

# A Home Gardener's Guide to Soils and Fertilizers

WASHINGTON STATE UNIVERSITY EXTENSION • EM063E



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*This manual is part of the WSU Extension Home Garden Series.*

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# A Home Gardener's Guide to Soils and Fertilizers

## Introduction

Soil is a mixture of weathered rock fragments and organic matter at the earth's surface. It is biologically active—a home to countless microorganisms, invertebrates, and plant roots. It varies in depth from a few inches to 5 feet or more. Native soil is roughly 50 percent pore space. This space forms a complex network of pores of varying sizes, much like those in a sponge. Soil provides nutrients, water, and physical support for plants as well as oxygen for plant roots. Soil organisms are nature's primary recyclers, turning dead cells and tissue into nutrients, energy, carbon dioxide, and water to fuel new life.

## Soil and Water

### Soil pores, permeability, and water supply

A productive soil is permeable to water and is able to supply water to plants. A soil's permeability and **water-holding capacity** depend on its network of pores:

- Large pores (**macropores**) control a soil's permeability and aeration. Macropores include earthworm and root channels. Because these pores are large, water moves through them rapidly by means of gravity. Thus, rainfall and irrigation infiltrate the soil, and excess water drains through it.
- Small or fine pores (**micropores**) are typically a fraction of a millimeter in diameter. They are responsible for a soil's water-holding capacity. Like the fine pores in a sponge, micropores hold water (acting against the force of gravity). Much of the water held in micropores is available to plants, however, some is held so tightly that plant roots cannot use it.

Soil that has a good balance of macropores and micropores provides adequate permeability and water-holding capacity for good plant growth. Soils that contain mostly macropores drain readily, but are droughty and need more frequent irrigation. Soils

that contain mostly micropores have good water-holding capacity, but take longer to dry out and warm up in the spring. Rainfall and irrigation water runoff are also more likely with these soils.

### Factors that affect soil porosity

Soil properties that affect porosity include texture, structure, compaction, and organic matter. Gardeners can evaluate these properties to understand how well their soil moves and holds water and what steps they can take to improve the soil.

#### *Soil texture*

Texture describes how coarse or fine a soil is. The coarsest soil particles are sand. They are visible to the naked eye and 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, flour-like feel. On close inspection, sand and silt particles look like miniature rocks. Clay particles are the smallest—about the size of bacteria and viruses—and can be seen only with a microscope. They typically have a flat shape, similar to a sheet of mica. 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 directly affects porosity. Pores between sand particles tend to be large, while those between silt and clay particles tend to be small. Thus, sandy soils contain mostly macropores and usually have rapid permeability but limited water-holding capacity. Micropores predominate in soils containing mostly silt and clay, creating high water-holding capacity, but reducing permeability. Particle size also affects the surface area in a volume of soil. Surface area is important because soil surfaces are the most active part of the soil. They hold plant nutrients, bind contaminants, and provide a home for microorganisms. Clay particles have a large surface area

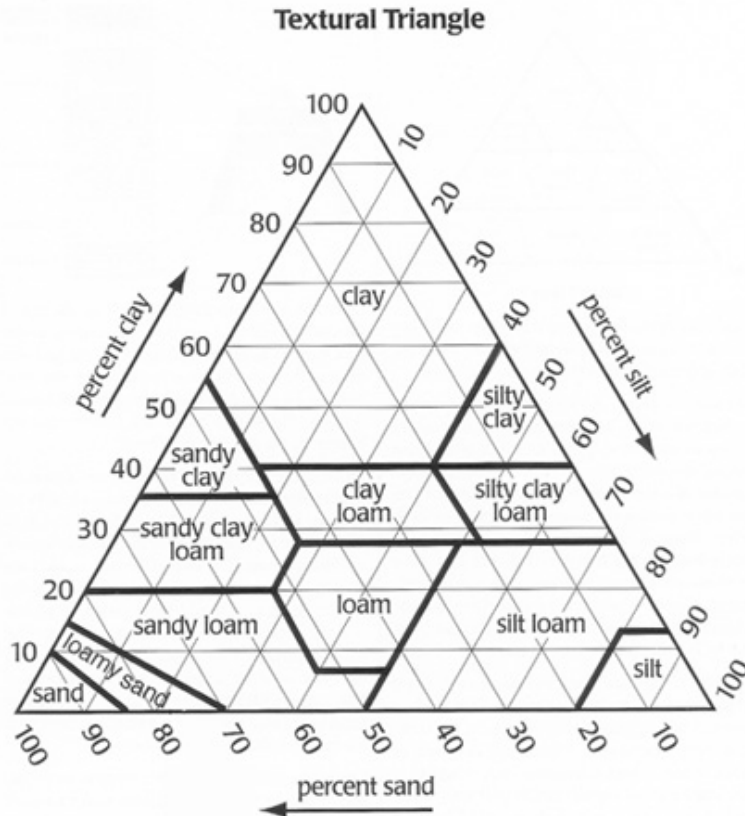


Figure 1. Soil textural triangle showing soil texture classes and percentages of sand, silt, and clay. Source: U.S. Department of Agriculture.

relative to their volume, and a small amount of clay makes a large contribution to a soil's surface area.

Nearly all soils have a mixture of particle sizes (Figure 1). A soil with roughly equal influences from sand, silt, and clay particles is called a **loam**. Loams usually make good agricultural and garden soils because they have a good balance of macropores and micropores. Thus, they 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 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, sticky when wet, and can be molded into wire and ribbon shapes when moist (Figure 2). They generally have high water-holding capacity and low permeability. To learn how to estimate the texture of soil, view the

WSU Extension Video, *Determining Soil Texture by Hand* (Cogger 2010b) located at [http://puyallup.wsu.edu/soilmgmt/Videos/Video\\_SoilTexture.html](http://puyallup.wsu.edu/soilmgmt/Videos/Video_SoilTexture.html).

Almost any soil texture can be suitable for gardening, as long as gardeners are aware of the soil's limitations and adjust their management practices to compensate. Clay soils hold a lot of water, but are hard to dig and dry slowly in the spring. Sandy soils need more frequent watering and lighter, more frequent fertil-



Figure 2. Estimating soil texture by hand (pictured sample is rich in clay). Photo by Andy Bary, WSU

ization, but they can be planted earlier in the spring. Most soils can benefit from additions of organic matter, as described in this publication under *Organic Amendments*.

Many soils contain coarse fragments, that is, gravel and rocks. Coarse fragments do not contribute to a soil's productivity and can be a nuisance when digging in the soil. However, gardeners should not feel compelled to remove all of them from their garden since coarse fragments are not harmful, and time is better spent on other gardening tasks. The only time rocks are a problem is when the soil is nothing but rocks. Then, water- and nutrient-holding capacities are so low that it is difficult to grow healthy plants. Raised beds are an alternative strategy for gardening in very rocky soils. For information on raised beds, refer to *Raised Beds: Deciding if They Benefit Your Vegetable Garden*, Washington State University Extension Publication FS075E (Cogger 2012) at <http://cru.cahe.wsu.edu/CEPublications/FS075E/FS075E.pdf>.

### Soil structure

Individual particles of sand, silt, and clay bind together with organic matter, forming aggregates called **ped**s, which provide structure to a soil. Dig up a piece of grass sod and examine the soil around the roots. The granules of soil clinging to the roots are examples of peds (Figure 3). **Aggregation** is a natural process caused largely by biological activity, such as earthworm burrowing, root growth, and microbial action. Soil organic matter is an important binding agent that stabilizes and strengthens peds.

The spaces *between* peds are the soil's macropores, which improve permeability, drainage, and oxygen levels in the soil profile. The pores *within* peds are predominantly micropores, which contribute to the soil's water-holding capacity. A well-structured soil is like a sponge, allowing water to enter and soak



Figure 3. Granular peds typical of topsoil (l); blocky peds typical of subsoil (r). Photo by Andy Bary, WSU

into the micropores and letting excess water drain downward through the macropores. Good structure is especially important in medium- to fine-textured soils because it increases the soil's macroporosity, thus improving permeability and drainage.

### Compaction and loss of structure

Soil structure is fragile and can be damaged or destroyed by compaction, excessive tillage, or tillage when the soil is too wet. Loss of organic matter also weakens soil structure. Compaction squeezes macropores into micropores and creates horizontal aggregates that resist root penetration and water movement (Figure 4). Compaction often occurs during site preparation or house construction, creating a difficult environment for establishing plants. Even sandy soils are at risk of compaction. Soil can be protected from compaction by eliminating unnecessary foot or machine traffic.



Figure 4. Soil compaction harms the rooting environment. Photo by Craig Cogger, WSU

Tilling when soil is too wet also damages soil structure. If a piece of soil can be molded into a wire or worm shape in your hand, it is too wet to till. If the soil crumbles when you try to mold it, it is dry enough to till.

