogen (C:N) ratio. Organic materials that have a low C:N ratio, such as undiluted manure or bloodmeal, are rich in nitrogen. They are a good source of nutrients, but growers must use them sparingly to avoid overfertilization.

Materials with an intermediate C:N ratio (including many composts, leaf mulches, and cover crop residues) have lower nutrient availability. They are the best materials to replenish soil organic matter. Because they are relatively low in available nutrients, they can be added to the soil in large amounts.

Materials with a high C:N ratio (such as straw, bark, and sawdust) contain so little nitrogen that they will reduce levels of available nitrogen when they are mixed into the soil. Soil microorganisms use available nitrogen from the soil when they decompose these materials, leaving little nitrogen for the plants. This process is called immobilization and it results in nitrogen deficiency. If you amend your soil with materials with a high C:N ratio, you will need to add extra nitrogen fertilizer to compensate for immobilization. The best use for these materials is as mulches around perennial crops or in walkways. They will not immobilize nitrogen until you mix them into the soil.

Green Manure

Green manures are cover crops grown specifically to be tilled into the soil. Planting green manure is a way to grow your own organic matter. The value of cover crops goes beyond their contribution of organic matter. Cover crops also can do the following:

- Capture and recycle nutrients that otherwise would be lost by leaching during the winter.
- Protect the soil surface from rainfall impact during the winter.
- Reduce runoff and erosion.
- Help suppress weeds.
- Supply nitrogen (if legumes are grown).

No one cover crop provides all of these benefits (Table 10). Deciding which cover crop or crop combination to grow depends on which benefits are most important to you, and which cover crops fit best into your farm plan.

Farmers usually plant cover crops in the fall and till them as green manure in the spring, before planting. The earlier cover crops are planted, the more benefits they will provide. Research in western Washington showed that cereal rye planted in September captured three times the amount of nitrogen as an October planting. Legumes such as vetch and crimson clover need an early start to cover the soil before cold weather arrives.

Table 10. Examples of cover crops grown in Washington.

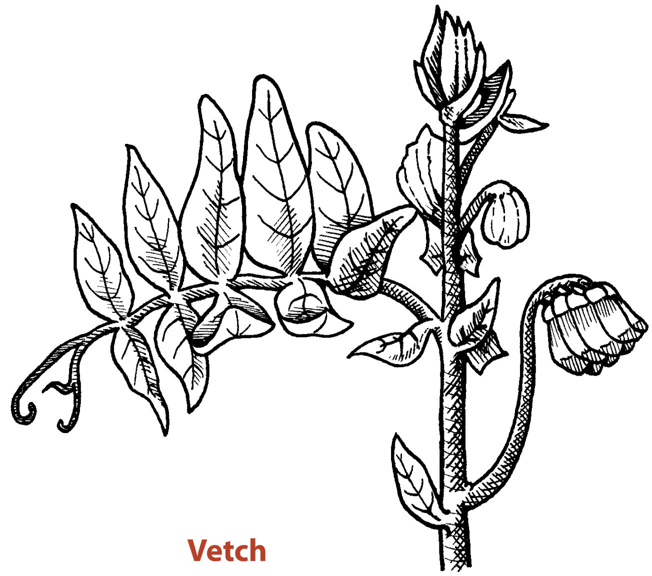
Cereal Rye
Very hardy, grows quickly, matures rapidly in spring. Helps suppress winter weeds, protects soil surface from raindrop impact and erosion.

Winter Wheat
Leafy, covers soil well, matures slowly. Helps suppress winter weeds, protects soil surface from raindrop impact and erosion.

Hairy Vetch
Legume, fixes nitrogen, starts slowly, grows quickly in spring, good companion crop for cereal rye.

Crimson Clover
Legume, fixes nitrogen, slower growth than vetch.

Buckwheat
Fast growing, frost-sensitive, ready to till in 30 days. Helps suppress weeds. Produces biomass quickly. Use as a summer cover crop.



Vetch

You will not get much benefit from cover crops planted after October. Plant cover crops in areas you harvest early, and consider applying compost mulches or using minimum tillage in areas you harvest later. You can also start cover crops between rows of late crops where space allows.

Till cover crops into the soil before they flower. After flowering, the plants become woody and decline in quality. Also, tilling the crop into the soil becomes more difficult if the plants grow too large.

The organic matter benefits from cover crops last only about one year. Where possible, make cover crops an annual part of your crop rotation. The WSU Cooperative Extension Bulletin EB1824, *Cover Crops for Gardens in Western Washington and Oregon*, gives details on choosing and managing cover crops in areas west of the Cascades. It is useful for small-acreage farmers as well as gardeners. For more details on specific cover crops, refer to the Oregon State University Extension Service cover crops series. These publications are available on the Web (see page 18 for WSU and OSU publications web addresses).

Composts

Composts provide an excellent source of organic matter. They also supply a modest amount of nutrients released slowly over the long term. You need to apply large amounts of compost (100 to 200 yards per acre) to see substantial benefits, so the cost of purchased composts can be prohibitive for all but small areas of intensively managed crops.

Commercial composts. Yard debris is the major raw material in most commercial composts sold in Washington and Oregon. Commercial composts may also contain animal manure, biosolids, food waste, or wood waste. Commercial composts are made on a large scale, with aeration and/or frequent turning to meet time and temperature requirements to kill weed seeds, plant pathogens, and human pathogens. They are high quality materials, but they are usually too expensive for general agricultural use.

On-farm composting. An alternative to commercial composts is making compost on your farm using crop residues, manure, or other appropriate materials generated on the farm. In some counties you can import material to compost and use on-farm without a permit, while other counties require a permit. If you sell or distribute your compost off-farm you will need a permit. Contact your local health department if you have questions about composting permits.

To produce high-quality compost you need to generate high temperatures within the pile and turn the pile frequently to make sure all material is exposed to high temperatures. High-temperature composting demands time and attention, and it's not for every farmer. Composting will still occur at lower temperatures, but you will not get a complete kill of weed seeds or pathogens. You can still produce suitable compost at lower temperatures, as long as you avoid raw materials that are full of weed seeds or pathogens.

For detailed information about on-farm composting, including raw materials, methods, and equipment, refer to the *On-Farm Composting Handbook*, available from the Northeast Regional Agricultural Engineering Service, Cornell University Cooperative Extension, Ithaca, New York, 14853-5701.

Partially Composted Yard Debris

Some commercial composters will provide partially composted yard debris to farmers during periods of peak flow. These periods usually occur during the spring when homeowners ship large volumes of yard debris to composters. If composters can divert some of the flow to farms, they can avoid overloading their composting facilities. The timing is usually good for farmers because it occurs when they are preparing land for spring crops.

Research in western Washington has shown that partially composted yard debris is a good source of nutrients and organic matter. Application rates of 20 to 30 dry tons per acre per year can supply all the nutrients needed for a corn crop and increase soil organic matter levels. Because the material is not fully composted, there is some risk of weeds, but no weed problems have been observed in the experiments and on-farm demonstrations done by researchers at WSU Puyallup.

Yard debris is inexpensive for farmers, but prices could rise depending on supply and demand. Processing of yard debris differs, depending on the facility. Some yard debris is composted actively for a few days before delivery to the farm, while others do not have active composting. Contact local composters to find out if they have a yard debris program for agriculture. Find out about their procedures, costs, and timing to see if it fits into your farm plan.

Soil pH and Liming

Soil pH measures the acidity or alkalinity of a soil. A pH of 7 is neutral—where acidity and alkalinity are balanced. Acidity increases by a factor of 10 with each 1 unit drop in pH below 7. For example, a pH of 5.5 is ten times as acidic as a pH of 6.5. Alkalinity increases by a factor of 10 with each 1-unit change in pH above 7. Native soil pH depends on the minerals present in the soil and the amount of rainfall. Soils tend to be near neutral in the low rainfall areas of western Washington (around Sequim, Port Townsend, and Coupeville) and acid in the moderate to high rainfall areas. Farming practices also affect soil pH; many nitrogen fertilizers tend to reduce soil pH, while liming increases soil pH.

Soil pH influences plant growth in three ways:

- by affecting availability of plant nutrients
- by affecting availability of toxic metals
- by affecting the activity of soil microorganisms, which in turn affects nutrient cycling and disease risk.

The availability of phosphorus decreases in acid soils, while the availability of iron increases. In alkaline soils, the availability of iron and zinc can be quite low. In acid soils aluminum availability increases. Aluminum is one of the most common elements in soil, but it is not a plant nutrient, and it is toxic to plants in high concentrations. Very little aluminum is in solution in soils above pH 6 and it causes no problems to plants. As pH declines and aluminum availability increases, aluminum toxicity becomes a problem.

Soil pH affects microbes in a similar way. The most numerous and diverse microbial populations exist in the middle of the pH range; fewer organisms are adapted to strongly acid or strongly alkaline soils. Nutrient cycling is slower in acid and alkaline soils because of reduced microbial populations. Soil pH also affects pathogenic microbes, and growers can adjust pH to manage some plant diseases.

Many crops perform best between pH 6 and 7.5, but some (such as blueberries) are adapted to more strongly acid soils. Before amending the soil to adjust pH, you must know the preferred pH ranges of your crops.

Increasing soil pH with lime. Lime is ground limestone, a rock containing calcium carbonate. It is a certified organic amendment, suitable for use in organic agriculture. Lime raises the pH of acid soils and supplies the essential nutrient, calcium. Dolomitic lime contains magnesium as well as calcium, and it can correct magnesium deficiencies in soil as well as raise soil pH. Dolomitic lime is more expensive and slower acting than agricultural lime, so use it only when you need to.

A basic soil test gives you a lime recommendation in tons of agricultural lime (calcium carbonate) per acre. Lime is a slow-release material. A fall application will benefit a spring crop. Do not lime areas where you grow acid-loving plants.

Gypsum (calcium sulfate) is not a substitute for lime. It provides calcium and sulfur to soils, but it has little effect on soil pH. Gypsum has been promoted as a soil amendment to improve soil structure, but it does not work in our environment. Gypsum improves structure only when the problem results from excess sodium in the soil, a rare condition west of the Cascades. Use organic amendments to improve soil structure, as described earlier.

Decreasing soil pH. Elemental sulfur lowers the pH of a soil. If your soil pH is too high for acid-loving crops that you are growing, ask your soil test lab for an acidification recommendation. Ammonium sulfate fertilizer also lowers pH, but the effect is not as fast as for sulfur. Urea reduces pH slowly, as do some organic fertilizers.

About the Author

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COOPERATIVE EXTENSION
Washington State University

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Soil Quality Information Sheet

Soil Quality Resource Concerns: Soil Biodiversity

USDA Natural Resources Conservation Service	January 1998

What is soil biodiversity?

Soil biodiversity reflects the mix of living organisms in the soil. These organisms interact with one another and with plants and small animals forming a web of biological activity.

Soil is by far the most biologically diverse part of Earth. The soil food web includes beetles, springtails, mites, worms, spiders, ants, nematodes, fungi, bacteria, and other organisms. These organisms improve the entry and storage of water, resistance to erosion, plant nutrition, and break down of organic matter. A wide variety of organisms provides checks and balances to the soil food web through population control, mobility, and survival from season to season.

What are the benefits of soil organisms?

Residue decomposition
Soil organisms decompose plant residue. Each organism in the soil plays an important role. The larger organisms in the soil shred dead leaves and stems. This stimulates cycling of nutrients. The larger soil fauna include earthworms, termites, pseudoscorpions, microspiders, centipedes, ants, beetles, mites, and springtails.

When mixing the soil, the large organisms bring material to smaller organisms. The large organisms also carry smaller organisms within their systems or as "hitchhikers" on their bodies.

Small organisms feed on the by-products of the larger organisms. Still smaller organisms feed on the products of these organisms. The cycle repeats itself several times with some of the larger organisms feeding on smaller organisms.

Some larger organisms have a life span of two or more years. Smaller organisms generally die more quickly, but they also multiply rapidly when conditions are favorable. The food web is therefore quick to respond when food sources are available and moisture and temperature conditions are good.

Infiltration and storage of water
Channels and aggregates formed by soil organisms improve the entry and storage of water. Organisms mix the porous and fluffy organic material with mineral matter as they move through the soil. This mixing action provides organic matter to non-burrowing fauna and creates pockets and pores for the movement and storage of water. Fungal hyphae bind soil particles together and slime from bacteria help hold clay particles together. The water-stable aggregates formed by these processes are more resistant to erosion than individual soil particles. The aggregates increase the amount of large pore space which increases the rate of water infiltration. This reduces runoff and water erosion and increases soil moisture for plant growth.

Nutrient cycling
Soil organisms play a key role in nutrient cycling. Fungi, often the most extensive living organisms in the soil, produce fungal hyphae. Hyphae frequently appear like fine white entangled thread in the soil. Some fungal hyphae (mycorrhizal fungi) help plants extract nutrients from the soil. They supply nutrients to the plant while obtaining carbon in exchange and thus extend the root system. Root exudates also provide food for fungi, bacteria, and nematodes.

When fungi and bacteria are eaten by various mites, nematodes, amoebas, flagellates, or ciliates, nitrogen is released to the soil as ammonium. Decomposition by soil organisms converts nitrogen from organic forms in decaying plant residues and organisms to inorganic forms which plants can use.

Management considerations

Cultivation

The effects of cultivation depend on the depth and frequency of the cultivation. Tilling to greater depths and more frequent cultivations have an increased negative impact on all soil organisms. No-till, ridge tillage, and strip tillage are the most compatible tillage systems that physically maintain soil organism habitat and biological diversity in crop production.

