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Soils and Fertility

Kentucky Master Gardener Manual Chapter 4

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Soil is a mixture of weathered rock fragments (minerals) 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. Soil is roughly 50% pore space (50% voids between soil particles). 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 air 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

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 two types of pores:

- Large pores (macropores) control a soil's permeability and aeration. Macropores include earthworm and root channels. Because they are large, water moves through them rapidly by gravity so that rainfall and irrigation infiltrate into the soil, and excess water drains through it.
- Micropores are fine soil pores, 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 or towel, micropores hold water against the force of gravity. Much of the water held in micropores is available to plants, but some is held so tightly that plant roots cannot use it.

Soil that has a 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. Runoff of rainfall and irrigation water also is more likely on micropore-dominant soils.

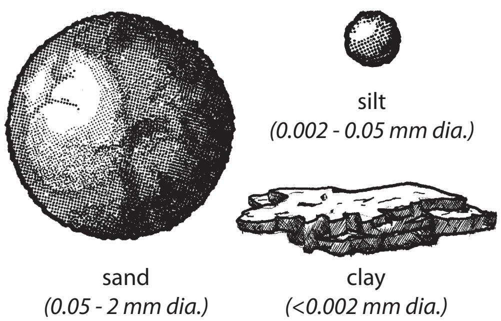
Soil texture, structure, organic matter, and human activity affect porosity. You can evaluate your garden soil in terms of these properties to understand their impact. The only tools you need are your eyes, fingers, and a shovel.

Texture

Texture describes the relative abundance of sand, silt, and clay-sized materials. The coarsest soil particles are sand. They are visible to the 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, floury feel. On close inspection, sand and silt particles look like miniature rocks (Figure 1).

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 high in clay feel very hard when dry but are easily shaped and molded when moist.

Figure 1. Shapes of soil particles.



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. That means sandy soils contain mostly macropores and usually have rapid permeability but limited water-holding capacity. In soils containing mostly silt and clay, micropores predominate, creating high water-holding capacity but reducing permeability.

Particle size also affects the surface area in soil. Surface area is important because surfaces are the most active part of the soil. Surfaces hold plant nutrients, bind contaminants, and provide a home for microorganisms. Clay particles have a large surface area relative to their volume, so a small amount of clay makes a large contribution to a soil's surface area.

Nearly all soils have a mixture of particle sizes and a both types of pore sizes (Figure 2). A soil with roughly equal influence from sand, silt, and clay particles is called a loam. Loams usually make good agricultural and garden soils. They have a balance of macropores and micropores, so they usually have both good water-holding capacity and moderate permeability.

A sandy loam is similar to a loam, but 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 wires and ribbons when moist. They generally have high water-holding capacity and low permeability.

Almost any texture of soil can be suitable for gardening as long as you are aware of the soil's limitations and adjust your management 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 fertilization, but you can plant them earlier in the spring. All soils can benefit from additions of organic matter, as described later in this chapter under "Adding Organic Matter."

Many soils contain coarse fragments—gravel and rocks. Coarse fragments do not contribute to a soil's productivity and can be a nuisance when you are digging. Don't feel compelled to remove all of them from your garden, however. Coarse fragments aren't harmful, and your time is better spent on other gardening tasks. The only time rocks are a problem is when you have nothing but rocks on your land. Then, water- and nutrient-holding capacities are so low that it is difficult to grow healthy plants.

Structure

Individual particles of sand, silt, and clay tend to cluster and bind together, forming aggregates called peds, 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. They contain sand, silt, clay, and organic matter.

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 a soil's macropores, which improve permeability, drainage, and recharging of air into the soil profile. The pores within peds are predominantly micropores, contributing to the soil's water-holding capacity. A well-structured soil is like a sponge, allowing water to enter and soak into the micropores and letting excess water drain down through the macropores. Good structure is especially important in medium- to fine-textured soils (soils with appreciable amounts of clay), because it increases the soil's macroporosity, improving permeability and drainage.