Structural damage caused by human activity usually is most severe within the top foot of soil and can be overcome by proper soil management. In some soils, there is deeper compaction caused by pressure from ancient glaciers. Glacially compacted subsoils (a type of hardpan) are common in the Puget Sound area, where the compacted layer often begins 18 to 36 inches below the soil surface. Where the land surface has been cut, leveled, or shaped for development, the compacted layer may be much closer to the surface. This layer looks like concrete and is so dense and thick that it is nearly impossible to work with. If a garden has a glacially compacted layer close to the soil surface, consider raised beds as a way to increase soil depth.

## Organic matter

Adding organic matter is the best way to improve the environment for most types of plants in most soils. Organic matter helps build and stabilize structure in fine-textured and compacted soils, thus improving permeability and aeration and reducing the risk of runoff and erosion. When organic matter decomposes, it forms **humus**, which acts as a natural glue to bind and strengthen soil aggregates. Organic matter also helps sandy soils hold water and nutrients. See *Organic Amendments* in this publication for information on amending soil with organic matter.

## Slope, aspect, depth, and water

Slope, **aspect** (direction of exposure), and soil depth affect water availability and its use in a soil. Choose plants that are best suited to a property's specific conditions. Ridge tops and side slopes shed water, while soils at the bottom of slopes and in low areas collect water (Figure 5). Often, soils that collect water have high winter water tables, which can affect the health of some plants. Soils on ridge tops are more likely to be droughty. Site aspect is also important. South- and southwest-facing exposures collect the most heat and use the most water.



Figure 5. Landscape position affects soil wetness, with drier soils on slopes and wetter soils in low areas. Photo by Craig Cogger, WSU

Soil depth affects water availability by defining the rooting zone. Soil depth is limited by compacted, cemented, or gravelly layers, or by bedrock. A shallow soil has less available water simply because the soil volume available to roots is smaller. The deeper one can dig below the topsoil before hitting a restrictive layer, the greater the soil volume for holding water.

## Water management in your garden

### Soils and irrigation

Most gardens in the Pacific Northwest require summer irrigation. The need for irrigation varies,

depending on soil water-holding capacity, weather, site aspect, type of plants grown, and plant growth stage. In most cases, the goal of irrigation is to recharge the available water in the top foot or so of soil. For sandy soil, one inch of irrigation water is all that is needed. Any more will **leach** (move downward) through the root zone, carrying away important nutrients with it. A silt loam or clay soil can hold more than two inches of water, but may need to be irrigated more slowly to prevent runoff.

The two most common types of garden irrigation systems are sprinklers and drip systems. Movable sprinklers are less expensive, but also less efficient than drip irrigation. It is easy to determine how much water is being applied with a sprinkler system. Simply set out some straight-sided cans, and measure how much water collects in each can over a set period of time.

Drip irrigation uses tubing with emitters to direct water to a plant's root zone, thus it is more efficient than sprinklers, but drip systems can be difficult to design and install. Soaker hoses provide similar benefits to drip irrigation and are easier to install; however, they are less efficient than drip systems. Estimating water application is more difficult with drip emitters and soaker hoses. One qualitative method for testing drip effectiveness is to dig in the soil one to two days after irrigation to see if the root zone is moist.

When choosing an irrigation system, consider the trade-offs in efficiency, cost, complexity, and the time required to move hoses. For more information on drip irrigation systems, refer to *Drip Irrigation for the Yard and Garden*, Washington State University Extension Publication FS030E (Peters 2011) at <http://cru.cahe.wsu.edu/CEPublications/FS030E/FS030E.pdf>.

### Wet soils

If soil stays wet in the spring, delay tilling and planting. Working wet soil can damage its structure, and seeds are less likely to germinate in cold, wet soil. Some plants do not grow well in wet soil. Raspberries, for example, often become infected with root diseases in wet soil and thus lose vigor and productivity. Soils may be wet because they are located in a low-lying area that collects runoff from surrounding areas. Soils on level ground may be wet if they have a compacted underlayer that restricts drainage through the soil profile. Either natural or human-caused compaction can restrict drainage.

A soil's color provides clues to its tendency to stay wet. If a subsoil is brown or reddish, the soil probably is well drained and has few wetness problems.

Gray subsoils, especially those with brightly colored mottles, often are wet (Figure 6). If soil is gray and mottled directly beneath the topsoil, it is probably saturated during the wet season.

Sometimes, simple actions can reduce soil wetness problems. For example:

- Divert runoff from roof drains away from garden areas.
- Avoid plants that perform poorly in wet conditions.
- Use raised beds for perennials that require well-drained soil and for early-season vegetables.
- Investigate whether a drain on a slope will remove excess water, although installing drainage can be expensive. When considering drainage, make sure there is a place to drain the water. Check with local regulatory agencies to determine whether there are restrictions on drainage projects.



Figure 6. The gray color with mottles in the lower part of this soil profile indicates a seasonal high water table. Photo by Craig Cogger, WSU

## Soil Organisms

Soil abounds with life. Besides plant roots, earthworms, insects, and other visible organisms, soil is home to an abundant and diverse population of microorganisms. A single gram of topsoil (about ¼ teaspoon) can contain as many as a billion microorganisms (Table 1). Microorganisms are most abundant in the rhizosphere—the thin layer of soil surrounding plant roots.

Table 1. Approximate abundance of microorganisms in agricultural topsoil.

Organism	Number per gram of soil (dry weight basis)
Bacteria	100 million to 1 billion
Actinomycetes	10 million to 100 million
Fungi	100,000 to 1 million
Algae	10,000 to 100,000
Protozoa	10,000 to 100,000
Nematodes	10 to 100

The primary function of soil organisms is to break down the remains of plants and other organisms. This process releases energy, nutrients, and carbon dioxide, and creates soil organic matter. Many types of organisms are involved, ranging from tiny bacteria to fungi, nematodes (Figure 7), insects, and earthworms.

Some soil organisms play other beneficial roles. Mycorrhizae are fungi that infect plant roots, resulting in an increase in their ability to take up nutrients from the soil. *Rhizobia* and *Frankia* bacteria are responsible for converting atmospheric nitrogen to plant-available forms, a process known as nitrogen fixation. Earthworms mix large volumes of soil and

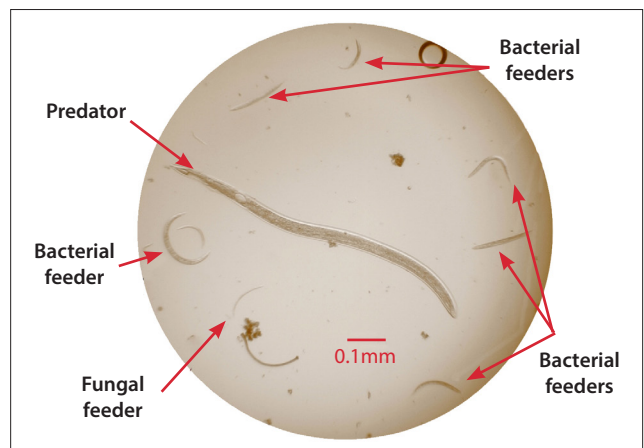


Figure 7. Nematodes isolated from agricultural soil. The smallest nematodes feed on bacteria and fungi. The largest ones are predators that feed on other nematodes. Photo by Doug Collins, WSU

create macropore channels that improve soil permeability and aeration. However, not all soil organisms are beneficial to garden plants. Some are pathogens, which cause diseases, such as root rot in raspberries and scab on potatoes. Moles can damage crops and lawns, and slugs are a serious pest in many Northwest gardens.

The activity of soil organisms depends on soil moisture and temperature, as well as on the soil's organic matter content. Microorganisms are most active between 70°F 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.

The relationships between gardening practices, microbial populations, and soil quality are complex and often poorly understood. However, almost all gardening activities—including tillage; the use of fertilizers, manures, and pesticides; and the choice of crop rotations—affect the population and diversity of soil organisms. For example, amending soils with organic matter, returning crop residues to the soil, and rotating plantings tend to increase the number and diversity of beneficial organisms.

## Soil Nutrients

Soil supplies 13 essential plant nutrients. Each nutrient plays one or more specific roles in plant growth. Nitrogen, for example, is a component of chlorophyll, amino acids, proteins, DNA, and many plant hormones. It plays a vital role in nearly all aspects of plant growth and development, and plants need a large amount of nitrogen to grow well. In contrast, plants need only a tiny amount of molybdenum, which is involved in the functioning of only a few plant enzymes. Molybdenum nonetheless is essential, and plant growth is disrupted if it is deficient. Plants also require carbon, hydrogen, and oxygen, which they derive from water and air.

A soil nutrient is classified as a major nutrient or micronutrient based on the amount plants need for health (Table 2). If a soil's nutrient supply is deficient, fertilizers can provide the additional nutrients needed for healthy plant growth.

### Nutrient deficiencies

The most common nutrient deficiencies found in soil are nitrogen (N), phosphorus (P), and potassium (K)—the nutrients that are in largest demand by plants. Sulfur deficiencies are also common in Washington soils. Nearly all soils lack enough available N for ideal plant growth, and phosphorus deficiencies are

Table 2. The 13 essential plant nutrients.