Compaction

Soil compaction reduces the larger pores and pathways, thus reducing the amount of suitable habitat for soil organisms. It also can move the soil toward anaerobic conditions, which change the types and distribution of soil organisms in the food web. Gaps in the food web induce nutrient deficiencies to plants and reduce root growth.

Pest control

Pesticides that kill insects also kill the organisms carried by them. If important organisms die, consider replacing them. Plant-damaging organisms usually increase when beneficial soil organisms decrease. Beneficial predator organisms serve to check and balance various pest species.

Herbicides and foliar insecticides applied at recommended rates have a small impact on soil organisms. Fungicides and fumigants have a much greater impact on soil organisms.

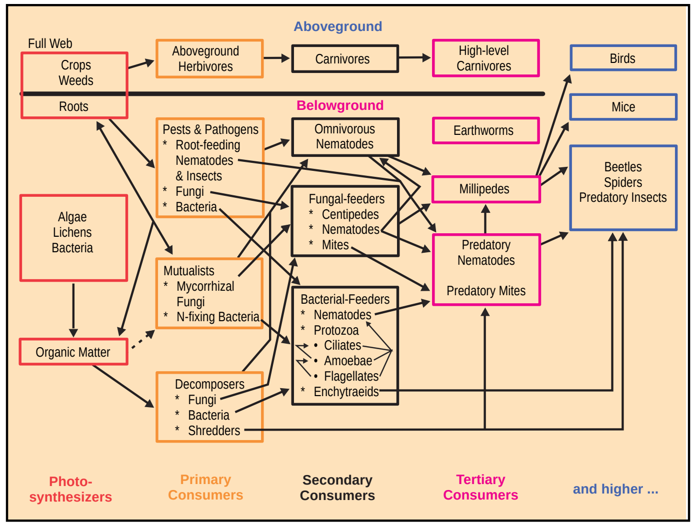
Fertility

Fertility and nutrient balances in the soil promote biological diversity. Typically, carbon is the limiting resource to biological activity. Plant residue, compost, and manure provide carbon. Compost also provides a mix of organisms, so the compost should be matched to the cropping system.

(Prepared by the National Soil Survey Center, NRCS, USDA in cooperation with the Soil Quality Institute, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA).

Cover crops and crop rotations

The type of crops that are used as cover or in crop rotations can affect the mix of organisms that are in the soil. They can assist in the control of plant pests or serve as hosts to increase the number of pests. Different species and cultivars of crops may have different effects on pests. However, the organisms and their relation to the crop are presently not clearly understood.



Crop residue management

Mixing crop residue into the soil generally destroys fungal hyphae and favors the growth of bacteria. Since bacteria hold less carbon than fungi, mixing often releases a large amount of carbon as carbon dioxide (CO_2). The net result is loss of organic matter from the soil.

When crop residue is left on the soil surface, primary decomposition is by arthropod shredding and fungal decomposition. The hyphae of fungi can extend from below the soil surface to the surface litter and connect the nitrogen in the soil to the carbon at the surface. Fungi maintain a high C:N ratio and hold carbon in the soil. The net result is toward building the carbon and organic matter level of the soil. In cropping systems that return residue, macro-organisms are extremely important. Manage the soil to increase their diversity and numbers.

Visit our Web site:
http://soils.usda.gov

Soil Quality Indicators: Organic Matter

USDA Natural Resources Conservation Service **April 1996**

What is soil organic matter?

Soil organic matter is that fraction of the soil composed of anything that once lived. It includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, and substances from plant roots and soil microbes. Well-decomposed organic matter forms *humus*, a dark brown, porous, spongy material that has a pleasant, earthy smell. In most soils, the organic matter accounts for less than about 5% of the volume.

What does organic matter do?

Organic matter is an essential component of soils because it:

- provides a carbon and energy source for soil microbes;
- stabilizes and holds soil particles together, thus reducing the hazard of erosion;
- aids the growth of crops by improving the soil's ability to store and transmit air and water;
- stores and supplies such nutrients as nitrogen, phosphorus, and sulfur, which are needed for the growth of plants and soil organisms;
- retains nutrients by providing cation-exchange and anion-exchange capacities;
- maintains soil in an uncompacted condition with lower bulk density;
- makes soil more friable, less sticky, and easier to work;
- retains carbon from the atmosphere and other sources;
- reduces the negative environmental effects of pesticides, heavy metals, and many other pollutants.

Soil organic matter also improves tilth in the surface horizons, reduces crusting, increases the rate of water infiltration, reduces runoff, and facilitates penetration of plant roots.

Where does it come from?

Plants produce organic compounds by using the energy of sunlight to combine carbon dioxide from the atmosphere with water from the soil. Soil organic matter is created by the cycling of these organic compounds in plants, animals, and microorganisms into the soil.

What happens to soil organic matter?

Soil organic matter can be lost through erosion. This process selectively detaches and transports particles on the soil surface that have the highest content of organic matter.

Soil organic matter is also utilized by soil microorganisms as energy and nutrients to support their own life processes. Some of the material is incorporated into the microbes, but most is released as carbon dioxide and water. Some nitrogen is released in gaseous form, but some is retained, along with most of the phosphorus and sulfur.

When soils are tilled, organic matter is decomposed faster because of changes in water, aeration, and temperature conditions. The amount of organic matter lost after clearing a wooded area or tilling native grassland varies according to the kind of soil, but most organic matter is lost within the first 10 years.

Rates of decomposition are very low at temperatures below 38 °F (4 °C) but rise steadily with increasing temperature to at least 102°F (40°C) and with water content until air becomes limiting. Losses are higher with aerobic decomposition (with oxygen) than with anaerobic decomposition (in excessively wet soils). Available nitrogen also promotes organic matter decomposition.

What controls the amount?

The amount of soil organic matter is controlled by a balance between additions of plant and animal materials and losses by decomposition. Both additions and losses are very strongly controlled by management activities.

The amount of water available for plant growth is the primary factor controlling the production of plant materials. Other major controls are air temperature and soil fertility. Salinity and chemical toxicities can also limit the production of plant biomass. Other controls are the intensity of sunlight, the content of carbon dioxide in the atmosphere, and relative humidity.

The proportion of the total plant biomass that reaches the soil as a source of organic matter depends largely on the amounts consumed by mammals and insects, destroyed by fire, or produced and harvested for human use.

Practices decreasing soil organic matter include those that:

1. **Decrease the production of plant materials by**
   - replacing perennial vegetation with short-season vegetation,
   - replacing mixed vegetation with monoculture crops,
   - introducing more aggressive but less productive species,
   - using cultivars with high harvest indices,
   - increasing the use of bare fallow.

2. **Decrease the supply of organic materials by**
   - burning forest, range, or crop residue,
   - grazing,
   - removing plant products.

3. **Increase decomposition by**
   - tillage,
   - drainage,
   - fertilization (especially with excess nitrogen).

Practices increasing soil organic matter include those that:

1. **Increase the production of plant materials by**
   - irrigation,
   - fertilization to increase plant biomass production,
   - use of cover crops
   - improved vegetative stands,
   - introduction of plants that produce more biomass,
   - reforestation,
   - restoration of grasslands.

2. **Increase supply of organic materials by**
   - protecting from fire,
   - using forage by grazing rather than by harvesting,
   - controlling insects and rodents,
   - applying animal manure or other carbon-rich wastes,
   - applying plant materials from other areas.

3. **Decrease decomposition by**
   - reducing or eliminating tillage,
   - keeping the soil saturated with water (although this may cause other problems),
   - keeping the soil cool with vegetative cover.

(Prepared by the National Soil Survey Center in cooperation with the Soil Quality Institute, NRCS, USDA, and the National Soil Tilth Laboratory, Agricultural Research Service, USDA). Animal waste photo courtesy University of Nebraska-Lincoln, Institute of Agriculture and Natural Resources

Soil Quality

IN ORGANIC AGRICULTURAL SYSTEMS

Building and maintaining soil quality is the basis for successful organic farming.

Organic Farming Requires Quality Soil

Building and maintaining soil quality is the basis for successful organic farming. However, before developing a soil management plan focused on soil quality in organic systems, farmers should become knowledgeable regarding the overall philosophies, legalities, and marketing opportunities in organic agriculture. A brief overview of organic agriculture follows, but for further details, see Iowa State University Extension publication *Organic Agriculture* (PM 1880). (See page 8 for ordering instructions.)

USDA NRCS

Periodic soil testing will help determine soil quality.

IOWA STATE UNIVERSITY
University Extension

PM 1882 August 2003

What Is Organic Agriculture?

In order to sell your crop as certified organic, you must follow USDA National Organic Program rules, and be certified by one of the accredited agencies listed in *Organic Agriculture* (PM 1880). State of Iowa organic certification rules will require the following:

- No synthetic fertilizers for 36 months prior to the certified organic crop's harvest.
- No synthetic pesticides (fungicides, insecticides, herbicides) for 36 months prior to the certified organic crop's harvest.
- Crop rotations, including a soil-building legume or small grain/legume mix following row crops, to break weed, insect, and disease cycles and maintain soil fertility.
- No synthetic hormones or antibiotics for livestock may be used, and organic feeds and pastures must be fed.
- Soil fertility in organic systems is maintained primarily through crop rotations (usually corn-soybeans-oat-alfalfa or some variation of this system) and through applications of composted or raw manure. Seaweed, fish emulsion, or plant/animal-based products, such as alfalfa- and feather-meal, can be applied as soil and foliar amendments in organic systems.

Crop Rotations

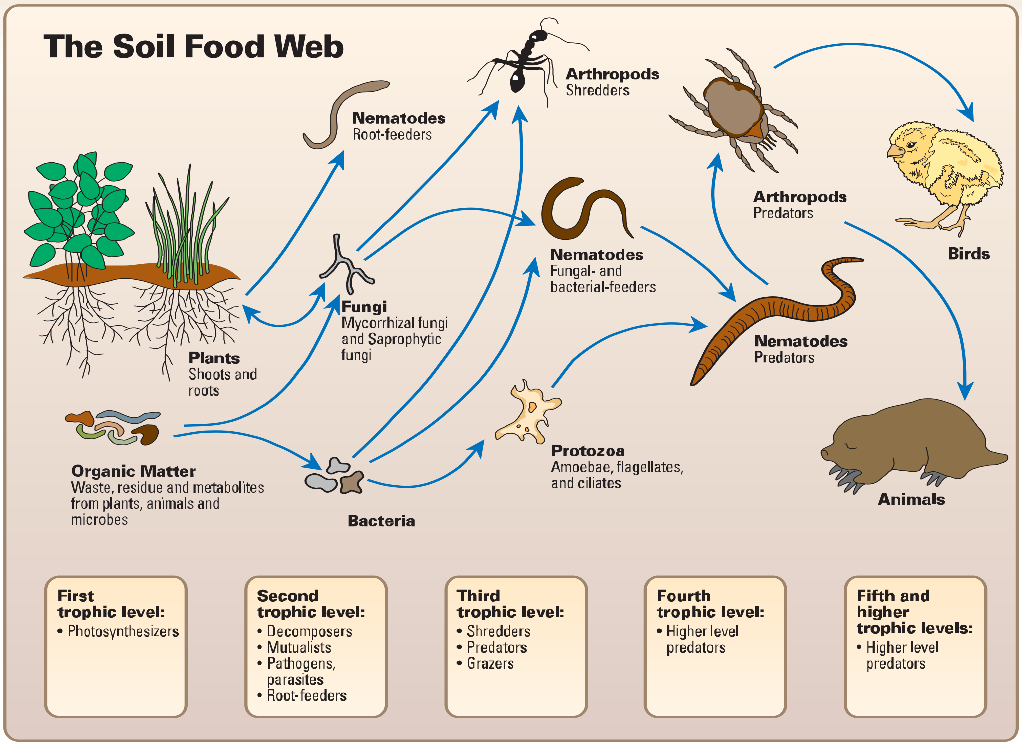
For an organic crop to be certified, a crop rotation plan must be in place to protect against pest problems and to maintain soil health. A good general rule is that no more than four out of five years should be in row crops, and it is required that the same row crop cannot be grown in consecutive years in the same field. Legumes (e.g., alfalfa, red clover, berseem clover, and hairy vetch) alone, or in combination with small grains (e.g., wheat, oats, and barley), should be rotated with row crops (corn, soybeans, amaranth, and vegetables) to ensure a healthy system. A typical six-year rotation in Iowa is corn (with a cover of winter rye)-soybeans-oat (with an underseeding of alfalfa)-alfalfa-corn-soybeans. Soybeans fix nitrogen and can generally be grown without fertilizer in the first year. Subsequent crops must include rotations of grain crops and nitrogen-adding cover crops to maintain adequate fertility. Horticultural crops should be rotated with a leguminous cover crop at least once every five years.

For an organic crop to be certified, a crop rotation plan must be in place to protect against pest problems and to maintain soil health.

Soil Amendments

Naturally mined lime products are used to adjust the soil pH to within a range of 6.0 to 7.0 (depending on crop requirements). In addition to lime, manure and composted manure are the most common forms of soil amendments in organic operations. Raw manure may be obtained from organic or conventional farms, provided the manure is applied at least 3 months prior to the harvest of an agronomic crop, or at least 4 months prior to the harvest of a horticultural crop. These rules were developed in order to provide adequate time for decomposition of manure and avoid bacterial contamination of produce. To prevent contamination of waterways, raw manure cannot be applied to frozen or snow-covered ground. Organic certification agencies recommend manure should be composted prior to land application (see photo on next page).