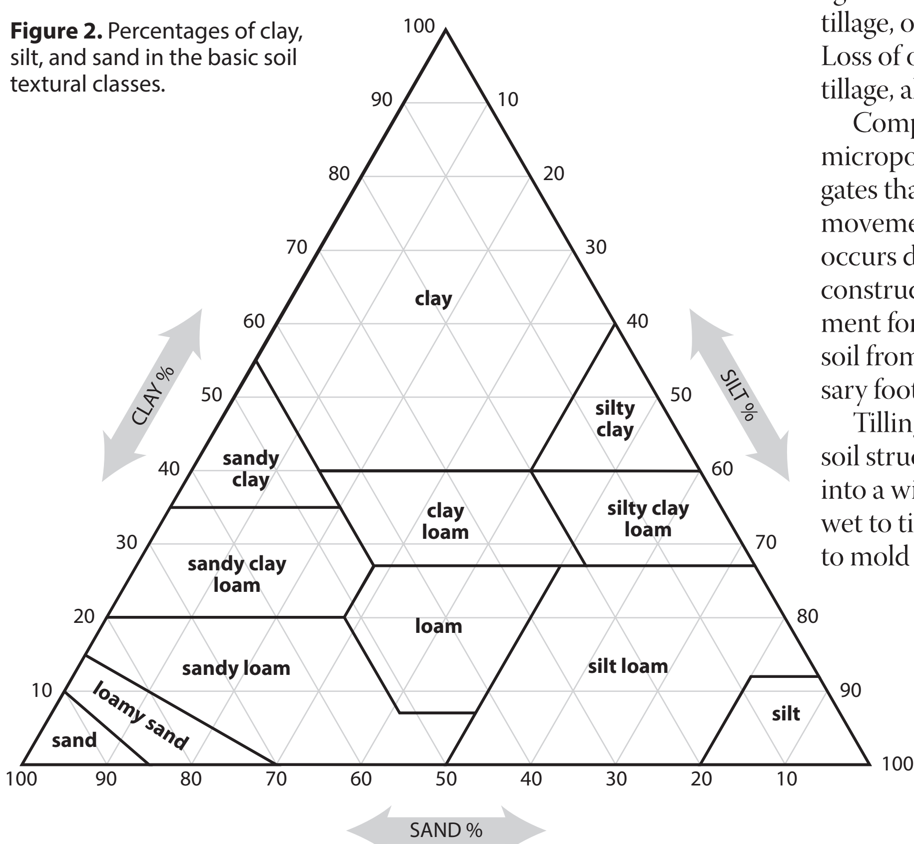
Human Activity

Soil structure is fragile and can be damaged or destroyed by compaction, excessive tillage, or tilling when the soil is too wet. Loss of organic matter, typically a result of tillage, also weakens structure.

Compaction squeezes macropores into micropores and creates horizontal aggregates that resist root penetration and water movement (Figure 3). Compaction often occurs during site preparation or house construction, creating a difficult environment for establishing plants. Protect your soil from compaction by avoiding unnecessary foot or machine traffic.

Tilling when soil is too wet also damages soil structure. If you can mold a piece of soil into a wire or worm 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.

Figure 2. Percentages of clay, silt, and sand in the basic soil textural classes.



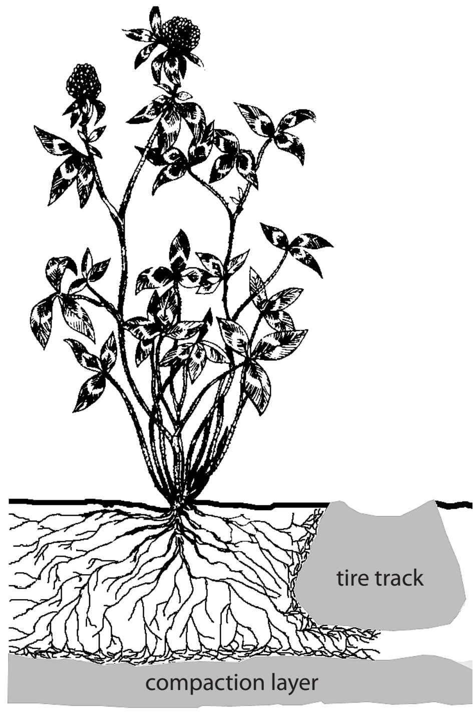


Figure 3. Compacted soil resists root penetration and water movement.

Structural damage caused by human activity usually is most severe within the top foot of soil and can be overcome by proper soil management.