Major nutrients		Micronutrients	
Nitrogen	N	Zinc	Zn
Phosphorus	P	Iron	Fe
Potassium	K	Copper	Cu
Sulfur	S	Manganese	Mn
Calcium	Ca	Boron	B
Magnesium	Mg	Molybdenum	Mo
		Chlorine	Cl

widespread in native soils. Potassium deficiencies are common west of the Cascades, but many soils east of the Cascades have adequate potassium for crop growth. Since phosphorus and potassium accumulate in soils that have experienced repeated fertilization, gardens with a history of fertilization are seldom deficient in these nutrients.

Calcium and magnesium may be deficient in acid soils, which are typically found west of the Cascades. Except for boron and zinc, micronutrients are rarely deficient in soils located in the Northwest. Boron deficiencies occur most often in soils west of the Cascades, particularly in root crops, brassica crops (for example, broccoli), and caneberries (for example, raspberries). Zinc deficiency is usually associated with high pH soils found east of the Cascades and most often affects tree fruits.

Each nutrient deficiency causes characteristic symptoms. In addition, affected plants grow more slowly, yield less, and are less healthy than plants with adequate levels of nutrients.

### Nutrient excesses

Excess nutrients can be a significant problem for plants and the environment. Excesses usually result because too much of a given nutrient is applied to the soil or because a nutrient is applied at the wrong time. For example, applying too much nitrogen can lead to excessive foliage production, increasing the risk of plant disease and wind damage, and delaying flowering, fruiting, and dormancy. Available nitrogen left in the soil at the end of the growing season can leach into ground water and threaten drinking water quality. Excess phosphorus can harm water quality if it moves into streams and lakes through runoff and erosion. The key to applying fertilizers is to meet plant needs without creating excesses that can harm plants or the environment.

### Nutrient availability to plants

Plants can only take up nutrients that are in **solution** (dissolved in soil water). Most soil nutrients are



not in solution; they are tied up in soil mineral and organic matter in insoluble forms. These nutrients become available to plants only after being converted to soluble forms and dissolving into soil water. This process occurs through weathering of mineral matter and biological decomposition of organic matter. Weathering of mineral matter slowly releases small amounts of nutrients into solution. Nutrient release from soil organic matter is somewhat faster and depends on the biological activity in the soil.

Nutrient release from soil organic matter is fastest in warm, moist soil and nearly nonexistent in cold or dry soil. Thus, the seasonal pattern of nutrient release is similar to the pattern of nutrient uptake by plants. Approximately 1 to 4 percent 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 a positive or negative electrical charge. Positively charged ions are called **cations**, and negatively charged ions are called **anions**. Potassium, calcium, and magnesium are examples of cations. Chloride is an example of an anion.

Clay particles and soil organic matter contain negative charges (anions) on their surfaces and thus can attract positive charges (cations) (Figure 8). They 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 soil fertility. A soil's capacity to hold cations is called its *cation exchange capacity* or CEC.

### The nitrogen cycle

Managing nitrogen is a key part of growing a productive and environmentally friendly garden. Nitrogen is the nutrient needed in the largest amount by plants, but excess nitrogen can harm plants, degrade water quality, or lead to increased

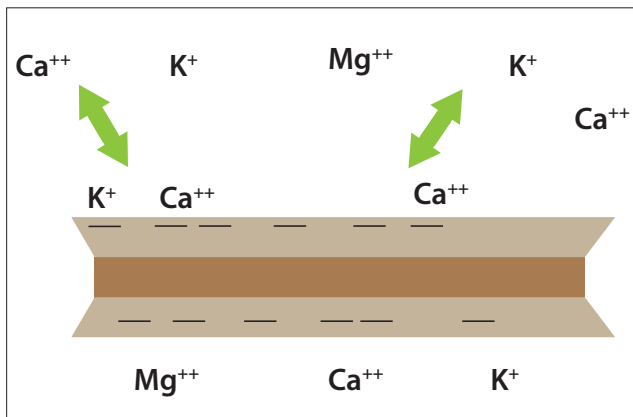


Figure 8. Simplified diagram of cation exchange showing cations held on a negatively charged clay particle and cations in solution. Illustration by Craig Cogger, WSU.

emissions of nitrous oxide ( $\text{N}_2\text{O}$ ), a greenhouse gas. Understanding how the nitrogen cycle affects nitrogen availability can help gardeners become better nutrient managers.

Nitrogen is found in four different forms in the soil (Table 3). Only two of the forms—ammonium and nitrate—can be used directly by plants.

Table 3. Common forms of nitrogen in soil.

Form of nitrogen	Characteristics
Organic N	Primary form of N in soil. Found in proteins, lignin, humus, etc. Not available to plants. Mineralized to ammonium by soil microorganisms.
Ammonium ( $\text{NH}_4^+$ )	Inorganic, soluble form. Available to plants. Converted to nitrate by soil microorganisms.
Nitrate ( $\text{NO}_3^-$ )	Inorganic, soluble form. Available to plants. Can be lost through leaching. Converted to gases in wet soils.
Atmospheric N ( $\text{N}_2$ )	Makes up approximately 80 percent of the soil atmosphere. Source of nitrogen for nitrogen-fixing plants. Not available to other plants.

Most nitrogen found in soil is tied up in organic matter in forms such as humus and proteins. This organic nitrogen is not available to plants. As soil warms in the spring, soil microbes begin breaking down organic matter, releasing some of the nitrogen as ammonium ( $\text{NH}_4^+$ ) (Figure 9). 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 ( $\text{NO}_3^-$ ). Nitrate is also soluble and available to plants. The ammonium and nitrate ions released from soil organic matter are the same as the ammonium and nitrate contained in processed fertilizers.

Because nitrate has a negative charge, it is not held to the surface of clay or organic matter, so it can be

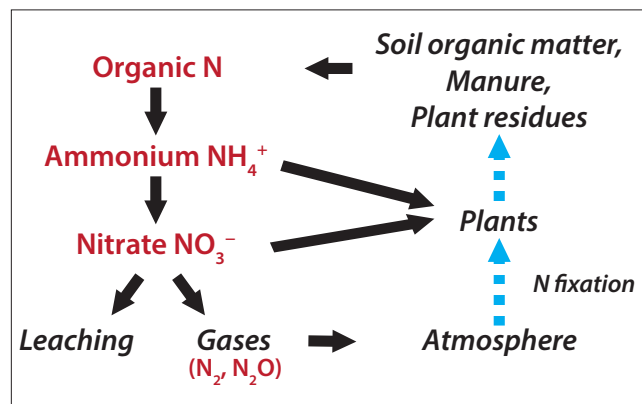


Figure 9. The nitrogen cycle. Illustrations by Craig Cogger, WSU.

lost readily by leaching. Nitrate remaining in the soil at the end of the growing season will leach out during the fall and winter and may reach groundwater, where it becomes a contaminant. In soils that are saturated during the wet season, soil microbes convert nitrate into nitrogen gases through a biological process called **denitrification**. Ammonium and nitrate taken up by plants are converted back to organic forms in plant tissue. When plant residues are returned to the soil, they decompose, slowly releasing nitrogen back into plant-available forms.

The nitrogen cycle is a leaky one, with losses to leaching and to the atmosphere. Harvesting crops also removes nitrogen. To maintain an adequate nitrogen supply, nitrogen must be added back into the system through fixation or fertilization.

Nitrogen **fixation** (Figure 9) is a natural process involving certain plants and nitrogen-fixing bacteria such as *Rhizobia* and *Frankia*. The bacteria form nodules in plant roots (Figure 10). Through these nodules the bacteria are able to take atmospheric nitrogen ( $N_2$  gas) from the soil and convert it to available N within the plant. The plants supply the bacteria with energy and nutrients. Legumes such as peas, beans, clover, and Scotch broom fix nitrogen using ***Rhizobia***. Alder trees fix nitrogen with ***Frankia***. Growing legumes as a cover crop will supply nitrogen to the next season's garden crops.



Figure 10. Roots of a legume cover crop (fava bean) with nodules that contain nitrogen-fixing *Rhizobia*. Photo by Chris Benedict, WSU

### Phosphorus deficiency and excess

Phosphorus has low solubility in soil water and thus low availability to plants. As a result, many soils are deficient in available phosphorus and need phosphorus fertilization to support fast-growing garden crops. Many crops benefit from phosphorus as a starter fertilizer because it provides adequate P to young plants with small root systems. Repeated applications of phosphorus-containing fertilizers or

organic amendments will increase P levels in the soil to the point that little or no additional P fertilizer is needed. Excess phosphorus accumulation can become a serious environmental problem. Loss of excess P through runoff or erosion into lakes and streams can contribute to **eutrophication** (algae blooms that harm water quality and aquatic ecosystems). Soil testing is a valuable tool for determining if your plants need more phosphorus, or if you have an excess amount of P and need to change your fertility plan. See *Fertilizer Calculation and Use* in this publication for more information on soil testing.