Composting is the preferred method of stabilizing manure. Composting is a controlled process in



The basis for all organic farming systems is the health of the soil.

Naturally mined lime products are used to adjust the soil pH to within a range of 6.0 to 7.0 (depending upon crop requirements).

which nitrogen-containing materials (e.g., manure, yard waste, or kitchen waste) are mixed with a carbon-containing source (e.g., corn stalks or cobs, straw, and wood chips) to produce a mixture preferably with a carbon-to-nitrogen ratio (C:N) of 30 to 1. The compost mixture must reach and maintain a temperature of ≥ 140° F for at least three days during the composting process in order to limit bacterial contamination. Adequate moisture and temperature are required for proper composting. Most organic farmers utilize front-end loaders or windrow turners to construct outdoor composting systems. Other composting systems include vermi-composting (utilization of earthworms in "beds" to decompose manure and other wastes), in-vessel digesters, and anaerobic systems. Additional information on composting practices is listed in the references.

K. DELATE

Compost can be made in a 50-gallon barrel, with a front-end loader or with a commercial windrow turner.

Many soil amendments are available for organic farming. The key, however, is that the material is

naturally based, and that no prohibited substances, such as hexane, are used in the processing or collection of the materials. In addition to manure-based fertilizers, many organic farmers rely on fish emulsion and seaweed preparations to supply nitrogen and other elements. When phosphorus and potassium limit crop production, rock phosphate and naturally mined potassium chloride are allowed. It is imperative that farmers check with their certification agencies before applying any materials. A farmer's certification may be revoked for three years if it is discovered that he or she has applied a material found to be contaminated with prohibited materials.

Soil Health in Organic Systems

Soil organic matter, created through decomposition and recycling of plant and animal residues, has many important roles in organic systems, including supplying the necessary elements for plant growth. The first step in formation of soil organic matter is fixation of carbon dioxide (CO_2) by plants. Capturing the energy of sunlight and efficiently recycling it through various forms of different soil organic matter is, therefore, a basic goal associated with organic production systems. The soil organic matter or carbon (C) inputs improve soil physical properties, such as aggregate stability, and provide food, habitat, and shelter for billions of soil organisms. Increased aggregate stability, improved soil structure, and surface protection provided by crop residues, manure or compost, and cover crops reduce soil erosion losses and increase water-holding capacity and aeration. Maintaining soil organic matter content at levels that are consistent with the natural characteristics of the soil (i.e., loamy soils will generally have higher organic matter than sandy soils) helps soil biological activity and the healthy microbial and macrofaunal populations that are required for efficient nutrient cycling. These populations include bacteria, fungi, actinomycetes, nematodes, and earthworms. Crop rotations (required for all organic operations) are crucial for organic systems because the legume crops (e.g., alfalfa and red clover) provide nitrogen (N) and also help recycle nutrients, such as phosphorus (P) and potassium (K). Including crops with deep root systems in the rotation helps extract nutrients from lower soil depths and return them to the surface when the vegetation dies. Crop residues also provide the carbonaceous biomass upon which soil microfauna (e.g., earthworms and beetles) and microorganisms depend on for survival.

Soil organic matter, created through decomposition and recycling of plant and animal residues, has many important roles in organic systems, including supplying the necessary elements for plant growth.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Hairy vetch *(Vicia villosa)* and rye can supply up to 120 lb. of nitrogen per acre to crop fields.

Cooperative research by scientists at Iowa State University and USDA-Agricultural Research Service (ARS) is being conducted to evaluate soil quality within organic and conventional crop production systems. After one growing season, several soil quality indicators showed a positive response to organic management (Table 1).

Table 1
First-Year Effect of Organic and Conventional Management Practices on Selected Soil Quality Indicators at the Neely-Kinyon Farm, Greenfield, Iowa

	Carbon Pools[1]			Nitrogen Pools[2]		Other Indicators[3]		
Farming System	Total	POM	Biomass	PMN	NO_3-N	WSA	EC	PH
	Mg ha^{-1} to 30 cm		kg ha^{-1} to 7.5 cm	kg ha^{-1} to 30 cm		%		dS cm^{-1}
Conventional (n=8)	82.1 a[4]	10.7 a	36.6 b	136 a	29.6 a	20.6 a	240 a	6.4 a
Organic (n=28)	85.0 a	12.1 a	83.2 a	144 a	14.8 b	22.6 a	223 a	6.4 a

[1]POM—particulate organic matter; Biomass—microbial biomass

[2]PMN—potentially mineralizable nitrogen; NO_3-N—nitrate nitrogen

[3]WSA—water stable aggregation; EC—electrical conductivity

[4]Means followed by the same letter are not significantly different at p=0.10.

Soil microbial biomass carbon was 228 percent higher in plots fertilized with compost than in those receiving inorganic N fertilizer. The conventional treatment also had 50 percent higher residual nitrate nitrogen (NO_3-N) and excessive levels of NO_3-N in basal corn stalk samples collected at physiologic maturity. (For more information on corn stalk sampling, see Iowa State University Extension publication PM 1584, *Corn Stalk Testing to Evaluate Nitrogen Management.)*

Soil quality evaluations generally include indicators such as microbial biomass carbon (MBC) and particulate organic matter carbon (POM-C) because these carbon pools are more responsive to changes in soil and crop management practices than total organic carbon. Changes in these indicators occur more quickly because MBC and POM-C are associated with nutrient cycling and turnover throughout the year. Potential nitrogen mineralization (PMN) also showed a slight response (+8 percent) to organic management, which coupled with the lower NO_3-N concentration in the soil, suggests the N applied through compost was being incorporated into biologically active soil organic matter. The 15 percent increase in water stable aggregation (Table 1) also suggests the slight increase in soil organic matter was beginning to have positive effects on soil physical properties.

Relevant Field Research

Organic Soybeans and Cover Crops for Organic Vegetable Production

Building improved soil quality is laudable, but a moot point, if organic production systems are not profitable. Organic soybean production is one of the most lucrative crops for organic farmers in Iowa today. A typical crop rotation that includes organic soybeans is corn followed by a winter cover of rye, soybeans, and oat with an underseeding of alfalfa or red clover in the third year. In the spring, rye that is less than 8" in height can be killed with a field cultivator. If plants are taller, rye should be mowed or cut with a stalk chopper before cultivating. A second cultivation may be necessary if there are remaining rye plants. Sample soil in the fall to determine if soil conditions are adequate for soybean production. Adjustments to a proper soil

Organic soybean production is one of the most lucrative crops for organic farmers in Iowa today.

pH of 6.5 to 7.0 can be made through applications of lime in the fall or spring. Iowa soils usually do not require dolomitic lime. For additional details on organic soybean production, see the Iowa State University Extension publication *Growing Organic Soybeans on CRP Land* (PM 1881).

Cover crops should be grown at least once every five years in certified organic horticultural operations in Iowa. Therefore, to help sustain or improve soil quality and to remain in compliance with the organic standards, many organic farmers rotate to a soil-building legume cover crop after every vegetable crop. Successful cover crops in Iowa include hairy vetch, alfalfa, clover, and medics. The annual legumes typically have 3.5 to 4 percent nitrogen in leaves before flowering and 3 to 3.5 percent at flowering. After flowering, much of the nitrogen is directed to seed production. Therefore, it is recommended that legumes be incorporated at the start of flowering. To estimate nitrogen additions from a cover crop, take cuttings from several areas in the field and dry and weigh them. Use a yardstick or metal frame of set dimensions (e.g., 1 square foot) and clip the plants at ground level. After drying for several days, use the following estimate to determine the per acre yield of dry matter:

$$\text{Yield (lb./acre)} = \frac{\text{Total weight of dried sample (lb.)}}{\text{3 sq. ft. you sampled}} \times \frac{\text{43,560 sq. ft.}}{\text{1 acre}}$$

Divide this quantity from the above equation by 2 if the cover crop will be conventionally tilled or divide by 4 if it is to be left on the surface in a no-till system. To estimate the total N in green manure:

$$\text{Total N (lb./acre)} = \frac{\text{Biomass yield from above calculation}}{\text{(lb./acre)}} \times \frac{\text{\% N (in leaves)}}{100}$$


K. DELATE

Red or crimson clover, in addition to alfalfa, is used as a legume plowdown on many organic farms. To estimate nitrogen additions from a cover crop, follow the instructions on this page.

If sufficient biomass is produced by cover crops, there may be adequate nitrogen for the subsequent crop. If the cover crop growth is limited by poor weather, however, additional nitrogen, from compost or manure, may be needed. Details on cover crop additions can be found in *Managing Cover Crops Profitably* (EDC 201), which is available through Iowa State University Extension.)

Cover crops should be grown at least once every five years in certified organic horticultural operations in Iowa. Successful cover crops in Iowa include hairy vetch, alfalfa, clover, and medics.

Philosophies in Organic Agriculture

Inputs

Environmental, economic, and food safety concerns are among the many reasons why some farmers choose organic production. Likewise, organic producers differ in the methods they use to achieve the ideal system. Some organic farmers completely shun external inputs, and these farmers enhance the native biological insect control on their farms by conserving beneficial insects' food and nesting sites instead of importing natural pesticides. Compost is created on the farm for their fertilization needs. Other organic farmers do not make a distinction in inputs, and they rely on imported inputs for soil fertility and pest management. This philosophy of "input substitution" is discredited by many long-time advocates of organic agriculture who believe that a truly sustainable method of organic farming would seek to eliminate, as much as possible, reliance on external inputs. Organic certification, however, is based on the use of allowable substances, regardless of their origin.

USDA NRCS

Leaving plant residue from the previous year's crop can increase the level of soil carbon sequestration in organic fields.

Organic Agriculture and Carbon Sequestration

Recently, some world governments have promoted soil carbon sequestration (storage) as a way to help mitigate elevated levels of atmospheric CO_2 caused by burning fossil fuels and other sources of industrial pollution. The use of crop rotations, effective manure management, and green manure crops as required for effective and efficient organic farming are all management practices that can enhance carbon storage in soils. However, tillage practices, which can increase CO_2 emissions, must be considered when evaluating the tradeoffs associated with organic systems and carbon sequestration. Additional information on carbon sequestration can be obtained in the Iowa State University Extension publication *Impact of Tillage and Crop Rotation Systems on Soil Carbon Sequestration* (PM 1871).

The use of crop rotations, effective manure management, and green manure crops . . . are all management practices that can enhance carbon storage in soils.

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For the latest on organic agriculture from Iowa State University go to **http://extension.agron.iastate.edu/organicag/.**

Publications mentioned in this booklet can be ordered by contacting any ISU Extension county office or the ISU Extension Distribution Center at (515) 294-5247. There is a charge, plus shipping and handling, for some publications.

File: Agriculture 2 **[A]**

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Soil Quality Management

Overview

The six components of soil quality management are discussed briefly below. Choosing specific practices within each component depends on the situation since different types of soil respond differently to the same practice. Each combination of soil type and land use calls for a different set of practices to enhance soil quality. Go to Agronomy - Cropland, Grazing Lands, Forest, Urban, and Organic Agriculture for more information by land use. Use the following documents to help teach basic management concepts to improve soil quality.

Farming in the 21st Century: a practical approach to improve Soil Health (PDF, 8MB) - Four practical approaches for improving soil health are presented as a publication. The four practical approaches are: manage more by disturbing soil less, diversify with crop diversity, grow living roots throughout the year, and keep the soil covered as much as possible.

Farming in the 21st Century: a practical approach to improve Soil Health Fact Sheet (PDF, 4MB) - The four practical approaches for improving soil health are presented as a fact sheet.

1. **Enhance organic matter**: Whether your soil is naturally high or low in organic matter, adding new organic matter every year is perhaps the most important way to improve and maintain soil quality. Regular additions of organic matter improve soil structure, enhance water and nutrient holding capacity, protect soil from erosion and compaction, and support a healthy community of soil organisms. Practices that increase organic matter include: leaving crop residues in the field, choosing crop rotations that include high residue plants, using optimal nutrient and water management practices to grow healthy plants with large amounts of roots and residue, growing cover crops, applying manure or compost, using low or no tillage systems, and mulching.

2. **Avoid excessive tillage**: Reducing tillage minimizes the loss of organic matter and protects the soil surface with plant residue. Tillage is used to loosen surface soil, prepare the seedbed, and control weeds and pests. But tillage can also break up soil structure, speed the decomposition and loss of organic matter, increase the threat of erosion, destroy the habitat of helpful organisms, and cause compaction. New equipment allows crop production with minimal disturbance of the soil. For more information about conservation tillage, visit the Conservation Technology Information Center.

3. **Manage pests and nutrients efficiently**: An important function of soil is to buffer and detoxify chemicals, but soil's capacity for detoxification is limited. Pesticides and chemical fertilizers have valuable benefits, but they also can harm non-target organisms and pollute water and air if they are mismanaged. Nutrients from organic sources also can pollute when misapplied or over-applied. Efficient pest and nutrient management means testing and monitoring soil and pests; applying only the necessary chemicals, at the right time and place to get the job done; and taking advantage of non-chemical approaches to pest and nutrient management such as crop rotations, cover crops, and manure management.

4. **Prevent soil compaction**: Compaction reduces the amount of air, water, and space available to roots and soil organisms. Compaction is caused by repeated traffic, heavy traffic, or traveling on wet soil. Deep compaction by heavy equipment is difficult or impossible to remedy, so prevention is essential.

