

SOIL MANAGEMENT FOR SMALL FARMS

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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

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.

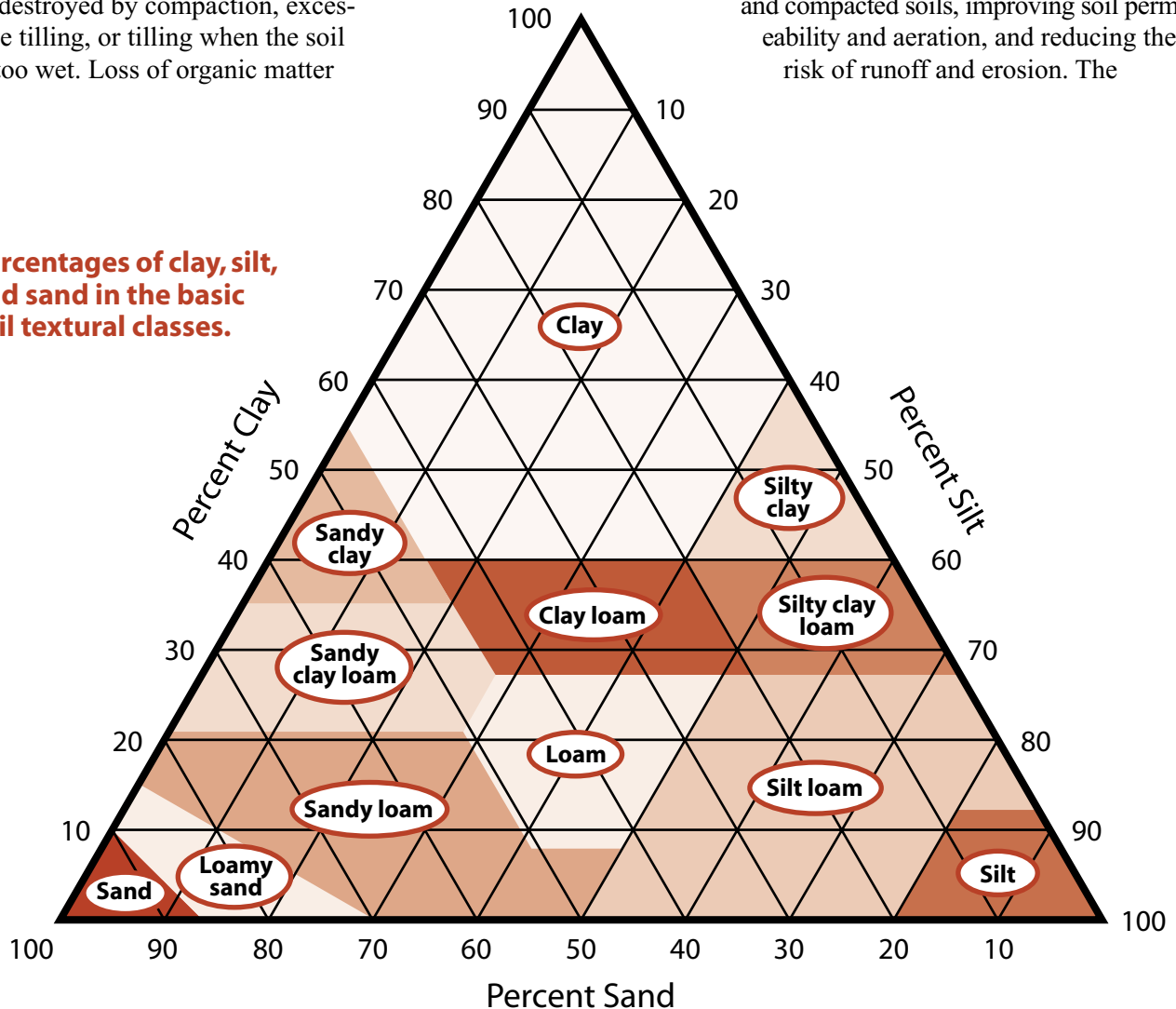
Compaction and loss of structure. Soil structure is fragile and can be damaged or destroyed by compaction, excessive tilling, or tilling when the soil is too wet. Loss of organic matter

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 melt-water 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	$\text{HPO}_4^{=}$, H_2PO_4^-	very low
Potassium	K	K^+	low
Secondary Nutrients			
Sulfur	S	$\text{SO}_4^{=}$	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	$\text{MoO}_4^{=}$	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.