### Soil pH

Soil pH is a measure of the acidity or alkalinity of a soil. At a pH of 7 (neutral), 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 10 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 on the climate. Soils in arid locations tend to be alkaline, and those in rainy areas tend to be acid. Gardening practices also affect soil pH; for example, many nitrogen fertilizers tend to reduce pH, while liming increases pH. Soil pH influences plant growth by affecting the availability of plant nutrients and toxic metals, and 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, resulting in deficiencies in sensitive plants. Aluminum availability increases in acid soils. Aluminum is one of the most common elements in soil, but it is not a plant nutrient and is toxic to plants in high concentrations. Very little aluminum is in solution in soils above pH 6, so it does not cause problems for plants at this level. However, as pH declines and aluminum availability increases, aluminum toxicity can become a problem.

Microbes are also affected by soil pH. The most numerous and diverse soil 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 strongly acid and alkaline soils as a result of reduced microbial populations.

Many garden crops perform best in soil with a pH of 6 to 7.5, but some (such blueberries and rhododen-

drons) are adapted to more strongly acid soils. Before amending soil to adjust pH, it is important to know the preferred pH ranges of your plants.

### Increasing soil pH

Many western Washington soils are below the ideal pH level for growing vegetable crops. The most common way to increase soil pH is to add lime. **Lime** is ground limestone, a rock containing calcium carbonate. It is an organic (natural) amendment, so it is suitable for use by organic gardeners. Lime not only raises the pH of acid soils, it supplies calcium, an essential nutrient. **Dolomitic lime** contains magnesium as well as calcium and is a good choice for gardeners in western Washington and Oregon, where soils often are deficient in magnesium.

Lime is a slow-release material, so apply it in the fall to benefit spring crops. Finely ground lime works more quickly than coarser particles, but it can be dusty. Pelletized lime is more expensive than ground limestone, but many gardeners find it convenient to use. The best way to determine whether your soil needs lime is to have it tested. Do not lime areas where you grow acid-loving plants because they are adapted to acid soils. Wood ashes are a readily available source of potassium, calcium, and magnesium. Like lime, they also raise soil pH. High rates of wood ash may cause short-term salt injury, so apply no more than 15 to 25 pounds per 1,000 square feet.

Gypsum (calcium sulfate) is not a substitute for lime. It supplies calcium and sulfur, but has little effect on soil pH. Gypsum has been promoted as a soil amendment to improve soil structure. In the vast majority of cases, it does not work. Gypsum improves soil structure when poor structure results from excess sodium in the soil, a rare condition in the Northwest. Use organic amendments to improve soil structure, as described under *Organic Amendments* in this publication.

### Decreasing soil pH

Soil pH east of the Cascades is often too high to grow healthy acid-loving plants, such as blueberries, rhododendrons, and maple trees. Even some soils west of the Cascades are not acid enough for good blueberry production. Elemental sulfur lowers soil pH. The amount of sulfur needed depends on the soil's original and desired soil pH and soil texture. Soil testing is the best way to determine whether sulfur is needed and, if so, how much. Applying too much sulfur can cause the pH to drop below desirable levels. Ammonium sulfate fertilizer lowers pH more gradually than sulfur does, and urea also reduces pH slowly, as do some organic fertilizers.

For specific guidelines on acidifying soils, see *Acidifying Soils in Landscapes and Gardens East of the Cascades*, Oregon State University Extension Publication EC 1560-E (Locke et al. 2006) or *Acidifying Soils for Blueberries and Ornamental Plants West of the Cascades*, Oregon State University Extension Publication EC 1560-E (Hart et al. 2003).

### Soil Salinity

Soil salinity can be a problem in irrigated soils in arid areas of eastern Washington. Salts from irrigation water, fertilizer, compost, and manure applications can accumulate to the point where they harm plant growth. In areas with more rainfall, salts are leached from the soil each winter and do not accumulate in the root zone.

An electrical conductivity (EC) test measures the level of soil salinity. Table 4 provides information on how to interpret electrical conductivity in a soil. For a list of saline tolerances for selected vegetable and field crops, refer to *Managing Saline Soils*, Colorado State University Extension Fact Sheet 0503 (Cardon et al. 2007) at <http://www.ext.colostate.edu/pubs/crops/00503.html>.

Salts can be leached from soil by applying irrigation water in excess of the water-holding capacity of the soil. The excess water must drain downward through the soil to carry away excess salts. When leaching, apply water slowly enough that it drains freely through the subsoil. Six inches of excess water removes about half of the soluble salts in a soil. A foot of water removes about 80 percent.

Table 4. Soil salinity measured in electrical conductivity units (millimhos/cm) and its potential effects on plants.

Electrical conductivity (millimhos/cm)	Interpretation
4 or above	Severe accumulation of salts. Restricts growth of most vegetables and ornamental plants. Reduce salt by leaching.
2 to 4	Moderate accumulation of salts. Restricts growth of sensitive plants. May require more frequent irrigation.
Less than 2	Low salt accumulation. Most plants are not affected.

### Comparing Organic and Processed Fertilizers

Fertilizers supplement a soil's native nutrient supply. They are essential to good plant growth when the soil nutrient supply is inadequate. Rapidly growing

plants, such as annual vegetable crops, generally need more nutrients than slowly growing plants, such as established perennials. Processed fertilizers, organic fertilizers, or a combination of the two can supply soil nutrients.

Processed fertilizers are manufactured or refined from natural ingredients to make them more concentrated. Also, they are typically processed into soluble, ionic forms that are immediately available to plants. Some processed fertilizers are manufactured to mimic the slow nutrient release of organic fertilizers. Examples include specialty slow-release fertilizers for lawns and potted 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). Once in the soil, organic fertilizers release nutrients through natural processes, including biological breakdown of organic matter and chemical weathering of mineral materials. The released nutrients are available to plants in water-soluble forms. These water-soluble nutrients are the same as those supplied by processed fertilizers.

When compared with processed fertilizers, organic fertilizers usually have a lower concentration of nutrients and release nutrients more slowly. Thus, larger amounts of organic fertilizers are needed, but their effects last longer.

Using organic fertilizers recycles materials that otherwise would be discarded as waste products. Production of processed fertilizers, on the other hand, can create waste products and use substantial amounts of energy. Most organic fertilizers also supply organic matter to soil, which can improve soil physical properties and long-term nutrient release. Although the amount of organic matter applied through organic fertilizers is small compared to composts or cover crops, organic fertilizers can still improve soil quality.

Choosing organic fertilizers involves trade-offs in cost or convenience. Farmyard manure is usually inexpensive or free, but can be inconvenient to store

and apply. Packaged organic blends, on the other hand, are convenient but often expensive.

### Nutrient release

Nutrients in most processed fertilizers are available immediately. Processed fertilizers can furnish nutrients to plants in the spring before the soil is warm. However, nitrogen in these fertilizers is vulnerable to leaching loss from heavy rainfall or irrigation. Once nitrogen moves below the root zone, plants can no longer use it, and it may leach into groundwater.

Organic fertilizers are slow-release fertilizers because their nutrients become available to plants over the course of the growing season. The rate of nutrient release from organic materials depends on the activity of soil microorganisms, just as it does for nutrient release from soil organic matter. Temperature and moisture conditions that favor plant growth also favor the release of nutrients from organic matter.

Some organic fertilizers contain immediately available nutrients, as well as slow-release nutrients. These fertilizers can supply nutrients to plants both early in the season and later on. Poultry manure and fish emulsion are examples of organic fertilizers containing immediately available nutrients.

Some material in organic fertilizers breaks down so slowly that it is not available the first season after application. Repeated application of organic fertilizers builds up a pool of material that releases nutrients very slowly, similar to soil organic matter. In the long run, this nutrient supply decreases the need for supplemental fertilizer.

### Fertilizer labels

The labels on fertilizer packages show the amount of the three primary nutrients contained in the fertilizer, expressed as a percent of total fertilizer weight. Nitrogen (N) is always listed first, phosphorus (P) second, and potassium (K) third.

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 undergo extensive processing.
Examples	Manure, alfalfa meal, fish meal, rock phosphate	Ammonium sulfate, potassium chloride, urea
Nutrient Availability	Usually slow release. Nutrients are released by biological and chemical processes in the soil.	Usually immediately available to plants. Some are slow-release, mimicking organic fertilizers.
Nutrient Concentration	Usually low	Usually high

Historically, the amount of phosphorus in fertilizer has been expressed not as P, but as units of phosphate ( $P_2O_5$ ). Similarly, fertilizer potassium is expressed as potash ( $K_2O$ ). This practice is still used for fertilizer labels and recommendations, even though there is no practical reason for the system, except that people are accustomed to it. (If there is a 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  $K_2O$ ).

Thus, a bag of fertilizer labeled 12-4-8 contains 12 percent nitrogen, 4 percent phosphorus expressed as  $P_2O_5$ , and 8 percent potassium expressed as  $K_2O$ . This information on chemical content is called a fertilizer analysis. The analysis for processed fertilizers guarantees the amount of available nutrients in the fertilizer, whereas the analysis for organic fertilizers represents the total amount of nutrients, rather than the amount of available nutrients. Because nutrients in most organic fertilizers are released slowly, the amount of immediately available nutrients is less than the total amount.

## Common 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 requires a substantial amount of fossil fuel energy. Examples of processed nitrogen fertilizers available for home garden use are listed in Table 6.