5. **Keep the ground covered**: Bare soil is susceptible to wind and water erosion, and to drying and crusting. Ground cover protects soil, provides habitats for larger soil organisms, such as insects and earthworms, and can improve water availability. Ground can be covered by leaving crop residue on the surface or by planting cover crops. In addition to ground cover, living cover crops provide additional organic matter, and continuous cover and food for soil organisms. Ground cover must be managed to prevent problems with delayed soil warming in spring, diseases, and excessive build-up of phosphorus at the surface.

6. **Diversify cropping systems**: Diversity is beneficial for several reasons. Each plant contributes a unique root structure and type of residue to the soil. A diversity of soil organisms can help control pest populations, and a diversity of cultural practices can reduce weed and disease pressures. Diversity across the landscape can be increased by using buffer strips, small fields, or contour strip cropping. Diversity over time can be increased by using long crop rotations. Changing vegetation across the landscape or over time not only increases plant diversity, but also the types of insects, microorganisms, and wildlife that live on your farm.

Soil Quality Concepts

Overview

Soil quality is how well soil does what we want it to do. More specifically, soil quality is the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation. Soil Organic Matter and Soil Biology play a major role in soil quality.

People have different ideas of what a quality soil is. For example:

- for people active in production agriculture, it may mean highly productive land, sustaining or enhancing productivity, maximizing profits, or maintaining the soil resource for future generations;
- for consumers, it may mean plentiful, healthful, and inexpensive food for present and future generations;
- for naturalists, it may mean soil in harmony with the landscape and its surroundings;
- for the environmentalist, it may mean soil functioning at its potential in an ecosystem with respect to maintenance or enhancement of biodiversity, water quality, nutrient cycling, and biomass production.

What Soil Does

Healthy soil gives us clean air and water, bountiful crops and forests, productive rangeland, diverse wildlife, and beautiful landscapes. Soil does all this by performing five essential functions:

- Regulating water - Soil helps control where rain, snowmelt, and irrigation water goes. Water and dissolved solutes flow over the land or into and through the soil.
- Sustaining plant and animal life - The diversity and productivity of living things depends on soil.

- Filtering potential pollutants - The minerals and microbes in soil are responsible for filtering, buffering, degrading, immobilizing, and detoxifying organic and inorganic materials, including industrial and municipal by-products and atmospheric deposits.
- Cycling nutrients - Carbon, nitrogen, phosphorus, and many other nutrients are stored, transformed, and cycled through soil.
- Supporting structures - Buildings need stable soil for support, and archeological treasures associated with human habitation are protected in soils.

The Inherent and Dynamic Qualities of Soil

Soil has both inherent and dynamic qualities. Inherent soil quality is a soil’s natural ability to function. For example, sandy soil drains faster than clayey soil. Deep soil has more room for roots than soils with bedrock near the surface. These characteristics do not change easily.

Dynamic soil quality is how soil changes depending on how it is managed. Management choices affect the amount of soil organic matter, soil structure, soil depth, water and nutrient holding capacity. One goal of soil quality research is to learn how to manage soil in a way that improves soil function. Soils respond differently to management depending on the inherent properties of the soil and the surrounding landscape.

For more information about inherent soil characteristics, see the NRCS Soils web site.

Soil Quality Link to Sustainability

Understanding soil quality means assessing and managing soil so that it functions optimally now and is not degraded for future use. By monitoring changes in soil quality, a land manager can determine if a set of practices is sustainable.

Assessing Soil Quality

Soil quality assessment is the process of measuring the management induced changes in soil as we attempt to get soil to do what we want it to do. The ultimate purpose of assessing soil quality is to provide the information necessary to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms including people.

Go to Soil Quality Assessment for more information.

Managing for Soil Quality

Managing soil to improve soil quality entails the use of conservation practices that improve soil function. In general, practices that reduce disturbance, increase crop diversity, and efficiently cycle nutrients, water and energy will accomplish this.

Go to Soil Quality Management for more information.

Research Potential

Most soil quality research is motivated by one of two goals:

1. improving land management on farms and watersheds, or
2. monitoring soil at a national or regional scale.

The first goal involves site-specific assessment and decision-making, so the link between researchers and farmers is important to the success of the research.

Most research attempts to identify the links among management practices, observable soil characteristics (i.e. soil quality indicators), soil processes (e.g. nutrient cycling), and the performance of soil functions (e.g. productivity and environmental quality). A single study may examine only one or two of these links.

Some important directions for future research include:

- measuring the spatial and temporal variability of soil characteristics, and using patterns of variability as an indicator of soil quality,
- further defining the characteristics of a healthy soil biological community, and approaches to managing soil biology,
- describing and managing changes during the transition time when farmers switch from one set of practices to another,
- improving nutrient cycling by managing soil biology, and
- identifying low-cost remote techniques for monitoring soil quality regionally.

Soil Quality is Not an End in Itself

The ultimate purpose of researching and assessing soil quality is not to achieve high aggregate stability, biological activity, or some other soil property. The purpose is to protect and improve long-term agricultural productivity, water quality, and habitats of all organisms including people. We use soil characteristics as indicators of soil quality, but in the end, soil quality must be identified by how it performs its functions.

Soil Organic Matter

Overview

Managing soil organic matter is the key to air and water quality (Figure 1).

Figure 1. Best Management Practices can increase soil organic matter and enhance soil quality, positively affecting air and water quality and soil productivity.

Erosion control is not enough

Soil conservation policy in the United States stems from the devastating erosion events of the 1920s and ’30s. Out of concern for preserving agricultural productivity came the concept of tolerable soil loss and the creation of the T factor - the maximum annual soil loss that can occur on a particular soil while sustaining long-term agricultural productivity. Conservationists focused on reducing soil loss to T by applying practices, such as terraces, contour strips, grassed waterways, and residue management.

By the end of the century, concerns about air and water quality became as important as concerns about agricultural productivity. To address these environmental goals and maintain the land’s productive potential, we must now go beyond erosion control and manage for soil quality. How soil functions on every inch of a farm–-not just in buffers or waterways–-affects erosion rates, agricultural productivity, air quality, and water quality. The most practical way to enhance soil quality today is to promote better management of soil organic matter or carbon. In short, we should go beyond T and manage for C (carbon).

Why focus on soil organic matter?

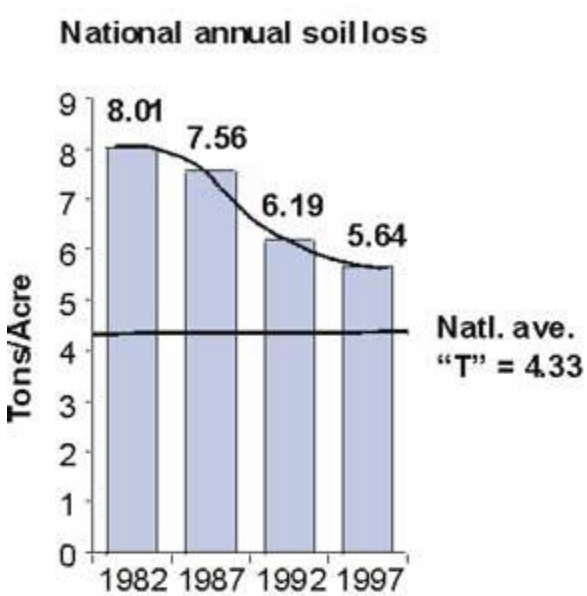
Many soil properties impact soil quality, but organic matter deserves special attention. It affects several critical soil functions, can be manipulated by land management practices, and is important in most agricultural settings across the country. Because organic matter enhances water and nutrient holding capacity and improves soil structure, managing for soil carbon can enhance productivity and environmental quality, and can reduce the severity and costs of natural phenomena, such as drought, flood, and disease. In addition, increasing soil organic matter levels can reduce atmospheric CO_2 levels that contribute to climate change.

Go beyond T - Manage for C

The goal of reducing soil erosion to T (tolerable soil loss rates) generated remarkable improvements in the nation's natural resources (Figure 2). We can achieve a new level of soil conservation by focusing on building soil organic matter or soil carbon (C).

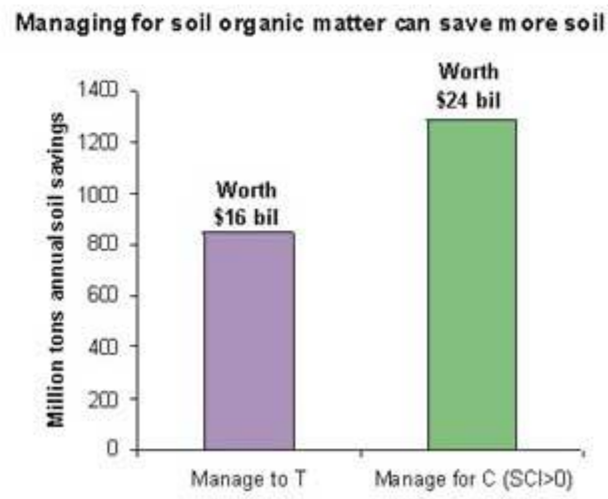
- By emphasizing organic matter management technology, soil loss can be reduced on those lands that still suffer excessive erosion.
- Even moderate erosion rates can harm air quality, water quality, and wildlife habitat. Improving soil organic matter levels can further stabilize soil within fields and protect environmental quality (Figure 3).
- Keeping soil in place is only the beginning of soil conservation. Soil also has to function well. It must hold nitrogen, phosphorus, and pesticides in place and keep them out of surface water. Soil must deliver nutrients and water to plants as they need them. Soil should minimize the effects of floods and droughts. Organic matter helps soil perform all these functions.

Figure 2. National annual soil loss.



The pace of erosion control has slowed as we approach the goal of managing to T. However, 1.8 billion tons of soil are still lost from cropland annually, and 120 million acres of cropland are eroding at a rate greater than T.

Figure 3. Managing for soil organic matter can save more soil than managing for T.



If all cropland were managed to T, annual soil loss would decline by 0.85 billion tons. If all cropland were managed for C (SCI>0), soil loss would decline by 1.29 billion tons. Thus, conservation efforts could save an additional $8.2 billion worth of soil annually by managing for C instead of managing to T. Reaching this higher standard is possible by focusing on different conservation tools and benefits.

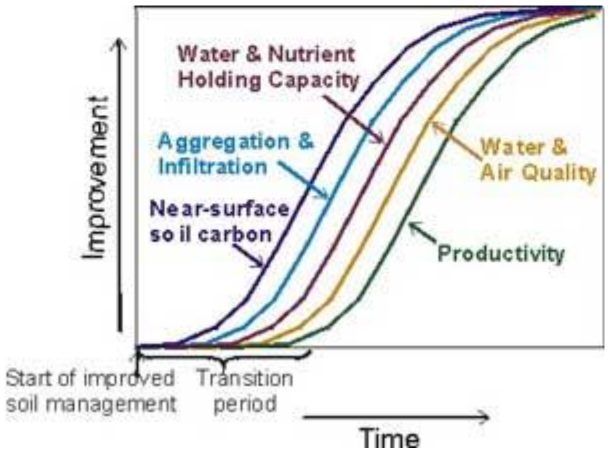
What does this mean for conservation?

Managing for C means using well-known technology in a new way. By addressing conservation issues from the perspective of soil organic matter instead of erosion, the focus is on enhancing the soil as opposed to managing for tolerable degradation. The full potential of cover crops, crop rotations, and reduced tillage can be exploited to address conservation concerns. Moreover, managing for C provides additional on-site benefits and incentives for the landowner, creating greater motivation for the person making the ultimate decisions about managing the Nation’s natural resources.

How does organic matter work?

Once a land manager begins working towards enhancing soil organic matter, a series of soil changes and environmental benefits follow (Figure 4). The rate and degree of these changes and the best suite of practices needed to achieve results vary with soil and climate. Initially, managing for greater soil organic matter may require higher pesticide, herbicide, or nutrient applications. In time, productivity and environmental quality will be enhanced.

Figure 4. Clean air and water start with soil organic matter.



Apply practices that enhance soil organic matter

- Diverse, high biomass crop rotations
- Cover crops
- Reduced tillage
- Rotational or prescribed grazing

Organic matter dynamics change

- Increased surface residue forms a physical barrier to wind and water erosion.
- Higher residue rotations and cover crops contribute more organic matter and nutrients to the soil.
- Less soil disturbance means lower organic matter losses.

Soil properties change

- Surface structure becomes more stable and less prone to crusting and erosion.
- Water infiltration increases and runoff decreases when soil structure improves.
- Soil organic matter holds 10 to 1,000 times more water and nutrients than the same amount of soil minerals.
- Beneficial soil organisms become more numerous and active with diverse crop rotations and higher organic matter levels.

Air quality, water quality, and agricultural productivity improve

- Dust, allergens, and pathogens in the air immediately decline.

- Sediment and nutrient loads decline in surface water as soon as soil aggregation increases and runoff decreases.
- Ground and surface water quality improve because better structure, infiltration, and biological activity make soil a more effective filter.
- Crops are better able to withstand drought when infiltration and water holding capacity increase.
- Organic matter may bind pesticides, making them less active. Soils managed for organic matter may suppress disease organisms, which could reduce pesticide needs.
- Crop health and vigor increase when soil biological activity and diversity increase.
- Wildlife habitat improves when residue management improves.

Soil Conditioning Index

The Soil Conditioning Index (SCI) predicts the consequences of cropping systems and tillage practices on soil organic matter in a field. Soil organic matter is a primary indicator of soil quality and carbon sequestration. A positive SCI indicates a cropping system that, if continued, is likely to result in increasing levels of soil organic matter.