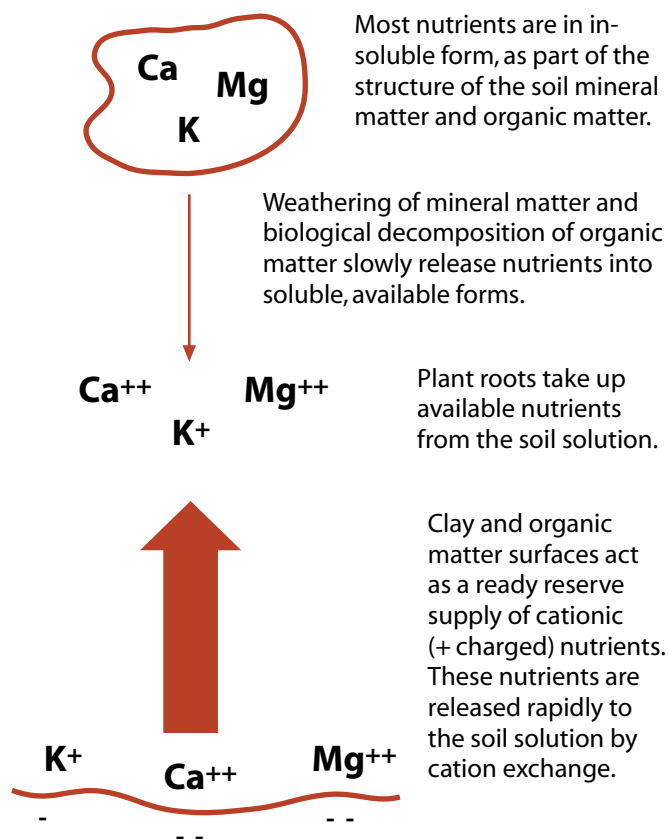
Soil nutrients become available to plants only after they dissolve into soil solution. This occurs by weathering of mineral matter and biological decomposition of organic matter. Weathering of mineral matter is a very slow process, releasing small amounts of nutrients each year. The rate of nutrient 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 (NH₄⁺)

Soluble form. Available to plants. Converted to nitrate by soil microorganisms.

Nitrate N (NO₃⁻)

Soluble form. Available to plants. Can be lost by leaching. Converted to gases in wet soils.

Atmospheric N (N₂)

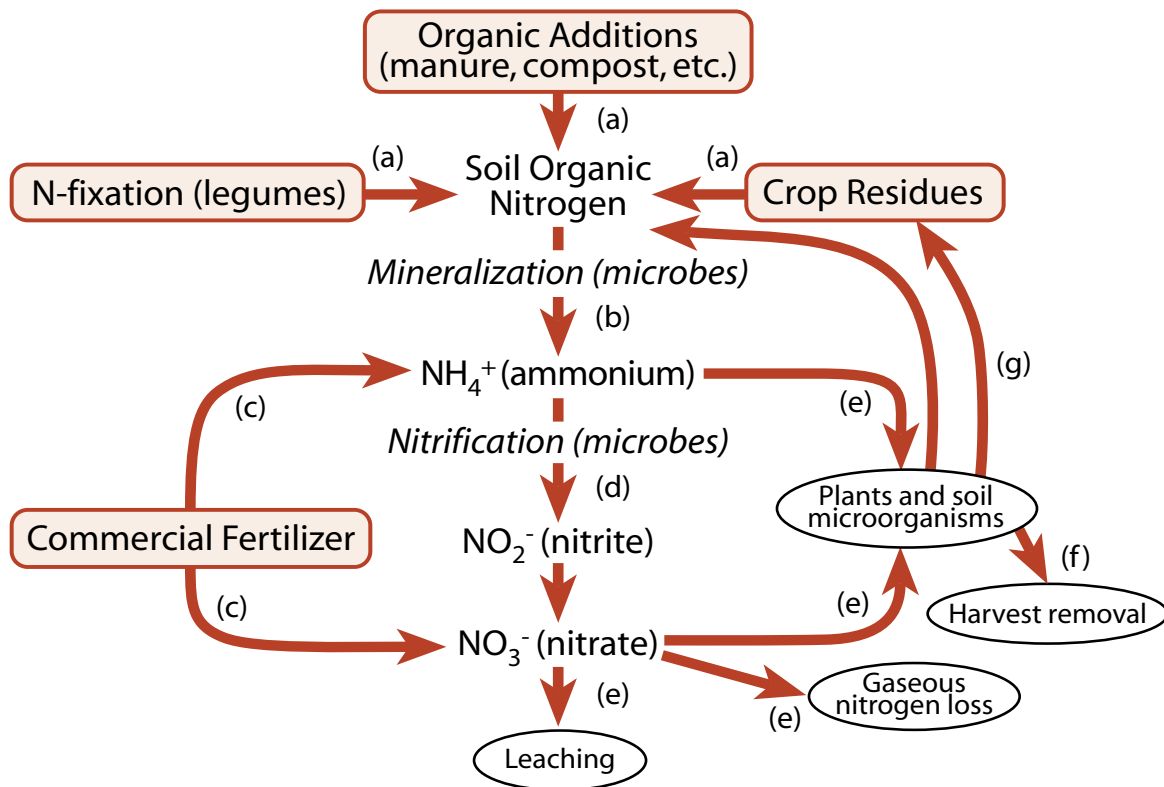
Comprises about 80% of soil atmosphere. Source of N for N-fixing plants. Not used by other plants.