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
Diammonium phosphate	18-46-0	Used in mixed fertilizers as a source of N and P
Sulfur-coated urea	35-0-0	Sulfur coating slows release of available N

### Phosphorus and potassium

Processed phosphorus fertilizers come from phosphate rock. The rock is treated with acid to release phosphorus into plant-available forms. The most common raw material for potassium fertilizers is **sylvinite**, a mixture of sodium chloride and potassium chloride salts. Sylvinite is mined and

then treated to remove the sodium salts to make it suitable for use as a fertilizer. Some other potassium fertilizers are potassium sulfate salts, which supply sulfur as well as potassium. Table 7 lists examples of processed phosphorus and potassium fertilizers.

Table 7. Examples of processed phosphorus and potassium fertilizer materials.

Material	Analysis	Comments
Triple superphosphate	0-46-0	
Monoammonium phosphate	11-52-0	Used in mixed fertilizers as a source of N and P
Diammonium phosphate	18-46-0	Used in mixed fertilizers as a source of N and P
Potassium chloride	0-0-60	
Potassium sulfate	0-0-50	Also contains 18% sulfur

### Mixed fertilizers

Mixed fertilizers contain all three primary nutrients, although the ratios can vary. Fertilizers for annual gardens typically have N: $P_2O_5$ : $K_2O$  ratios in the range of 1:1:1, such as 8-8-8 and 16-16-16 blends. Lawn fertilizers are higher in nitrogen; an example is a 12-4-8 blend.

## Common organic types of fertilizers

### Animal manure

Farmyard manure can be an inexpensive source of nutrients. If gardeners or their neighbors have livestock, it makes environmental and economic sense to recycle the livestock manure as fertilizer. Packaged manure products cost more than manure off the farm, but they are usually more uniform and convenient to handle.

Table 8 shows average nutrient concentrations for several types of animal manure. Keep in mind that animal manures vary widely in nutrient content and nutrient availability, depending on the type of animal that produced the manure and the age and handling of the manure. For example:

- Manure diluted with bedding has fewer nutrients than undiluted manure.
- Manure exposed to rain loses nutrients to leaching.
- Manure composted under cover retains more nutrients, but reduces nutrient availability.

It does not take much nutrient-rich manure, such as poultry broiler litter, to fertilize a garden. A 5-gallon

Table 8. Average nutrient content of uncomposted animal manures.<sup>1,2,3</sup>

Type	N	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	Moisture	Weight
	lb/cubic yard as-is <sup>4</sup>			%	lb/cubic yard
Chicken with litter	23	29	30	30	900
Rabbit	11	7	10	75	1400
Horse	6	4	11	70	1400
Separated dairy manure solids	3	1	2	80	1400

<sup>1</sup>Divide these numbers by 40 to estimate the nutrients in a 5-gallon bucket of manure.

<sup>2</sup>Manure can vary widely in moisture content, density, and nutrient concentrations, depending on how it is handled.

<sup>3</sup>Data are from Gale et al. (2006) and Cogger (2004).

<sup>4</sup>"As-is" is typical for manure stored under cover.

bucket of broiler litter contains enough nutrients to fertilize 100 to 150 square feet of vegetable garden. A similar amount of rabbit manure will fertilize 20 to 30 square feet of garden. If more is applied, there is a risk of harming crops and leaching nitrogen into groundwater. Dilute manures, such as separated dairy solids and horse manure with bedding, contain few available nutrients and can be applied in larger amounts. As much as an inch of these materials can be used in a garden. It is best to use these manures mainly as a source of organic matter.

To fine-tune a manure application rate, experiment with the amount applied and observe its effect on crop performance. It is better to be conservative initially and add more nutrients later if crops seem deficient, rather than applying too much at the start. Apply manure evenly over annual beds, or between rows of perennial crops. Digging or tilling manure into the soil reduces the risk of nutrient loss and harm from runoff.

### Timing manure applications

The best time to apply manure is in the spring before planting. Manure can also be applied in the fall, but some of the nutrients may be lost during the winter, especially west of the Cascades. Environmental risks of leaching and runoff also increase in winter. If manure is applied in the fall, apply it no later than mid-September and immediately plant a cover crop to capture nutrients and prevent runoff. See *Green Manure* in this publication for more information on cover crops.

### Biosolids

Biosolids are a product of municipal wastewater treatment. Federal organic standards do not include biosolids as an organic fertilizer; however, biosolids do have two important characteristics of organic fertilizers: 1) their nutrients are released slowly from

### USING MANURE SAFELY

Fresh manure may contain disease-causing pathogens that can contaminate garden produce. **Salmonella** and **E. coli O157:H7** bacteria are among the most serious pathogens found in animal manure. Manure from dogs, cats, and other carnivores can contain **helminths**, which are worm-like parasites.

These pathogens are not taken up into plant tissue, but they can adhere to soil on plant roots or to the leaves or fruit of low-growing crops. The risk of infection is greatest from crops eaten raw, especially where the edible part is close to the soil (for example, carrots, radishes, salad greens, and strawberries). The risk is negligible if crops are thoroughly cooked. Composting manure at high temperatures kills pathogens, but it is very hard to maintain rigorous composting conditions in a backyard compost pile. Commercial manure composts are composted under controlled conditions to destroy pathogens. Bacterial pathogens die naturally over a period of weeks or months, so well-aged (one year or more) manure should not contain them. However, Helminths in dog or cat manure can persist for years, so they should not be added to gardens or compost piles.

Apply fresh manure only where low-risk crops are being grown. Use composted or aged manure or other fertilizers where high-risk crops are being grown. Gardeners can rotate high- and low-risk crops, applying fresh manure to low-risk crops one year, and rotating that area to high-risk crops the following year. This allows time for the pathogens to die off before growing high-risk crops.

the organic form by natural processes in the soil, and 2) they are a product of the waste stream that can benefit crop growth. Most of the biosolids produced in Washington are used to fertilize agricultural and forest crops. The material used on farms is rich in nutrients and acts similarly to poultry manure. Biosolids typically contain 4% to 7% N, 3% to 7% P<sub>2</sub>O<sub>5</sub>, and less than 1% K<sub>2</sub>O, as a percentage of dry weight.

Some communities in Washington produce a special class of biosolids and market them to gardeners. These are called Class A biosolids. They have been treated using heat or composting to reduce pathogens to background levels, making them safe for all garden uses. Three types of Class A biosolids are available in Washington as composts, blends, and heat-dried pellets. Biosolids composts are made from biosolids and yard debris or woody materials and can be used similarly to other composts. Biosolids blends are formulated for different uses, including turf topdressing, mulches, and soil amendments. Heat-dried pellets are rich in nutrients and are used similarly to commercial organic fertilizers. Check with local wastewater treatment plants to see if they have Class A biosolids available for home use. For more information on biosolids, refer to *Using Biosolids in Gardens and Landscapes*, Washington State University Extension Publication FS156E (Cogger 2014) at <http://cru.cahe.wsu.edu/CEPublications/FS156E/FS156E.pdf>.

### Commercial organic fertilizers

Many organic by-products and some unprocessed minerals are sold as organic fertilizers. Table 9 shows the approximate nutrient content of some of these materials. The numbers shown in this table represent total nutrient content. Because most of these materials are slow-release fertilizers, not all of the nutrients are available in the year they are applied.

Many organic fertilizer materials are rich in one primary nutrient (Table 9). The other nutrients are present in smaller amounts. Some companies blend organic ingredients into fertilizers that provide all of the primary nutrients in balanced proportions. Use balanced fertilizers or fertilizers rich in P or K if those nutrients are deficient. If the soil has adequate levels of P and K, use N-rich organic fertilizers or supply N with legume cover crops.

Commercial organic fertilizers tend to be more expensive per pound of nutrients than either processed fertilizers or manures. Sometimes the difference in price is substantial. Nevertheless, many gardeners use these products for convenience or quick availability of nutrients. They are most economical for small gardens where little fertilizer is

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

Material	Nitrogen	P <sub>2</sub> O <sub>5</sub> %	K <sub>2</sub> O %
Blood Meal	12–15	1	1
Feather Meal	11–14	0	0
Fish Meal	10	4	2
Canola Meal	6	2	1
Cottonseed Meal	6	2	1
Crab Shell Meal	4	1.5	0
Fish Emulsion	3–5	1	1
Alfalfa Meal	2–3	0.5	1–2
Bone Meal	1–4	12–24	0
Rock Phosphate <sup>1</sup>	0	25–30	0
Greensand	0	0	3–7

<sup>1</sup>Very low P availability. Useful only in acid soils.

needed. The cost-per-pound of nutrients in organic fertilizers varies widely, depending on the type of material, the concentration of nutrients, and the package size. Compare costs and nutrient availability when shopping for organic fertilizers.

### Fertilizer Calculation and Use

The goal of applying fertilizer is to supply enough nutrients to meet plant needs without accumulating excess nutrients in the soil that could leach into groundwater or run off into surface water. Soil tests and information contained in University Extension publications are two standard tools for estimating fertilizer needs.