The SCI is embedded in RUSLE2. It has three main components including the amount of organic material returned to or removed from the soil, the effects of tillage and field operations on organic matter decomposition, and the effect of predicted soil erosion associated with the management system. See Section 508 of the NRCS National Agronomy Manual for more information.

The following document requires Microsoft PowerPoint Viewer.

Using SCI to Assess Management Effects on Soil Carbon (PPT, 5.7MB)

PNW0533

Fertilizing with Manure

Andy Bary, Craig Cogger, Dan M. Sullivan

A Pacific Northwest Extension Publication
Washington • Oregon • Idaho

Farming West of the Cascades

This publication is designed for the small to mid-sized crop producer (organic and conventional) to assist the producer in more efficiently managing nutrients from solid animal manures. The purpose of this publication is to (1) describe how to determine the appropriate manure application rate based on the type of manure and crops, and (2) describe how to apply the manure at that rate.

Manure is a good source of plant nutrients and organic matter. Properly managed manure applications recycle nutrients to crops, improve soil quality, and protect water quality. Manure is highly variable source to source, and growers must be able to understand and reduce that variability to make best agronomic and environmental use of manure.

The three main sources of variability and uncertainty when using manure are:

- Nutrient content of the manure
- Availability of manure nutrients to crops
- Application variability

If you do not account for this variability, you may apply too much or too little manure. Applying too little manure can lead to inadequate crop growth because of lack of nutrients, while applying too much manure may reduce crop quality or increase risk of plant diseases. Over-applying nutrients also may increase the risk of contaminating surface or groundwater. For more information on livestock water quality issues see *Manure Management in Small Farm Livestock Operations, Protecting Surface and Groundwater*, EM8649, available from the Oregon State University Extension Service.

Fertilizing with Manure outlines a systematic method to help you manage nutrients from manures. Even with the best methods, there is still some degree of uncertainty when using manures as nutrient sources. This publication describes how to:

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- Decide if manure is a good choice for your farm.
- Determine the nutrient content of manure.
- Estimate manure nutrient availability based on manure type, handling, and nutrient content.
- Calculate the application rate.
- Calibrate manure spreaders and apply manure at the target rate.
- Store manure.
- Test soil and monitor crops to adjust manure application rates.
- Evaluate long-term effects of manure applications on soil quality.

Three worksheets in this publication (Worksheets A, B, and C) will help you calibrate your manure spreader.

Is Manure a Good Choice for Your Farm?

Consider the following questions before applying animal manure on your farm:

- What is the local availability of manure?
- What is the quality of local manure sources?
- Where does manure fit in your crop rotation?
- Will your crops respond to added nutrients?

Local Availability of Manure

If you raise livestock, or if you have neighbors who do, you will likely have plenty of manure available nearby. If you have to import manure from more distant sources, transportation can greatly increase costs. If you are considering importing manure, you will need to decide if it makes economic sense.

Quality of Manure Sources

Manure quality varies considerably, as discussed later in this bulletin. You will need to compare the quality of available manure sources (nutrient supply, ease of handling, odor, and risk of weed seeds or pathogens) with your farming needs. See below for a comparison of composted and uncomposted manure sources.

Crop Rotations

Manure use is compatible with most crops and crop rotations. Remember that crop nutrient needs vary and manure applications should be consistent with the nutrient needs of your crops. Soil test results and

Composted Vs. Uncomposted Manure

When you are looking for organic forms of nutrients for crop production, manure and manure composts are two of the logical choices. Composting is more than just piling the material and letting it sit. Composting is the active management of manure and bedding to aid the decomposition of organic materials by microorganisms under controlled conditions.

What are the benefits or detriments of using uncomposted or composted manure? In some cases they have comparable properties and in other ways they are quite different. The table below compares the two materials.

Compost	Manure
• slow release form of nutrients	• usually higher nutrient content
• easier to spread	• sometimes difficult to spread
• lower potential to degrade water quality	• higher potential to degrade water quality
• less likely to contain weed seeds	• more likely to contain weed seeds
• higher investment of time or money	• lower investment of time or money
• reduced pathogen levels (e.g., salmonella, *E. coli*)	• potential for higher pathogen levels
• more expensive to purchase	• less expensive to purchase
• fewer odors (although poor composting conditions can create foul odors)	• odors sometimes a problem
• improves soil tilth	• improves soil tilth

extension bulletins are good sources of information on crop nutrient needs. Fresh manure is not a good choice for most salad and root crops because of food safety concerns. For more information see the section titled "Using Manure Safely."

Soil Fertility

Manure provides the most benefits on soils with deficient to adequate levels of nutrients. Soils with high to excessive levels of nutrients are not a good choice for manure use, because the nutrients in manure are less likely to benefit crops and more likely to leach into groundwater or run off into surface water. If you have excessive levels of nutrients in your soil, limit applications of those nutrients to recommended starter levels, and use an alternative source of organic matter input, such as growing cover crops.

How To Determine the Nutrient Content of Manure

Not knowing the nutrient content of manure can lead to large errors in nutrient application rate. We strongly advise you test the manure you plan to use. If you buy manure from a commercial source, they should be able to provide you with nutrient test values; you would not need to do further testing. In the absence of test values, use the published values in Table 1 as a starting point.

Laboratory Analysis

Laboratory analysis measures the nutrients in manure instead of just estimating them based on table values. Testing laboratories will charge from $30 to $60. (See the section "Deciding What To Test" for specifics on nutrient analysis of manure.) Using testing laboratories requires proper sampling techniques and timely delivery of the sample to the laboratory.

Choosing a Laboratory

It is important to use a laboratory that routinely tests animal manure as they will know the correct type of analysis to use when testing animal manures. Extension offices can provide you publications that list manure testing laboratories in the Pacific

Using Manure Safely

Fresh manure sometimes contains pathogens that can cause diseases in humans. Salmonella bacteria are among the most serious pathogens found in animal manure. Pathogenic strains of *E. coli* bacteria can be present in cattle manure. Manure from swine and carnivores can contain helminths, which are parasitic worms.

These pathogens are not taken up into plant tissue, but they can adhere to soil on plant roots, or on the leaves or fruit of low-growing crops. Cooking destroys pathogens, but raw food carries a risk of pathogen exposure. Washing and peeling raw produce removes most pathogens, but some may remain. The risk from pathogens is greatest for root crops (e.g., carrots and radishes) or leaf crops (e.g., lettuce or spinach), where the edible part touches the soil. The risk is negligible for crops such as sweet corn, which does not come in contact with the soil, or for any crop that is cooked thoroughly.

Consider any raw manure to be a potential source of pathogens, and avoid using fresh manure where you grow high-risk crops. Bacterial pathogens die off naturally during extended storage or after field application. Complete die-off of bacterial pathogens occurs in days to months depending on the pathogen and environmental conditions. Helminths in swine manure can persist in soil for years, however.

Composting manure at high temperatures will kill pathogens, including helminths, but you need careful quality control to make sure that all of the manure reaches conditions for pathogen kill. If you plan to compost manure, refer to the *On-Farm Composting Handbook* (listed in "Additional Resources") for procedures to compost manure under conditions to destroy pathogens.

If you grow certified organic crops you must follow the manure and compost practices in the National Organic Standards. These practices specify waiting periods between the application of fresh manure and the harvest of different types of crops, and time and temperature requirements for killing pathogens in manure compost.

Northwest (see the "Additional Resources" section for references).

Questions to ask when choosing a lab:

- Does the lab routinely analyze manure?
- How many manure samples do they analyze in a year?
- Can they perform the tests you need?
- Are the results reported in the form you need?
- How are the samples handled before analysis? Do they thoroughly mix the samples? Do they dry the samples before analysis? Drying samples prior to analyzing for ammonium nitrogen results in loss of most of the ammonium nitrogen from the sample.
- Can the laboratory supply quality control information to you? Do they participate in a regional, national, or university sample exchange program? Participation in a sample exchange program is a good indicator of a commitment to accurate results.
- How much does analysis cost? ($30–$60)

Laboratories report results on an as-received or a *dry-weight* basis. As-received results usually are reported in units of lb/ton, while dry weight results usually are reported in percent or mg/kg. The as-received results are most helpful when determining application rates. The dry-weight results can be used to compare analyses over time and from different manure sources. If you are not sure what reporting basis the lab is using, contact them for clarification. It is a good idea to ask for a sample reporting sheet before you choose a lab, to make sure you can interpret their results.

To convert manure analyses reported on a dry-weight basis (in percent) to an as-received basis (in lb/wet ton), multiply by 20 to convert the dry weight percent to lb/ton; then multiply by the decimal equivalent of the solids content.

Example:

For beef manure at 23% solids and 2.4% nitrogen (N) on a dry weight basis:

Step 1. 2.4% x 20 = 48 lb N/ton dry weight

Step 2. 48 lb N/ton dry weight x .23 = 11 lb N/ton as-is.

Deciding What To Test

The main components you should have measured are total nitrogen, ammonium nitrogen, total phosphorus, total potassium, electrical conductivity, and solids. If the manure is old or has been composted you may also want to test for nitrate-N. Total carbon (C) and pH sometimes are useful measurements. Total C can be useful for manure with bedding, so you can determine the C:N ratio. Manure with a C:N ratio greater than 25 is likely to tie up nitrogen when you apply it to the soil.

Sampling Manure

A nutrient analysis is only as good as the sample you take. Samples must be fresh and representative of the manure. Follow these steps carefully:

1. Ask the laboratory what type of containers they prefer. Also, make sure the laboratory knows when your sample is coming. Laboratories should receive samples within 48 hours of collection. Plan to collect and send your sample early in the week so the sample does not arrive at the lab on a Friday or a weekend.

2. If you have a bucket loader and a large amount of manure, use the loader to mix the manure before sampling.

3. Take 10 to 20 small samples from different parts and depths of the manure pile to form a composite sample. The composite sample should be about 5 gallons. The more heterogeneous your pile, the more samples you should take.

4. With a shovel or your hands thoroughly mix the composite sample. You may need to use your hands to ensure complete mixing. Wear rubber gloves when mixing manure samples with your hands.

5. Collect about one quart of manure from the composite sample and place in an appropriate container.

6. Freeze the sample if you are mailing it. Use rapid delivery to ensure that it arrives at the laboratory within 24 to 48 hours. You can refrigerate the sample if you are delivering it directly to the lab.

Published Values

Table 1 shows typical published values for livestock manure. These values may not accurately represent your situation. The nutrient content of manure varies widely with amount and type of bedding used, storage conditions, age of manure, manure handling, and animal diet. Nutrient values can vary by a factor of two or more from the values listed in Table 1.

For example, leaving manure piles uncovered in western Washington will reduce manure nutrient content by leaching. The use of bedding reduces manure nutrient by dilution. The amount of reduction from either of these factors is difficult to determine without laboratory testing.

Nitrogen Availability for Crop Growth

Manure application rates are usually N based, because N is usually the nutrient needed in the largest quantity for crop growth. Manure is not like commercial fertilizer in that it does not come with a guaranteed N availability. Nitrogen availability from manure varies greatly, depending on the type of animal, type and amount of bedding, and age and storage of manure.

Manure contains nitrogen in the organic and ammonium forms. The organic form releases N slowly, while ammonium-N is immediately available for crop growth. Ammonium-N can be lost to the atmosphere as ammonia gas when manure is applied to the soil surface. Most solid manures contain most of their nitrogen in the organic form, but poultry manure contains substantial ammonium-N. Poultry and other manures that contain a large proportion of ammonium-N may lose substantial N to the atmosphere if they are not tilled into the soil the same day they are spread. Ammonia loss is greater in warm, dry, and breezy conditions; less in cool, wet weather.

There is no simple test to determine N availability for an individual manure sample. Use Table 2 or Figure 1 to estimate N availability from manure.

The N availability numbers in Table 2 are approximate ranges for each type of manure. Use the lower part of the ranges if manure contains a large proportion of ammonium-N (such as poultry manure), and it is not tilled into the soil soon after application. Also, use the lower part of the ranges if the manure contains large amounts of bedding, or if the measured N content is lower than typical values. Use the higher part of the ranges if the manure contains less bedding or if the measured N content is higher than typical values.

Thorough composting generally reduces the rate of release of manure N by incorporating the N into more biologically resistant forms. Composting can reduce the amount of first-year N release by 50% or more,

Table 1. Typical nutrient content, solids content, and bulk density of uncomposted animal manures at the time of application.[1]

Type	N	P[2]	K	Solids	Bulk density
		lb per ton as-is[3]		*percent*	*lb/cu yard*
Broiler with litter	73	28	55	70	900
Laying hen	37	25	39	40	1400
Sheep	18	4.0	29	28	1400
Rabbit	15	4.2	12	25	1400
Beef	12	2.6	14	23	1400
Dry stack dairy	9	1.8	16	35	1400
Separated dairy solids	5	0.9	2.4	19	1100
Horse	9	2.6	13	37	1400

[1] Dairy manure data and some horse manure data were collected in the Pacific Northwest. Other data sources are listed in *Additional Resources*.

[2] Manure analyses are usually reported in terms of P and K, while fertilizer labels use P_2O_5 and K_20. To convert from P to P_2O_5, multiply P by 2.3. To convert from K to K_2O, multiply K by 1.2.

[3] *As-is* is typical moisture content for manure stored under cover.

Table 2. Typical nitrogen availability for uncomposted animal manures.