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 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.

¹ If you need to convert from P to P_2O_5 , the conversion is 1 lb P = 2.3 lb P_2O_5 . For potassium the conversion is 1 lb 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 ₂ O ₅	K ₂ O	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.

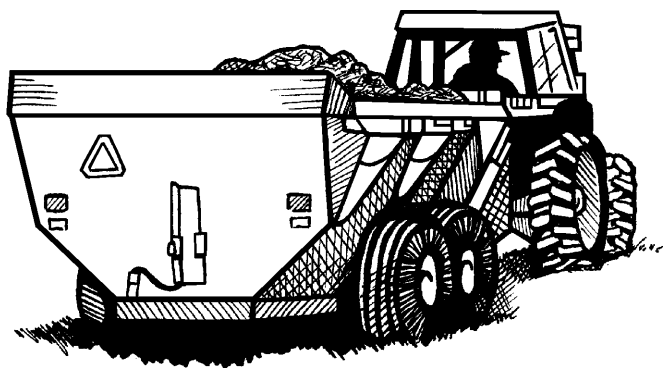
These pathogens are not taken up into plant tissue, but they can adhere to soil on plant roots, or on the leaves or fruit of low-growing crops. Cooking destroys pathogens, but raw food carries a risk of pathogen exposure. Although washing and peeling raw produce removes most pathogens, some may remain. 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.

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 UIIdaho 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.

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

Material	% Nitrogen	% P ₂ O ₅	% K ₂ O
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

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

²Very low availability. Useful only in acid 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).

$$100 \text{ lb N/acre} / .46 = 218 \text{ lb urea/acre}$$

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

$$218 \text{ lb/acre} \times 5 \text{ acres} = 1,090 \text{ lb urea}$$

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).

$$80 \text{ lb N/acre} / .46 = 174 \text{ lb urea/acre}$$

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

$$174 \text{ lb urea/acre} / 44 = 4.0 \text{ lb urea/1,000 square feet}$$

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.

$$(4.0 \text{ lb urea/1,000 square feet}) \times 2 = 8.0 \text{ lb urea}$$

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.

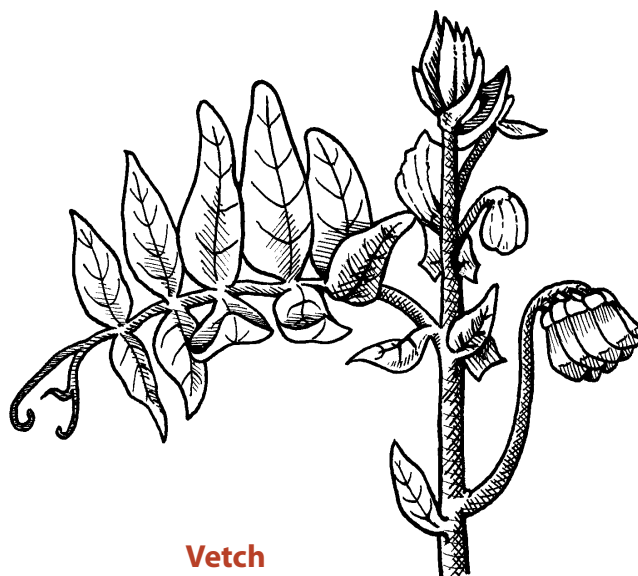
Green Manure

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



Vetch

need an early start to cover the soil before cold weather arrives.

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

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.

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.

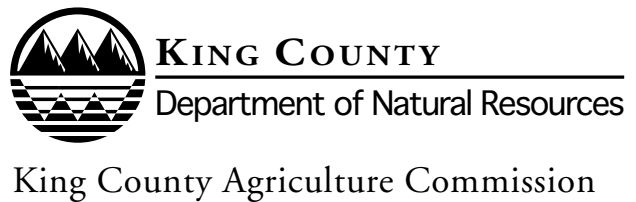
Gypsum (calcium sulfate) is not a substitute for lime. It provides calcium and sulfur to soils, but it has little effect on soil pH. Gypsum has been promoted as a soil amendment to improve soil structure, but it does not work in our environment. Gypsum improves structure only when the problem results 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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