#### Soil tests

A soil test provides information on the amount of nutrients in a soil sample and recommends the amount of fertilizer that should be added based on the test results and the types of crops grown. Soil need not be tested every year; every 2 to 4 years is often enough. A basic garden soil test typically includes testing for soil pH and lime requirement, as well as for phosphorus, potassium, calcium, magnesium, and sometimes boron. In arid locations, the basic soil test also includes testing for electrical conductivity, a measure of soluble salts.

Although some soil-testing labs test for nitrate-N, these numbers are seldom useful for predicting crop N requirements because nitrate levels can change rapidly due to plant uptake, leaching, and microbial activity. There is no rapid and reliable test that can predict nitrogen availability during the coming

growing season. However, testing labs will provide a general nitrogen recommendation based on the type of plants grown and on any pertinent information about the soil (for example, whether there is a history of manure applications, which would increase soil-available nitrogen). WSU Extension publications are a good source of information on crop-specific nitrogen requirements.

To obtain a soil sample, first collect subsamples from at least 10 different garden locations. Avoid any atypical areas, such as the site of an old trash dump, burn pile, or rabbit hutch. Sample the top foot of soil (from the soil surface to a 12-inch depth). If the soil is too rocky to get a full 12-inch sample, then sample as deep as possible. Air-dry the samples and mix them together well. Send approximately one cup of the mixed sample to the soil-testing lab. The easiest way to collect samples is with a soil probe (Figure 11), but a trowel or spade can also be used. Because management and fertilizer recommendations vary for different crops, such as vegetables, lawns, and berries, collect separate samples for each area. View the WSU video, *Collecting a Soil Sample* (Cogger 2010a) at [http://puyallup.wsu.edu/soilmgmt/Videos/Video\\_HowToSoilSample.html](http://puyallup.wsu.edu/soilmgmt/Videos/Video_HowToSoilSample.html) for a demonstration of sample collection.

Washington State University does not test soils, but maintains a list of laboratories that do agricultural



Figure 11. Soil sampling using a push probe. Photo by Andy Bary, WSU

and garden soil analyses in the Pacific Northwest. This list can be found at <http://puyallup.wsu.edu/analytical-labs/services>. Also, WSU Extension county offices often have lists of analytical labs that are popular locally. Before choosing a lab, make sure they specifically test and make recommendations for garden soils.

Find out if the lab:

- Routinely tests garden soils for plant nutrients and pH,
- Uses WSU or OSU test methods and fertilizer guides, and
- Provides recommendations for garden fertilizer applications.

Also find out:

- What paperwork needs to accompany the soil sample,
- How much the test will cost, and
- How quickly the test results will be available.

## University Extension publications

Additional information on fertilizer rates, placement, and timing can be found in University Extension publications, such as those available from Washington State University and Oregon State University. These publications usually offer recommendations for processed fertilizers, but some provide guidelines for organic fertilizers as well.

As a general garden recommendation or rule of thumb, apply 2 lb of nitrogen per 1,000 square feet of garden space (3 oz–4 oz/100 square feet). Plants with high nitrogen demand, such as sweet corn and broccoli, need 3 lb to 4 lb of nitrogen per 1,000 square feet. Phosphorus rates vary from none to 2 lb of  $P_2O_5$  per 1,000 square feet of garden space, depending on soil-test recommendations, while potassium rates typically vary from none to 3 lb of  $K_2O$  per 1,000 square feet.

## Calculating processed fertilizer rates

Fertilizer recommendations are usually given in ounces or pounds of nutrient (such as nitrogen) per unit area (typically 100 or 1,000 square feet for gardens), per unit row length, or on a per plant basis (for example, blueberry or rhubarb). This means the recommended amount will need to be converted from pounds of nutrient to pounds of fertilizer and adjusted to garden size (See Example 1).

## Estimating organic fertilizer rates

Estimating how much organic fertilizer to use involves the additional step of estimating the availability of nutrients in the fertilizer. Here are some tips



### EXAMPLE 1. PROCESSED FERTILIZER CALCULATION:

A recommendation calls for adding 2 lb of N per 1,000 square feet of garden space, using a fertilizer with a 1:1:1 ratio of nitrogen, phosphorus, and potassium. Follow these steps to determine how much fertilizer to use:

1. **Choose a fertilizer with an appropriate content analysis.** For example, you can choose an 8-8-8 fertilizer, but not a 21-4-4.
2. **Calculate how much 8-8-8 is needed for 1,000 square feet of coverage.** Divide the amount of nitrogen recommended for 1,000 square feet (2 lb) by the percentage of nitrogen in the fertilizer (8), and multiply by 100:

$$(2 \text{ lb} \div 8) \times 100 = 25 \text{ lb per 1,000 square feet}$$

3. **Calculate the area of your garden space.** If it is a rectangle, the area is length times width. For example, a garden 20 feet long by 10 feet wide has an area of:

$$20 \text{ ft} \times 10 \text{ ft} = 200 \text{ square feet}$$

If your garden is an odd shape, divide it into rectangles, calculate the area of each rectangle, and then add them together.

4. **Calculate the amount of fertilizer needed for your garden.** Divide the area of your garden (200 square feet) by the area specified in the fertilizer recommendation (1,000 square feet). Then multiply by the fertilizer amount calculated in step 2 above:

$$(200 \div 1,000) \times 25 = 5 \text{ lb of 8-8-8 fertilizer}$$

This is the amount of fertilizer needed for your garden.

when using organic fertilizers:

- Apply organic fertilizers according to their nitrogen availability (See Example 2). Composts and plant residues generally have lower nitrogen concentrations and lower nitrogen availability than more concentrated animal products (for example, fish meal, feather meal, and chicken manure). Table 10 shows

### EXAMPLE 2: ORGANIC FERTILIZER CALCULATION

A recommendation calls for applying fertilizer to rhubarb at a rate of 1 oz of N per plant. A soil test shows there is no need to add P, so an organic fertilizer with an 8-0-4 label would be suitable. Based on this information, how much fertilizer should be applied to each plant?

1. **Estimate how much available N is in the fertilizer.** Table 10 shows that a fertilizer with 8% total N will have roughly 75% of that N available during the growing season, or 6% available N.
2. **Calculate how much fertilizer to apply.** Table 11 shows that to supply 1 oz of N using a fertilizer with 6% available N, 1 lb of fertilizer is needed.

Table 10. Estimated proportion of nitrogen from organic fertilizers and amendments that will become available to plants during the growing season.

Total N concentration (% of amendment)	N availability during growing season (% of total N)
1	0
2	15
4	45
6+	75

Data derived from Gale et al. 2006.

estimated N availability in organic fertilizers based on N concentration. For more information on nitrogen concentration and availability in a range of organic fertilizers, refer to the *Organic Fertilizer Calculator* from Oregon State University at <http://smallfarms.oregonstate.edu/calculator>.

- Observe your crops. Lush plant growth and delayed flowering and fruiting are signs of high amounts of available nitrogen and may indicate over-fertilization.
- Review more detailed guidelines for calculating organic fertilizer application rates. These guidelines can be found in the publication *Soil Fertility in Organic Systems: A Guide for Gardeners and Small-Acreage Farmers*, WSU Extension Publication PNW 646 (Collins et al. 2013) at <http://cru.cahe.wsu.edu/CEPublications/PNW646/PNW646.pdf>.

Table 11. Fertilizer application rates for individual plants or short row lengths based on recommended amounts of nitrogen and available N in the fertilizer material.

Available N%	N recommended (ounces)				
	0.2	0.5	1	2	4
	Fertilizer to apply (lb)				
0.5	2.5	6	13	25	50
1	1.3	3	6.3	13	25
2	0.6	1.6	3	6	13
4	0.3	0.8	1.6	3	6
6	0.2	0.5	1.0	2	4
8	0.16	0.4	0.8	1.6	3
10	0.13	0.3	0.6	1.3	2.5
15	0.08	0.2	0.4	0.8	1.7
20	0.06	0.16	0.3	0.6	1.3
30	0.04	0.1	0.2	0.4	0.8

### When to apply fertilizer

In most cases, the best time to apply fertilizer is close to the time when plants need the nutrients. This timing reduces the potential for nutrients to be lost before they are taken up by plants. Nutrient loss is not only inefficient, but may contaminate groundwater or surface water. Plants need the largest amount of nutrients when they are growing most rapidly. Rapid growth occurs in midsummer for corn and squash, but earlier for spring plantings of lettuce and other greens. Plants also need available nutrients shortly after seeding or transplanting.

For a long-season crop such as corn, many gardeners apply a small amount of fertilizer as a starter at the time of seeding and then add a larger amount in early summer, just before the period of rapid growth. When using slow-release organic fertilizers, a single application is usually adequate because nutrient release often is fastest when plant demand is greatest.

For perennial plants, timing depends on the plant's growth cycle. Table 12 gives examples of recom-

mended fertilizer application times for several perennial food crops typically grown in home gardens.

### How to apply fertilizer

If a large garden area will be planted all at the same time, measure the fertilizer into a hand-held broadcast spreader or drop spreader, apply it, and then incorporate it using a rake or tiller. To get a more uniform application, apply at a light rate, and go over the garden several times until the measured amount of fertilizer is gone.