Type	Typical Nitrogen Content	Nitrogen Availability[1]
	percent dry weight	*percent*
Broiler with litter	4–6	40–70
Laying hen	4–6	40–70
Sheep	2.5–4	25–50
Rabbit	2.5–3.5	20–40
Beef	2–3	20–40
Dry stack dairy	1.2–2.5	20–40
Separated dairy solids	1–2	0–20
Horse	0.8–1.6	0–20

[1] Nitrogen available in the first growing season after application.

and Table 2 will usually overestimate available N from manure composts.

This may not be the case for material sold as composted poultry litter, however. Poultry litter (from broiler production) is a mixture of manure and wood shavings. Dry stacked poultry litter will heat to high temperatures, but the composting process is often limited by insufficient moisture in the pile. Materials sold as "composted poultry litter" are frequently incompletely composted, and have similar N availability as fresh poultry litter. Incompletely composted poultry litter will have a strong ammonia odor and will have ammonium-N analyses above 2000 ppm (0.2 % ammonium-N on a dry weight basis).

Horse manure or other manures with lots of woody bedding may temporarily tie up nitrogen rather than supply nitrogen for crop growth, because the wood is still decaying, and bacteria that break down the carbon in the wood consume nitrogen. Expect first-year N tie-up from manures containing less than 1% N.

Figure 1 is an alternative way to estimate manure N availability, based on laboratory measurements of manure N content. In general, the higher the N content of manure, the higher the proportion of N that will become available to crops.

If you have been applying manure to the same field for several years, residual organic nitrogen from past applications will contribute to the supply of N available to crops. You will need to reduce the manure application rate for fields that receive repeated manure applications.

Calculating the Application Rate

Now that you have determined the nutrient content and estimated the N availability of the manure you will be using, you are ready to determine the application rate. Application rates of manure are usually based on providing adequate nitrogen for crop growth. In most cases supplying sufficient nitrogen will also provide adequate phosphorus and potassium for crop growth.

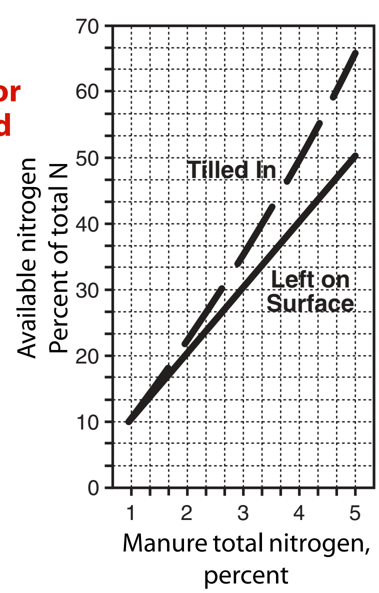
First, you will need to know the amount of nutrients your crop requires. Nutrient requirements for specific crops can be found in Cooperative Extension production guides or from soil test recommendations.

If you have your manure and soil tested at the same time at the same laboratory, the lab can provide a recommendation for the amount of manure to apply.

Once you know the amount of nitrogen needed for your crop, and the nutrient content of your manure, you can estimate the amount of manure to apply using a few simple calculations.

Observe the performance of your crops to help fine-tune your application rate. If you have a complicated

Figure 1. Nitrogen availability for uncomposted manure based on total N content.



nutrient management program, you may need to consult with a professional agronomist. See the "Additional Resources" section for publications listing laboratories and professional agronomists, or contact your local Extension office.

Applying Manure

Manure Spreaders

The best of manure application estimates will not be useful if you don't know how much you're applying once you get to the field. You will need a spreader appropriate to the size of your farm, and you will need to calibrate it so you have confidence in your application rates.

Equipment

There are several ways to spread manure. For small amounts, you can use buckets or apply it from the back of a pickup truck. Using a mechanical manure spreader is easier and more effective for spreading large amounts of manure.

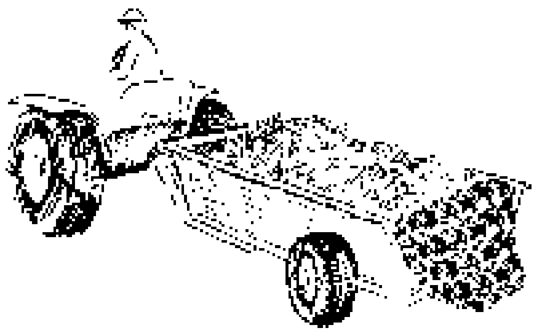
There are three general types of solid manure spreaders: rear delivery, side-delivery, and specialty spreaders. Rear delivery spreaders work best with drier materials. Side delivery spreaders handle both wet and dry

Table 3. Worksheet for calculating manure application rates.

Example: I am growing sweet corn and the nitrogen recommendation is 100 pounds N per acre. I have beef manure that has been tested by a laboratory and contains 11 pounds of N, 2.2 pounds of P, and 8.3 pounds of K per wet ton of manure.

Note: Unshaded cells in table are information about manure and crop. Shaded cells are calculations you make.

Step	Units	Example	Your Value
A. Type of manure		beef	
B. Crop		sweet corn	
C. Desired N application rate	lb N/acre	100	
D. Manure N concentration, from laboratory analysis or Table 1.	lb N/ton as-is	11	
E. Phosphorus concentration, from laboratory analysis or Table 1.	lb P/ton as-is	2.2	
F. Potassium concentration, from laboratory analysis or Table 1.	lb K/ton as-is	8.3	
G. Plant availability of N in manure from Table 2 or Figure 1.	percent	25	
H. Calculate manure available nitrogen **Line D x (line G / 100)**	lb N/ton as-is	2.75	
I. Calculate application rate **Line C / line H**	tons manure/acre as-is	36	
J. Calculate amount of phosphorus applied **Line I x line E x 2.3**	lb P_2O_5/acre	184	
K. Calculate amount of potassium applied **Line I x line F x 1.2**	lb K_2O/acre	362	



Manure Spreader

materials. Specialty spreaders have the capability of spreading material onto narrow beds found in perennial crop production. They are designed for drier materials. Prices for new equipment vary from $1,600 to $8,000. A good used spreader costs about 50–60% of a new spreader. Used spreaders are sometimes difficult to find because farmers usually wear them out before replacing them.

Calibrating Manure Applications

Calibrating your spreader will allow you to determine the actual application rate and adjust it to meet your target rate. You can calibrate your spreader by measuring a small part of the manure applied using pans or tarps. Or, you can weigh an entire spreader load and measure how much area the load covers. If you know the bulk density of the manure you can calculate the volume of a spreader load rather than the weight. These three methods are described in Worksheets A, B, and C beginning on page 10.

Calibrating your spreader will allow you to convert loads of manure applied to tons per acre. The spreader load calibration is the most accurate method, but it requires truck scales to complete. Calibration improves accuracy of the overall application rate, but there will still be variability in the actual application across your field.

If you apply manure to a small area and use buckets or a pickup truck, it is still important to know how much you are applying. You can do this by weighing the buckets or determining the weight or volume of the pickup load.

Regardless of which method you use, recheck your measurements periodically to make sure you stay on target.

Timing Manure Applications

The best time to apply manure to row crops is in the spring before planting. You also can apply manure in the fall, but some of the nutrients will be lost over the winter if you apply manure to bare ground. Environmental risks of leaching and runoff also increase. If you do apply manure in the fall, apply it early, and plant a cover crop to help capture nutrients and prevent runoff. You can apply manure to pastures from late February through mid-October in most places west of the Cascades, as long as the applications are at moderate rates.

Manure Storage

If you raise animals on your farm or import manure for crop production you may need to store manure on your farm prior to application. Proper manure storage conserves nutrients and protects surface and groundwater. Storing manure can be as elaborate as keeping it under cover in a building or as simple as covering the manure pile with a tarp. The important point is keeping the pile covered and away from drainage areas and standing water. The storage location should also be convenient to your animals and crop production. If you decide to build a manure storage structure, refer to extension bulletins that cover this subject (see "Additional Resources"), or see your nearest Natural Resources Conservation Service office.

Using Soil Testing To Adjust Application Rates

Taking soil test samples and observing your crops can help you determine if manure application rates are adequate or if they need adjusting. The report card soil test helps determine if you are applying too much manure. The report card test measures nitrate-N remaining in the soil in the fall. If you apply too much manure, nitrate N will accumulate in the soil, unused by the crop. When the fall and winter rains come, the nitrate will leach from the soil and become a potential contaminant in groundwater or surface water. Excess N can also harm some crops, delaying fruiting and increasing the risk of disease damage, freeze damage, and wind damage.

To do a report card test, sample the soil (0 to 12-inch depth) between August 15 and October 1. Timing is critical. You want to sample after most crop uptake of N has occurred, but before the fall rains leach nitrate from the soil. Take a report card sample as you would any other soil sample, collecting soil cores at multiple spots in the field, and combining the cores together into a composite sample. For details on soil sampling procedures, refer to *Soil Sampling*, Bulletin 704, available from the University of Idaho Cooperative Extension System.

If your report card nitrate-N results are greater than 15–20 mg/kg, this suggests you are supplying more N than your crop needs, and you can reduce manure application rates. Report-card nitrate-N levels greater than 30 mg/kg are excessive.

When interpreting report card results, consider the performance of your crop, too. If crop growth was poor because of drought, pests, or poor growing conditions, crop N uptake may have been less than expected, resulting in excess N remaining in the soil profile even if manure applications were on target for a normal crop.

You can use basic soil tests to evaluate the soil for sufficiency or excess of other nutrients. A basic soil test includes P, K, calcium (Ca), magnesium (Mg), boron (B), pH, and a lime recommendation. If you have consistently low levels of P and K and reduced crop growth, you can probably increase your manure application rates. If you have consistently excessive levels of P and K, you may need to decrease or eliminate manure applications, as described below.

Long-Term Effects of Manure Applications

Repeated applications of manure can increase soil organic matter content and the soil nutrient pool. Because the pool of slow-release nutrients increases in the soil with repeated manure applications, the amount of manure needed to meet crop needs will decline over time.

When manure applications are based on nitrogen need, manure usually supplies P and K in excess of crop needs. As a result, P and K can accumulate in soils with a history of manure applications, and may eventually reach excessive levels. Excess levels of soil P can increase the amount of P in runoff, increasing the risk of surface water degradation. Many crops can handle high levels of K, but livestock can be harmed by nutrient imbalances if they consume a diet of forages with high K levels.

If you apply manure repeatedly to the same fields, it is important to have a regular soil testing program to track nutrient levels. If P and K reach excessive levels, you may need to switch to a commercial fertilizer to supply N. If you are an organic farmer and do not use synthetic fertilizers, consider replacing some or all of your manure with legume cover crops. Legumes will fix N from the atmosphere, but they do not supply P or K. Reserve manure for fields that have lower P and K levels.

Summary

To reduce variability and uncertainty in manure applications, follow these four steps:

1. Determine the nutrient content of the manure you are using. Laboratory testing will give you the most reliable estimate.
2. Estimate manure N availability based on the type of manure, handling, and nitrogen content.
3. Calibrate your manure spreader so that you have confidence in the rate applied.
4. Do soil testing (report card and basic tests) and observe plant growth to evaluate the effect of manure applications on crop production and soil nutrient levels. Adjust manure rates as necessary based on your evaluations.

Worksheet A

Application Calibration Using a Tarp

You will need some tarps and a scale on which to weigh the manure. Hanging scales work well. Then follow these steps:

1. Weigh the tarp and record the weight and size of the tarp on Worksheet A.
2. Place tarps in application area.
3. Spread manure over the application area using the spreading pattern typically used in the field. Make sure the spreader is traveling at the speed it would typically travel. On Worksheet A, record tractor speed and gear, and note spreader settings.
4. Collect and weigh the manure. Record the weight on Worksheet A.
5. Calculate an average application by completing Worksheet A.
6. Repeat steps 1–4 five to nine times. Replication gives you more accurate results.
7. Adjust the application rate by changing tractor speed or gearing, or making an adjustment on the manure spreader. After adjustment, you will need to repeat the calibration procedure until you have arrived at the desired application rate.
8. Keep the calibration records for future use.

Worksheet A

Date ____________________ **Field** ____________________ **Spreader ID** ____________________

Speed ____________________ **Gear** ____________________ **Operator** ____________________

	Tarp ID						
	Example	A	B	C	D	E	F
1. Weight of tarp with manure (lb)	*9.2*						
2. Weight of empty tarp (lb)	*6.5*						
3. Weight of manure **(line 2 minus line 1)**	*2.7*						
4. Tarp area (sq ft)	*9.0*						
5. Manure applied (lb/ sq ft) **(line 3 / line 4)**	*0.3*						
6. Convert to tons/acre **(line 5 x 21.78)**	*6.5*						
7. Average application rate (Ave. over all locations) tons/acre							

Worksheet B

Spreader Calibration Using a Full Spreader Load and Scales

Use this method to monitor the manure application rate on the entire field. After the initial weighing to determine the capacity of the application vehicle, the only tool you need is a field-measuring wheel or long tape.

1. Determine the weight of manure the spreader will hold using a truck scale to weigh the spreader when empty and full. Record the weights on Worksheet B.
2. Spread a load on the field, using constant, even tractor speed and settings to cover field uniformly. Spread in a rectangular pattern so the area calculation will be simple. Record tractor speed and gear settings used on Worksheet B.
3. Measure the length and width covered by one full load and compute the application rate in tons per acre using Worksheet B below.
4. Adjust the application rate by changing tractor speed or gearing, or making an adjustment on the manure spreader. After adjustment, you will need to repeat the calibration procedure until you have arrived at the desired application rate.
5. Keep the calibration records for future use.