Gardeners often need to fertilize areas that are too small for a spreader, such as individual plants or rows, so they should fertilize these areas by hand. Since fertilizer recommendations are calculated by weight, weigh the fertilizer to determine the correct amount, transfer it to a cup, pint, or quart container, and mark the volume on the container. The marked container can be used for future applications. Incorporate the fertilizer using a rake or hand-held cultivator.

Table 12. Recommended fertilizer application timing for common perennial garden crops.

Crop	Nitrogen Rate	Application Timing
Blueberry	0.6–0.8 oz N/plant	Split into three applications: April, May, and June
Raspberry	2 oz N/10 ft row	Split into three applications: When primocanes emerge, late May, late June
Strawberry	1.5–2 oz N/100 ft <sup>2</sup>	June bearing: Apply in August Day-neutral: Split into three applications between April and August
Asparagus	1.5 oz N/100 ft <sup>2</sup>	Before shooting or after harvest ends
Rhubarb	1 oz N/plant	Split into two applications: Early spring and after completing harvest (June)

Adapted from the following publications: Hart et al. 2006; Strik 2008; Strik 2013; Jauron 2004; Parsons et al. 2003.

## Organic Amendments

The best use of specific organic materials varies, depending on their nitrogen concentration. Organic materials that contain > 3% total N are rich in nitrogen. Examples include poultry manure, feather meal, and other N-rich materials listed in Table 9. These materials are a good source of nutrients, but must be used sparingly to avoid over-fertilization. Refer to the section on *Fertilizer Calculation and Use* in this publication to determine how much and when to apply these fertilizers.

Materials with intermediate levels of nitrogen (including many composts, leaf mulches, and cover crop residues) have lower nutrient availability. Because they are relatively low in available nutrients, they can be added to the soil in large amounts to replenish soil organic matter. Organic matter builds and stabilizes soil structure, thus reducing erosion and improving soil porosity, infiltration, and drainage. It effectively holds water and nutrients for plants and soil organisms.

Materials with low nitrogen concentrations (< 1 to 1.5% total N), such as straw, bark, and sawdust (Figure 12), contain so little nitrogen that they actually reduce levels of available nitrogen when mixed into the soil. Soil microorganisms use available nitrogen when they break down these materials, leaving little nitrogen for plants. This process is called **immobilization** and results in nitrogen deficiency. When using materials with nitrogen-poor organic amendments in a garden, add extra nitrogen fertilizer to compensate for immobilization. The best use for these materials is for mulches because they do not cause nitrogen immobilization until they are mixed into the soil.



Figure 12. Bark mulch with a low nitrogen concentration (l) and yard debris compost with a moderate nitrogen concentration (r). Photo by Rita Hummel, WSU

## Compost

Compost is an excellent source of organic matter for garden soils. Composting also closes the recycling loop by turning waste materials into a soil amendment. Gardeners can make compost at home or buy commercially prepared compost.

### Making compost

The key to composting is to supply a balance of oxygen, water, energy materials (materials with a low C:N ratio, such as grass clippings, green garden trimmings, or fresh manure), and bulking agents (materials with a high C:N ratio, such as corn stalks, straw, and woody materials). Gardeners do not need additives to stimulate their compost piles; they just need to provide conditions favorable for natural composting organisms. Home composting can be done in hot or cold piles, or in worm bins:

- Hot (fast) composting produces compost in 2 to 4 months. Mix together balanced amounts of energy materials and bulking agents, keep the pile moist, and turn it frequently to keep it porous (Figure 13). Most gardeners find it difficult to maintain hot compost piles on a backyard scale and use slow composting instead.
- Cold (slow) composting requires less work than hot composting. Build the pile and leave it until it decomposes. This process may take a year or longer. Cold composting does not kill weed seeds or pathogens. Also, rats and other pests can be attracted to edible wastes in unprotected cold compost piles.
- Worm bins can be used to compost fruit and vegetable scraps. This method works well for urban gardeners who have little space.



Figure 13. Measuring the temperature of a hot compost pile. Photo by Craig Cogger, WSU

For more information on home composting, refer to *Backyard Composting*, WSU Extension Publication 1784E (Cogger and Sullivan 2009) at <http://cru.cahe.wsu.edu/CEPublications/eb1784e/eb1784e.pdf>.

### Commercial compost

Yard debris is the major raw material in most commercial compost sold in Washington. Commercial compost also may contain animal manure, biosolids, food waste, or wood waste. Commercial compost is made on a large scale, with frequent aeration and/or turning to create conditions that kill weed seeds, plant pathogens, and human pathogens.

### Using compost

When establishing a new garden or landscape bed, add 1 to 3 inches of compost to build soil organic matter. For an established garden bed, add about ½ inch of compost each year. If soil testing shows very high levels of phosphorus, stop adding compost and grow cover crops instead. Till or dig compost directly into garden soil, or use it as mulch before turning it into the soil. One cubic yard of compost covers approximately 300 square feet of soil at a depth of 1 inch. For more information on how much compost to apply, refer to *Organic Soil Amendments in Yards and Gardens: How Much is Enough?* WSU Extension Publication FS123E (Cogger 2013) at <http://cru.cahe.wsu.edu/CEPublications/FS123E/FS123E.pdf>.

In the first or second year after application, partially decomposed woody compost may immobilize some soil nitrogen, resulting in nitrogen deficiency for plants. If plants show signs of nitrogen deficiency (for example, poor growth or yellow leaves), add extra nitrogen fertilizer (either organic or inorganic). In following years, most composts contribute small amounts of available nitrogen to the soil.

When gardening in arid locations, be aware that some composts may increase the salinity of the soil. Yard-debris composts generally contain few salts, but manure-based composts may contain enough salts to be harmful in some environments. If there are problems with salinity in the garden soil, reduce or avoid the use of manure composts.

### Green manure (cover crops)

**Green manures** are cover crops specifically grown to be tilled or dug into the soil, or left on the soil surface as mulch. Planting green manure is a way for gardeners to grow their own organic matter (Figure 14). However, the value of cover crops goes

beyond their contribution of organic matter. These crops are also able to:

- Capture and recycle nutrients that otherwise would be lost by leaching during the winter,
- Protect the soil surface from the impact of rainfall,
- Reduce runoff and erosion,
- Suppress weeds, and
- Supply nitrogen (legumes only).

However, no one cover crop provides all of these benefits. Deciding which cover crop or crop combination to grow depends on which benefits are most desired and which cover crops best fit into the overall garden plan (Table 13). With the exception of buckwheat, all of the cover crops listed in Table 13 are suitable for fall planting and spring termination. For more information on cover crops, including seeding rates, planting dates, and uses, refer to *Cover Crops for Home Gardens West of the Cascades*, WSU Extension Publication FS111E (Cogger et al. 2014) at <https://pubs.wsu.edu/ListItems.aspx?Keyword=fs111e>, or *Cover Crops for Home Gardens East of the Cascades*, WSU Extension Publication FS117E (Cogger et al. 2014) at <https://pubs.wsu.edu/ListItems.aspx?Keyword=fs117e>.

Gardeners usually plant cover crops in the fall and terminate them by tilling or cutting them before spring planting begins. The earlier cover crops are planted, the more benefits they provide. Research in western Washington found that cereal rye planted in September captured three times as much nitrogen as an October planting. Legumes such as vetch and crimson clover need an early start to achieve enough growth to cover the soil before cold weather arrives.

If a garden has crops still growing into November or December, it will not be possible to plant early cover



Figure 14. Fava bean and rye cover crop planted in raised beds. Hilltop Urban Gardens, Tacoma, WA. Photo by Craig Cogger, WSU

Table 13. Examples of cover crops grown in Washington and Oregon.

Cover crop	Type	Characteristics
Annual ryegrass	Grass	Hardy, tolerates wet soils in winter, difficult to till once established
Austrian winter pea	Legume	Fixes nitrogen, does not compete well with winter weeds, not for wet soils
Barley	Cereal	Not as hardy as rye, tolerates drought, leafy growth in spring
Buckwheat	Broadleaf	Fast-growing, frost-sensitive, summer cover
Cereal rye	Cereal	Very hardy, grows quickly, matures rapidly in spring
Common vetch	Legume	Fixes nitrogen, similar to hairy vetch, but easier to till in spring
Crimson clover	Legume	Fixes nitrogen, less biomass than vetches, easy to till in spring
Fava bean	Legume	Fixes nitrogen, not as winter hardy as vetches
Hairy vetch	Legume	Fixes nitrogen, starts slowly, grows quickly in spring, good companion crop for cereal rye
Oats	Cereal	Not as winter hardy as other cereals, leafy, tolerates wet soils
Triticale	Cereal	Hardy cross between rye and wheat, leafy
Winter wheat	Cereal	Good for late plantings, leafy

crops over the entire area. In this case, plant cover crops in areas that are harvested early, and use mulch in those areas that are harvested later. For example, plant a cover crop in a sweet corn bed immediately following harvest in September, and mulch a bed of fall greens after removing the crop in November. Gardeners can also interseed cover crops between rows of late crops if space allows.