Worksheet B

Date ____________ **Field** ____________ **Spreader ID** ____________

Speed ____________ **Gear** ____________ **Operator** ____________

	Replicates				
	Example	A	B	C	D
1. Weight of loaded spreader (lb)	*12,000*				
2. Weight of empty spreader (lb)	*2,000*				
3. Weight of manure in spreader (lb) **(line 2 - line 1)**	*10,000*				
4. Length of area spread (ft)	*1,300*				
5. Width of area spread (ft)	*25*				
6. Area spread (sq ft) **(line 4 x line 5)**	*32,500*				
7. Manure applied (lb/sq ft) **(line 3 / line 6)**	*0.308*				
8. Convert to tons/acre **(line 7 x 21.78)**	*6.7*				

Worksheet C

Spreader Calibration Using Manure Bulk Density

This method can be used if you know or estimate the manure bulk density, but is not as accurate as one of the other methods. You will need a tape measure, calculator and a measurement or estimate of the manure bulk density.

1. Determine the length, width, depth, and stacking height of the manure spreader and enter values in Worksheet C. Measure or estimate manure bulk density from Table 1 and enter in the worksheet.
2. Calculate the volume and weight of manure in a spreader load using Worksheet C.
3. Spread a load on the field, using constant, even tractor speed and settings to cover field uniformly. Spread in a rectangular pattern so the area calculation will be simple. Record tractors speed and gear settings used on Worksheet C.
4. Measure the length and width covered by one full load and compute the application rate in tons per acre using Worksheet C.
5. Adjust the application rate by changing tractor speed or gearing, or making an adjustment on the manure spreader. After adjustment, you will need to repeat the calibration procedure until you have arrived at the desired application rate.

Worksheet C

Date ____________________ **Field** ____________________ **Spreader ID** ____________________

Speed ____________________ **Gear** ____________________ **Operator** ____________________

	Replicates			
	Example	A	B	C
1. Manure bulk density from table (lb/yd)	*1,100*			
2. Length of manure spreader (ft)	*7.0*			
3. Width of manure spreader (ft)	*3.0*			
4. Depth of manure to top of spreader side boards (ft)	*1.4*			
5. Stacking height from the top of the side boards to top of pile (ft)	*1.1*			
6. Volume of manure in spreader (ft^3) **(line 2 x line 3 x (line 4 + (line 5 x 0.8))**	*48*			
7. Weight of manure in the spreader (lb) **(line 1 x line 6) / 27**	*1,951*			
8. Length of area spread (ft)	*245*			
9. Width of area spread (ft)	*4*			
10. Area spread (sq ft) **(line 8 x line 9)**	*980*			
11. Manure applied (lb/sq ft) **(line 7 / line 10)**	*1.99*			
12. Convert to tons/acre **(line 11 x 21.78)**	*43*			

Additional Resources

Typical Nutrient Analyses of Manure

Camberato, J. J. *Land application of animal manure*. EC 673 (Clemson University Cooperative Extension, 1996).

Web site http://virtual.clemson.edu

Jokela, B., F. Magdoff, R. Bartlett, S. Bosworth, and D. Ross. *Nutrient recommendations for field crops in Vermont*. BR 1390 (University of Vermont Cooperative Extension, 2004).

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Sullivan, D., C. Cogger and A. Bary. *Which test is best? Customizing dairy manure nutrient testing*. PNW 505 (Oregon State University, 1997).

Web site http://eesc.orst.edu

Manure Handling on the Farm

Godwin, D. and J, A. Moore. *Manure Management in Small Farm Livestock Operations, Protecting Surface and Groundwater*. EM8649 (Oregon State University, Cooperative Extension Service, 1997).

Web site http://eesc.orst.edu

Koelsch, R. *Manure applicator calibration*. G95-1267-A (University of Nebraska Cooperative Extension, 1995).

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Midwest Plan Service. *Livestock Waste Facilities Handbook*. MWPS-18 (Iowa State University, Ames Iowa, 2001).

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

Lists of Laboratories and Consultants

Daniels, C. H. *Analytical Laboratories and Consultants Serving Agriculture in the Pacific Northwest*. EB1578E (Washington State University Extension, 2002).

Hart, J. *A list of analytical laboratories serving Oregon*. EM8677 (Oregon State University Extension Service, 2002).

Soils and Soil Testing

Cogger, C.G. *Soil Management for Small Farms*. EB1895 (Washington State University Extension, 2000).

Mahler. R.L. and T.A. Tindall. *Soil Sampling*. Bulletin 704 (University of Idaho Cooperative Extension System, 1997).

Notes

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Nutrient Management for Fruit & Vegetable Crop Production

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USING MANURE AND COMPOST AS NUTRIENT SOURCES FOR VEGETABLE CROPS

Manure is a valuable fertilizer for any farming operation and has been used for centuries to supply needed nutrients for crop growth. The use of manure has generally declined on many farms over the past 50 years due to: 1) Farm specialization with increasing separation of crop and livestock production, 2) Cost of transporting manure, which is a bulky, relatively low analysis nutrient source, and 3) Increased availability of high analysis synthetic fertilizers that usually provide a cheaper source per unit of nutrient than manure. Despite these limitations, manure (and other organic nutrient sources) produced on or near a vegetable farm provide many benefits and should be beneficially utilized whenever possible.

Manure and compost not only supply many nutrients for crop production, including micronutrients, but they are also valuable sources of organic matter. Increasing soil organic matter improves soil structure or tilth, increases the water-holding capacity of coarse-textured sandy soils, improves drainage in fine-textured clay soils, provides a source of slow release nutrients, reduces wind and water erosion, and promotes growth of earthworms and other beneficial soil organisms. Most vegetable crops return small amounts of crop residue to the soil, so manure, compost, and other organic amendments help maintain soil organic matter levels.

Proper use of manure and compost is essential from both a production and environmental standpoint. Applying rates that are too low can lead to nutrient deficiency and low yields. On the other hand, too high a rate can lead to nitrate leaching, phosphorus runoff, accelerated eutrophication of lakes, and excessive vegetative growth of some crops. Thus, understanding how to manage manure is important for any farming operation with livestock that relies on manure as a major source of nutrients, as well as for vegetable producers who have access to an economical supply of manure, compost, or other organic nutrient sources.

This discussion addresses differences between the composition of fresh and composted manure, nutrient availability from manure/compost, and calculation of how much manure/compost to apply. Although focused on manure or composted manure, much of the discussion and the methods for calculating rates are generally applicable to effective use of different types of compost, biosolids, and similar organic nutrient sources.

Nutrient Composition of Manure and Compost

Many different types of manure are available for crop production. For this discussion, it is assumed that most vegetable growers will be using solid manure with or without bedding. Similar principles will apply to the use of liquid manures. The nutrient content of manures varies with animal, bedding, storage, and processing. The approximate nutrient composition of various solid manures, including some composted manures, is presented in Table 1. While this table provides a general analysis of manure or compost nutrient content, it is strongly recommended that if routine applications are made for crop production the specific manure being used should be tested by a laboratory for moisture and nutrient content. Nutrient analysis should include: total nitrogen (N), ammonium-N, phosphate (P_2O_5), and potash (K_2O). Accurate manure or compost analysis requires that a representative sample be submitted; so several subsamples should be collected and composited to make up the sample. If manure or compost is being purchased, request a nutrient analysis from the seller for N, P_2O_5, and K_2O content.

Fresh vs. composted manure. Fresh, non-composted manure will generally have a higher N content than composted manure (Table 1). However, the use of composted manure will contribute more to the organic matter content of the soil. Fresh manure is high in soluble forms of N, which can lead to salt build-up and leaching losses if over applied. Fresh manure may contain high amounts of viable weed seeds, which can lead to weed problems. In addition, various pathogens such as *E. coli* may be present in fresh manure and can cause illness to individuals eating fresh produce unless proper precautions are taken. Apply and incorporate raw manure in fields where crops are intended for human consumption at least three months before the crop will be harvested. Allow four months between application and harvest of root and leaf crops that come in contact with the soil. Do not surface apply raw manure under orchard trees where fallen fruit will be harvested.

Heat generated during the composting process will kill most weed seeds and pathogens, provided temperatures are maintained at or above 131°F for 15 days or more (and the compost is turned so that all material is exposed to this temperature for a minimum of 3 days). The microbially mediated composting process will lower the amount of soluble N forms by stabilizing the N in larger organic, humus-like compounds. A disadvantage of composting is that some of the ammonia-N will be lost as a gas. Compost alone also may not be able to supply adequate available nutrients, particularly N, during rapid growth phases of crops with high nutrient demands. Composted manure is usually more expensive than fresh or partially aged manure.

Heat-dried manure/compost. Drying manure or compost to low moisture content reduces their volume and weight, which lowers transportation costs, but it also requires energy inputs. Dried products can be easier to handle and apply uniformly to fields, especially those that have been processed into pellets. Heat drying also reduces pathogens if temperatures exceed 150 to 175°F for at least one hour and water content is reduced to 10 to 12% or less. The significant energy costs to heat-dry manure or compost at high temperatures are in contrast to the self-heating generated by microbial respiration during the composting process. Heat-dried composts vary widely in the degree to which they are composted before drying. Many are only partially composted and have higher amounts of soluble (inorganic) N forms than mature, stable compost. This readily available N gives these products some characteristics that are similar to soluble N fertilizers, such as ammonium nitrate. Heat drying of manure and immature compost may increase volatilization of ammonia-N and reduce the total N content of the finished product. In addition, composted or partially composted material that is dried at high temperature rather than going through a curing phase at ambient temperatures is not as biologically active as mature compost. The disease suppressive properties of some composts depends upon recolonization of the compost by disease suppressing organisms during the curing phase.

Nutrient Availability from Manure and Compost

The analysis of manure or compost provides total nutrient content, but availability of the nutrients for plant growth will depend on their breakdown and release from the organic components. Generally, 70 to 80% of the phosphorus (P) and 80 to 90% of the potassium (K) will be available from manure the first year after application. Numbers from a table or from an analysis report should to be multiplied by these factors to obtain the amount of P_2O_5 and K_2O available to crops from a manure or compost application.

Calculating N availability is more complex than determining P and K availability. Most of the N in manure is in the organic form and essentially all of the N in compost is organic. Organic N is unavailable for uptake until microorganisms degrade the organic compounds that contain it. A smaller fraction of the N in manure is in the ammonium/ammonia or inorganic form. The ammonium-N form is a readily available fraction. Other inorganic forms such as nitrate and nitrite can also exist, but their quantities are usually very low. Estimated levels of ammonium-N and total N in fresh and composted manure are shown in Table 1.

When applied to soil, manure, compost, and other organic amendments undergo microbial transformations that release plant-available N over time. Volatilization, denitrification, and leaching result in N losses from the soil that reduce the amount of N that can be used by crops.

The steps of N transformation in manure, compost, and other organic amendments, and the plant-available N forms, are as follows:

```
            volatilization (NH3)                              denitrificaton
                   |                                            (N gases)
                   |                                                /
organic N ------> NH3 <------> NH4+ -----> NO2- -----> NO3- ---------->
unavailable    (ammonia)   (ammonium)  (nitrite)  (nitrate)     \
                           available              available    leaching
                                                                  (NO3)

   |----- mineralization -----||--- nitrification ---|
```

Table 1. Approximate Nutrient Composition of Various Types of Animal Manure and Compost (**all values are on a fresh weight basis).**

Manure Type	**Dry Matter**	**Ammonium-N**	**Total N [a]**	**P_2O_5**	**K_2O**
	%	------------------------ lb/ton	--------------------------		
Swine, no bedding	18	6	10	9	8
Swine, with bedding	18	5	6	7	7
Beef, no bedding	52	7	21	14	23
Beef, with bedding	50	8	21	18	26
Dairy, no bedding	18	4	9	4	10
Dairy, with bedding	21	5	9	4	10
Sheep, no bedding	28	5	18	11	26
Sheep, with bedding	28	5	14	9	25
Poultry, no litter	45	26	33	48	34
Poultry, with litter	75	36	56	45	34
Turkey, no litter	22	17	27	20	17
Turkey, with litter	29	13	20	16	13
Horse, with bedding	46	4	14	4	14
Poultry compost	45	1	17	39	23
Dairy compost	45	<1	12	12	26
Mixed compost Dairy/Swine/Poultry	43	<1	11	11	10

[a] Total N = Ammonium-N plus organic N

Sources: *Livestock Waste Facilities Handbook*, 2nd ed., 1985, Midwest Plan Service; *Organic Soil Amendments and Fertilizers*, 1992, Univ. of Calif. #21505.

Table 2 provides estimates of N availability from manure the first growing season after application. The actual amount available is dependent on manure type, bedding, and whether the manure has been composted. Usually 25 to 50% of the organic-N in fresh manure is available the first year. In addition to the organic fraction, N availability from manure also has to take into account the amount of ammonium-N present. This form of N is readily available for plant uptake, but is prone to losses as ammonia if not incorporated within 12 hours after application. Assuming direct manure incorporation after application, 45 to 75% of the total N (organic-N + ammonium-N) is available the first year. Note that for composted manure, the percentage of the organic N available in the first year following application is much lower than it is for fresh manure. Because there is very little ammonium-N in composted manure, the organic N fraction is basically the same as the total N fraction.

Bedding or litter will usually decrease nutrient content by dilution. If materials high in carbon (C) like straw or wood shavings are used as bedding, N availability may be reduced by the larger C/N ratio of the product. High C relative to N will lead to a tie-up of N, potentially causing N deficiency in the crop. A C/N ratio of 25/1 or greater will lead to N tie-up in the soil. A C/N ratio of less than 25/1 will release N to the crop. The C/N ratio is also an important consideration in the use of various composts, as well as a controlling factor in the composting process itself.

Manure and Compost Application

As discussed above, some of the N in fresh manure will be lost to the atmosphere during application in the form of ammonia gas. The higher the ammonium-N fraction is in manure, the more prone it is to ammonia volatilization. Manure should be incorporated within 12 hours of application to avoid excessive ammonia losses. Unincorporated manure will supply the organic N fraction and at most 20% of the ammonium-N fraction. Incorporation of composted manure is not as critical, because the N is stabilized in organic compounds with little free ammonium present. However, in order to obtain full benefit from compost, incorporation is recommended whenever possible. Manure and compost are often high in soluble salts, so to avoid salt injury seeding operations should take place about 3 to 4 weeks after application.

Residual Nutrients in Soil from Manure and Compost Application

The residual effects of the manure and compost are important. Some benefit will be obtained in the second and third years following application. When manure and compost are used to fertilize crops, soil organic matter will increase over time and subsequent rates of application can generally be reduced because of increased nutrient cycling. Continuous use of manure or compost can lead to high levels of residual N, P, and other nutrients, which can potentially be transported to lakes and streams in runoff or leach and pollute the groundwater. Taking into account residual release of N in subsequent years should help to avoid excessive applications. General rules of thumb for N are that organic N released during the second and third cropping years after initial application will be 50% and 25%, respectively, of that mineralized during the first cropping season. Remember that some manures and composts contain high levels of P, so if organic nutrient sources are regularly applied at rates to meet crop N demands, the amount of P in the soil can build up to excessively high levels. Use of soil tests, plant tissue tests, and monitoring of crop growth will help in determining the amount of residual N and other nutrients in the soil and the need for further applications.

Table 2. Estimated Organic N Availability (Km) from Manure and Composted Manure the First Season After Application.

Manure Type	Organic N
	(% available)
Swine, fresh	50
Beef, no bedding	35
Beef, with bedding	25
Dairy, no bedding	35
Dairy, with bedding	25
Sheep, solid	25
Poultry, no litter	50
Poultry, with litter	45
Horse, with bedding	20
Composted poultry	30
Composted dairy	14

Calculating the Amount of Manure or Compost to Apply

Methods for calculating the amount of manure or compost to apply have been adapted and summarized from *Livestock Waste Facilities Handbook*, 2nd ed., 1985, Midwest Plan Service. Composts can be thought of as similar to manure, but with little or no ammonium-N present. The amount of compost required to meet crop nutrient demands can be very large. For these situations, more readily available nutrients from other sources may be required to supplement compost additions, especially early in the growing season.

Use the following steps to determine the manure or compost rate needed for a particular crop:

Step 1

Determine the nutrient needs of the crop – Base nutrient needs on soil test recommendations.

Step 2

Determine the total nutrient content of the manure or compost – Chemical analysis of the actual product is strongly recommended; a general estimate can be obtained from Table 1 above.

Step 3

Determine the available nutrient content – Use 80% availability for P_2O_5 and 90% availability for K_2O. Calculate N availability using the following equation:

Available N = (Organic N x Km) + Ammonium-N*

Where:

- Organic N = Total N – Ammonium-N (lb/ton) (from manure or compost analysis or Table 1)
- Km = Fraction of organic N released (% available/100, from Table 2)
- Ammonium-N* = Ammonium-N in lb/ton (from manure analysis or Table 1)

* **Note**: if manure is not incorporated within 12 hours after application, reduce the value for ammonium-N using Table 3 to account for volatilization losses; reduce ammonium-N in the <u>Available N</u> equation, but use the full value in the equation for <u>Organic N</u>

Table 3. Percent of the Ammonium-N Available to a Crop When the Time Between Application and Incorporation Is More Than 12 Hours.

Days Until Incorporation	% of Ammonium-N Available to Crop
0.5-2	80
2-4	60
4-7	40
>7	20

Step 4

Calculate the rates of application needed to supply the recommended amounts of N, P_2O_5, and K_2O – Divide the recommended nutrient needs from Step 1 by the pounds of available nutrients per ton of manure or compost determined in Step 3.

Step 5

Select the rate of manure or compost to apply – Frequently, manure and compost application rates are based on the N need of the crop. If manure or compost is applied on a regular basis, you may need to base rates on P to avoid excessive buildup of P in the soil, and supplement with other N sources to meet the total crop N requirement. For legumes, either P_2O_5 or K_2O can be used as a basis for rates, depending on crop needs and soil test levels.

Step 6

Determine the amount of available nutrients applied with the manure or compost – multiply the application rate of manure or compost determined in Step 5 (in tons/A) times the estimated available nutrients (in lb/ton) determined in Step 3. The amounts calculated can be compared with crop needs (from Step 1) to determine if supplemental nutrients are needed (next Step).

Step 7

Determine whether application of additional nutrients is needed – Subtract the amount of nutrients needed by the crop (based on the soil test in Step 1) from the amounts of available nutrients applied with the manure or compost (calculated in Step 6). If the number obtained for a nutrient is zero or negative, then no further application is necessary. A positive number indicates the amount of that nutrient (in lb/A) that needs to be applied from another nutrient source to meet crop demands.

EXAMPLE CALCULATION

The following steps provide an example manure rate calculation for the following situation:

- **Crop –** sweet corn
- **Nutrient source –** turkey manure with litter
- **Soil test results**
  - pH = 6.3
  - Organic matter = 4.8%
  - Available P (Bray-P1) = 8 ppm
  - Available K = 70 ppm

Step 1 – Determine the nutrient needs of the crop

- Yield goal = 9 tons/acre
- Previous crop = pumpkin
- NPK soil test recommendations
  - **120 lb N/A**
  - **60 lb P_2O_5/A**
  - **100 lb K_2O/A**
  - For the basis of these recommendations, refer to the University of Minnesota Extension bulletin *Nutrient Management for Commercial Fruit & Vegetable Crops in Minnesota* (BU-5886)

Step 2 – Determine the total nutrient content of the manure

- Chemical analysis of the manure is strongly recommended for efficient nutrient use
- For this example, we will use the general estimates in Table 1 (all values on a wet weight basis)
  - **Ammonium-N – 13 lb/ton**
  - **Total N – 20 lb/ton**
  - **P_2O_5 – 16 lb/ton**
  - **K_2O – 13 lb/ton**

Step 3 – Determine the available nutrient content

- We will calculate **available N** first
- The equation is: Available N = (Organic N x Km) + Ammonium-N

- Organic N = Total N – Ammonium-N, so

  Organic N = 20 – 13 **= 7 lb/ton**

- Km = Fraction of organic N released the first season after application; get the percentage available from Table 2 and then convert to a decimal fraction, so

  Km = % available/100 **= 0.45**

- Substituting into the original equation: Available N = (Organic N x Km) + Ammonium-N, so

  Available N = (7 x 0.45) + 13* = **16.2 lb/ton**

* **Note**: we are assuming the manure is incorporated within 12 hours after application; if it is more than 12 hours before incorporation, reduce the value for ammonium-N using Table 3; reduce ammonium-N in the Available N equation, but use the full value in the equation for Organic N

- Next we can calculate **available P_2O_5**
  - Using the 80% availability factor (from Step 3 above) the equation is: Available P_2O_5 = 0.80 x Total P_2O_5
  - **Available P_2O_5** = 0.80 x 16 = **12.8 lb/ton**

- Finally, we can calculate **available K_2O**
  - Using the 90% availability factor (from Step 3 above) the equation is: Available K_2O = 0.90 x Total K_2O
  - **Available K_2O** = 0.90 x 13 = **11.7 lb/ton**

Step 4 – Calculate the rates of application needed to supply the recommended amounts of N, P_2O_5, and K_2O

- Divide the nutrient recommendations (from Step 1) by the pounds of available nutrient per ton of manure (calculated in Step 3)
- To meet the **N requirement**
  - 120 lb N/A divided by 16.2 lb available N/ton = **7.4 tons/A**
- To meet the **P_2O_5 requirement**
  - 60 lb P_2O_5/A divided by 12.8 lb available P_2O_5/ton = **4.7 tons/A**
- To meet the **K_2O requirement**
  - 100 lb K_2O/A divided by 11.7 lb available K_2O/ton = **8.5 tons/A**

Step 5 – Select the rate of manure to apply

- Decide whether to base the application rate on the N, P_2O_5, or K_2O requirement
- For this example, we will use the **N requirement**
  - The application rate will be **7.4 tons of manure/A**

Step 6 – Determine the amount of available nutrients applied with the manure

- Multiply the application rate of manure (selected in Step 5) times the amounts of available nutrients (calculated in Step 3)
- We decided to meet the N requirement and are applying **120 lb N/A**
- P_2O_5 application rate
  - 7.4 tons of manure/A x 12.8 lb available P_2O_5/ton = **94.7 lb P_2O_5/A**
- K_2O application rate
  - 7.4 tons of manure/A x 11.7 lb available K_2O/ton = **86.6 lb K_2O /A**

Step 7 – Determine whether application of additional nutrients is needed

- Subtract the amounts of nutrients needed by the crop (based on soil test in Step 1) from the amounts of available nutrients applied with the manure (calculated in Step 6)
- The N requirement is met
- P_2O_5 requirement
  - 60 – 94.7 = – 34.7
  - Excess of **34.7 lb P_2O_5/A**
  - This field has a medium soil test P level (8 ppm Bray-P1), so a single application of excess P should not cause a problem; however, continued manure applications based on crop N requirements will build up soil test P to levels that eventually could cause water quality problems
- K_2O requirement
  - 100 – 86.6 = 13.4
  - Shortage of **13.4 lb K_2O/A**
  - Supplemental K_2O could be applied in starter fertilizer

healthy, productive soils checklist for growers

unlock the SECRETS IN THE SOIL

Managing for soil health is one of the easiest and most effective ways for farmers to increase crop productivity and profitability while improving the environment.

Results are often realized immediately, and last well into the future. Using these four basic principles is the key to improving the health of your soil.

1. Keep the soil covered as much as possible
2. Disturb the soil as little as possible
3. Keep plants growing throughout the year to feed the soil
4. Diversify as much as possible using crop rotation and cover crops

Use the checklist on the back of this page to determine if you're using some or all of the core Soil Health Management System farming practices.

It is important to note that not all practices are applicable to all crops. Some operations will benefit from just one soil health practice while others may require additional practices for maximum benefit. But these core practices form the basis of a Soil Health Management System that can help you optimize your inputs, protect against drought, and increase production.

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Natural Resources Conservation Service

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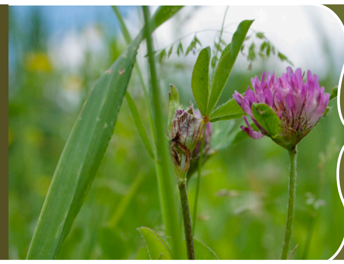
Helping People Help the Land

Soil Health Management Systems Include:

What is it?		What does it do?	How does it help?
Conservation Crop Rotation Growing a diverse number of crops in a planned sequence in order to increase soil organic matter and biodiversity in the soil.		• Increases nutrient cycling • Manages plant pest (weeds, insects, and diseases) • Reduces sheet, rill, and wind erosion • Holds soil moisture • Adds diversity so soil microbes can thrive	• Improves nutrient use efficiency • Decreases use of pesticides • Improves water quality • Conserves water • Improves plant production
Cover Crop An un-harvested crop grown as part of planned rotation to provide conservation benefits to the soil.		• Increases soil organic matter • Prevents soil erosion • Conserves soil moisture • Increases nutrient cycling • Provides nitrogen for plant use • Suppresses weeds • Reduces compaction	• Improves crop production • Improves water quality • Conserves water • Improves nutrient use efficiency • Decreases use of pesticides • Improves water efficiency to crops
No Till A way of growing crops without disturbing the soil through tillage.		• Improves water holding capacity of soils • Increases organic matter • Reduces soil erosion • Reduces energy use • Decreases compaction	• Improves water efficiency • Conserves water • Improves crop production • Improves water quality • Saves renewable resources • Improves air quality • Increases productivity
Mulch Tillage Using tillage methods where the soil surface is disturbed but maintains a high level of crop residue on the surface.		• Reduces soil erosion from wind and rain • Increases soil moisture for plants • Reduces energy use • Increases soil organic matter	• Improves water quality • Conserves water • Saves renewable resources • Improves air quality • Improves crop production
Mulching Applying plant residues or other suitable materials to the soil surface to compensate for loss of residue due to excessive tillage.		• Reduces erosion from wind and rain • Moderates soil temperatures • Increases soil organic matter • Controls weeds • Conserves soil moisture • Reduces dust	• Improves water quality • Improves plant productivity • Increases crop production • Reduces pesticide usage • Conserves water • Improves air quality
Nutrient Management Managing soil nutrients to meet crop needs while minimizing the impact on the environment and the soil.		• Increases plant nutrient uptake • Improves the physical, chemical, and biological properties of the soil • Budgets, supplies, and conserves nutrients for plant production • Reduces odors and nitrogen emissions	• Improves water quality • Improves plant production • Improves air quality
Pest Management Managing pests by following an ecological approach that promotes the growth of healthy plants with strong defenses, while increasing stress on pests and enhancing the habitat for beneficial organisms.		• Reduces pesticide risks to water quality • Reduces threat of chemicals entering the air • Decreases pesticide risk to pollinators and other beneficial organisms • Increases soil organic matter	• Improves water quality • Improves air quality • Increases plant pollination • Increases plant productivity

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