Till or dig cover crops into the soil before they flower and go to seed. After flowering, plants become woody and decline in quality. Also, digging plants into the soil becomes quite difficult if they grow too large. Cover crops that set seed can turn into weeds when the seeds germinate. If a cover crop cannot be tilled before it blooms, cut it off and compost it for later use, or leave it on the soil surface as mulch. This will retain the short-term benefit of organic matter from the crowns and roots and from the decomposing mulch.

The benefits of organic matter derived from cover crops last only about one year, so make cover crops an annual part of crop rotation. If cover crops do not fit into an overall garden plan, winter mulches can be used as a substitute. Refer to *Methods for Successful Cover Crop Management in Your Home Garden*, WSU Extension Publication FS119E (Benedict et al. 2014) at <https://pubs.wsu.edu/ListItems.aspx?Keyword=fs119e> for more information on methods of planting and terminating cover crops.

### Organic mulch

Some organic materials can be effective mulches. Mulches are applied to the surface of the soil to reduce the loss of water through evaporation, protect the soil surface, reduce compaction, smother weeds,

and modify the temperature of the soil. In annual gardens, mulches can be applied after harvest to protect the soil from the erosion during the winter, or they can be applied between rows during the growing season to conserve water and reduce weeds. A thin layer of mulch will conserve water, but at least 3 inches of mulch are needed to smother weeds. Straw, leaves, cover crop residues, and compost are effective annual mulches. Since straw and leaves have a high C:N ratio, gardeners may need to add extra N if they dig these mulches into the soil.

Materials such as wood chips, arborist chips, and bark resist decay, so they make effective, long-lasting mulches for perennial beds (Figure 15). As long as these mulches remain on the soil surface, they have little effect on available nutrients in the underlying soil. However, incorporating them into the soil can reduce nitrogen availability for a year or more.



Figure 15. Wood-chip mulch in paths between garden beds helps manage weeds, mud, and dust. Hilltop Urban Gardens, Tacoma, WA. Photo by Craig Cogger, WSU

## Glossary of Terms

**actinomycetes**—A group of soil bacteria that resemble fungi in appearance. Actinomycetes are the source of many antibiotics used in human medicine.

**aeration**—A process by which air is circulated through, mixed with, or dissolved in a substance.

**aggregation**—The process by which individual particles of sand, silt, and clay cluster and bind together to form peds.

**anion**—A negatively charged ion. Plant nutrient examples include nitrate ( $\text{NO}_3^-$ ), phosphate ( $\text{H}_2\text{PO}_4^-$ ), and sulfate ( $\text{SO}_4^{2-}$ ).

**aspect**—Direction of exposure to sunlight.

**biosolids**—Products of municipal wastewater treatment that contain nutrients, organic matter, and inorganic constituents. Class A biosolids have been treated to remove pathogens and are suitable for use in gardens and landscapes. Biosolids composts and blends are soil amendments, while dried biosolids products are used as fertilizers.

**capillary force**—The action by which water molecules bind to the surfaces of soil particles and to each other, thus holding water in fine pores against the force of gravity.

**cation**—A positively charged ion. Plant nutrient examples include calcium ( $\text{Ca}^{++}$ ) and potassium ( $\text{K}^+$ ).

**cation exchange capacity (CEC)**—A soil's capacity to hold cations as a storehouse of reserve nutrients.

**clay**—The smallest type of primary soil particle (less than 0.002 mm in diameter).

**C:N ratio**—The ratio of carbon to nitrogen in organic materials. Materials with a high C:N ratio (nitrogen-poor) are good mulches or bulking agents in compost piles, while those with a low C:N ratio (nitrogen-rich) are good nutrient sources.

**cold composting**—A slow composting process that involves simply building a compost pile and leaving it until it decomposes. This process may take a year or longer. Cold composting does not kill weed seeds or pathogens.

**compaction**—Pressure that squeezes soil into layers that resist root penetration and water movement. Often the result of foot or machine traffic.

**compost**—Humus-like material produced by the controlled biological decomposition of organic materials. Compost is used as a soil amendment to increase soil organic matter and to slowly release nutrients.

**cover crop**—Plants grown to protect soil from water runoff and soil erosion and to add organic matter to soil. Also called green manure.

**decomposition**—The breakdown of organic materials by microorganisms.

**dolomitic limestone**—A type of limestone that contains magnesium as well as calcium.

**electrical conductivity**—A measure of soil salinity (salt accumulation).

**eutrophication**—A process by which bodies of water receive excess nutrients (typically phosphorus in fresh water) resulting in excess algae growth and subsequent loss of oxygen when the algae die and decay.

**fertilizer**—A natural or synthetic product added to the soil to supply plant nutrients.

**fertilizer analysis**—The amount of nitrogen, phosphorus (as  $\text{P}_2\text{O}_5$ ), and potassium (as  $\text{K}_2\text{O}$ ) in a fertilizer, expressed as a percent of total fertilizer weight. Nitrogen (N) is always listed first, phosphorus (P) second, and potassium (K) third.

**Frankia bacteria**—Bacteria that live in association with roots of alders and some other plants and convert atmospheric nitrogen to plant-available forms, a process known as nitrogen fixation.

**green manure**—Same as cover crop.

**helminths**—Wormlike parasites that affect humans and other animals.

**hot composting**—A fast composting process that produces finished compost in 2 to 4 months. High temperatures are maintained by mixing balanced volumes of energy materials and bulking agents, keeping the compost pile moist, and turning it frequently.

**humus**—The end product of decomposed animal or vegetable matter.

**immobilization**—The process by which soil microorganisms use available nitrogen as they break down materials with a high C:N ratio, thus reducing the amount of nitrogen available to plants.

**infiltration**—The movement of water into soil.

**ion**—An atom or molecule with either a positive or negative electrical charge.

- leaching**—Movement of water and soluble nutrients down through the soil profile.
- loam**—A soil with roughly equal influence from sand, silt, and clay particles.
- macropore**—A large soil pore. Macropores include earthworm and root channels, and they control a soil's permeability and aeration.
- micronutrient**—A nutrient used by plants in small amounts (iron, zinc, molybdenum, manganese, boron, copper, and chlorine). Also called a trace element.
- micropore**—A small soil pore, typically a fraction of a millimeter in diameter. Micropores are responsible for a soil's ability to hold water.
- mycorrhizae**—Beneficial fungi that infect plant roots and increase their ability to take up nutrients from the soil.
- nitrifier**—A microbe that converts ammonium to nitrate.
- nitrogen cycle**—The sequence of biochemical changes undergone by nitrogen as it moves from living organisms, to decomposing organic matter, to inorganic forms, and back to living organisms.
- nitrogen fixation**—The conversion of atmospheric nitrogen into plant-available forms by *Rhizobia* bacteria.
- organic fertilizer**—A natural fertilizer material that has undergone little or no processing. It can include plant, animal, and/or mineral materials.
- organic matter**—Any material originating from a living organism (peat moss, compost, ground bark, manure, etc.).
- pathogen**—A disease-causing organism. Pathogenic soil organisms include bacteria, viruses, fungi, and nematodes.
- ped**—A cluster of individual soil particles.
- permeability**—The rate at which water moves through a soil.
- pH**—A measure of soil acidity or alkalinity. Values less than 7 indicate acidity, a value of 7 is neutral, and values greater than 7 indicate alkalinity. Most soils have a pH between 4.5 and 9.
- phosphate**—The form of phosphorus listed in most fertilizer analyses ( $P_2O_5$ ).
- potash**—The form of potassium listed in most fertilizer analyses ( $K_2O$ ).
- primary nutrient**—A nutrient required by plants in large amounts (nitrogen, phosphorus, and potassium).
- processed fertilizer**—A fertilizer that is manufactured or is refined from natural ingredients into a more concentrated form that is more available to plants.
- quick-release fertilizer**—A fertilizer that contains nutrients in plant-available forms such as ammonium and nitrate.
- Rhizobia* bacteria**—Bacteria that live in association with roots of legumes and convert atmospheric nitrogen to plant-available forms, a process known as nitrogen fixation.
- rhizosphere**—The thin layer of soil immediately surrounding plant roots.
- sand**—The coarsest type of primary soil particle (0.05 to 2 mm in diameter).
- secondary nutrient**—A nutrient needed by plants in a moderate amount (sulfur, calcium, and magnesium).
- silt**—A primary soil particle of intermediate size (between the size of sand and clay) at 0.002 to 0.05 mm in diameter.
- slow-release fertilizer**—A fertilizer material that is converted into a plant-available form by soil microorganisms.
- soil**—A natural, biologically active mixture of weathered rock fragments and organic matter at the earth's surface.
- soil salinity**—The saltiness of a soil. Saline soils contain enough soluble salts to harm seed germination and crop growth.
- soil solution**—The solution of water and dissolved minerals found in soil pores.
- soil structure**—The arrangement of aggregates (peds) in a soil.
- soil texture**—How coarse or fine a soil is. Texture is determined by the proportions of sand, silt, and clay in the soil.
- water-holding capacity**—The ability of a soil's pores to hold water for plant use.

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EM063E

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