Organic Materials, Organic Matter, and Humus

Organic materials (called organic residues), such as plant and animal residues of recognizable origin, are the building blocks of organic matter, or humus. Soil organic matter and humus (terms often used synonymously) contain decomposed plant and animals remains of unrecognizable origin, their partial decomposition products, and the wastes from soil biomass.

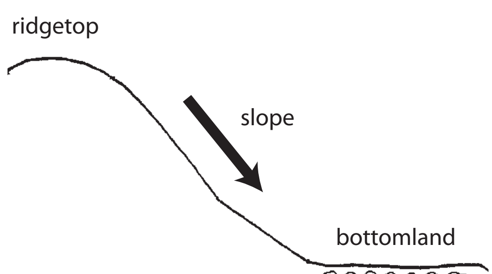


Figure 4. Ridgetops and slopes tend to shed water, while soils at the bottom of slopes and in low areas collect water.

Increasing soil organic matter is the best way to improve the plant environment in nearly all soils, because it helps build and stabilize soil structure in fine-textured and compacted soils, improving permeability and aeration and reducing the risk of runoff and erosion. In addition, when organic material decomposes, it forms humus, which acts as a natural glue to bind and strengthen soil aggregates. Organic matter also helps soils, particularly sandy soils, hold water and nutrients and is a reservoir of energy for soil microbes. See "Adding Organic Matter" later in this chapter for more information.

Water Management in Your Garden

Slope, aspect, and soil depth

Slope, aspect (direction of exposure), and soil depth affect availability of water and its use in a soil. Choose plants that are best suited to your property's conditions.

Ridgetops and side slopes tend to shed water, while soils at the bottoms of slopes and in low areas collect it (Figure 4). Soils that collect water often have high winter water tables, which can affect the health of some plants. Soils on ridgetops are more likely to be droughty.

Site aspect also is important. Exposures facing south or southwest collect the most heat and use the most water.

Soil depth also affects water availability by determining 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 volume of soil available to roots is smaller. Dig below the topsoil in your garden. The deeper you can dig before hitting a restrictive layer, the greater the soil volume for holding water.

See the Cooperative Extension publication *Improving the Productivity of Landscapes with Little or No Topsoil* (AGR-203) for more information.

Irrigation

Most gardens in Kentucky require summer irrigation. The need for irrigation varies, depending on soil water-holding capacity, weather, site aspect, the plants grown, and the plants' 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, 1 inch of irrigation water is all you need. Any more will leach (move downward) through the root zone, carrying nutrients with it. A silt loam or clay soil can hold more than 2 inches of water, but you may need to irrigate more slowly to prevent runoff.

Wet soils

If your soil stays wet in the spring, you will have to delay tilling and planting. Working wet soil can damage its structure, and seeds are less likely to germinate in cold, wet soil.

Some plants don't grow well in wet soil. Raspberries, for example, often become infected by root diseases in wet soil and lose vigor and productivity.

A soil's color gives clues to its tendency to stay wet. If a subsoil is brown or reddish, the soil probably is well drained and is rarely too wet. Gray subsoils, especially those with brightly colored mottles, often are wet. If your soil is gray and mottled directly beneath the topsoil, it will be saturated in some part of the year.

Table 1. Approximate abundance of microorganisms in agricultural topsoil.

Organism	Number/gram (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

Sometimes, simple practices can reduce problems with wet soil, including the following:

- Divert runoff from roof drains away from your garden.
- 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 on your property. Installing drainage can be expensive, however. When considering drainage, make sure there is a place to drain the water. Check with local regulatory agencies about any restrictions on the project.

Organisms

Soil abounds with life. Besides the plant roots, earthworms, insects, and other creatures you can see, soil is home to an abundant and diverse population of microorganisms. Soils with more organic matter tend to have more organisms.

The more microorganisms the better. The important thing is to make the environment favorable for microorganism activity, which includes well aerated soils, warm, moist, near-neutral pH and good levels of organic matter. Other factors must also be considered; for example, if trying to grow blueberries, which like more acidic conditions, this constraint for plant growth would be more important than a near-neutral pH for microbial growth. You must first satisfy the needs of the plant.

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.

The main 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.

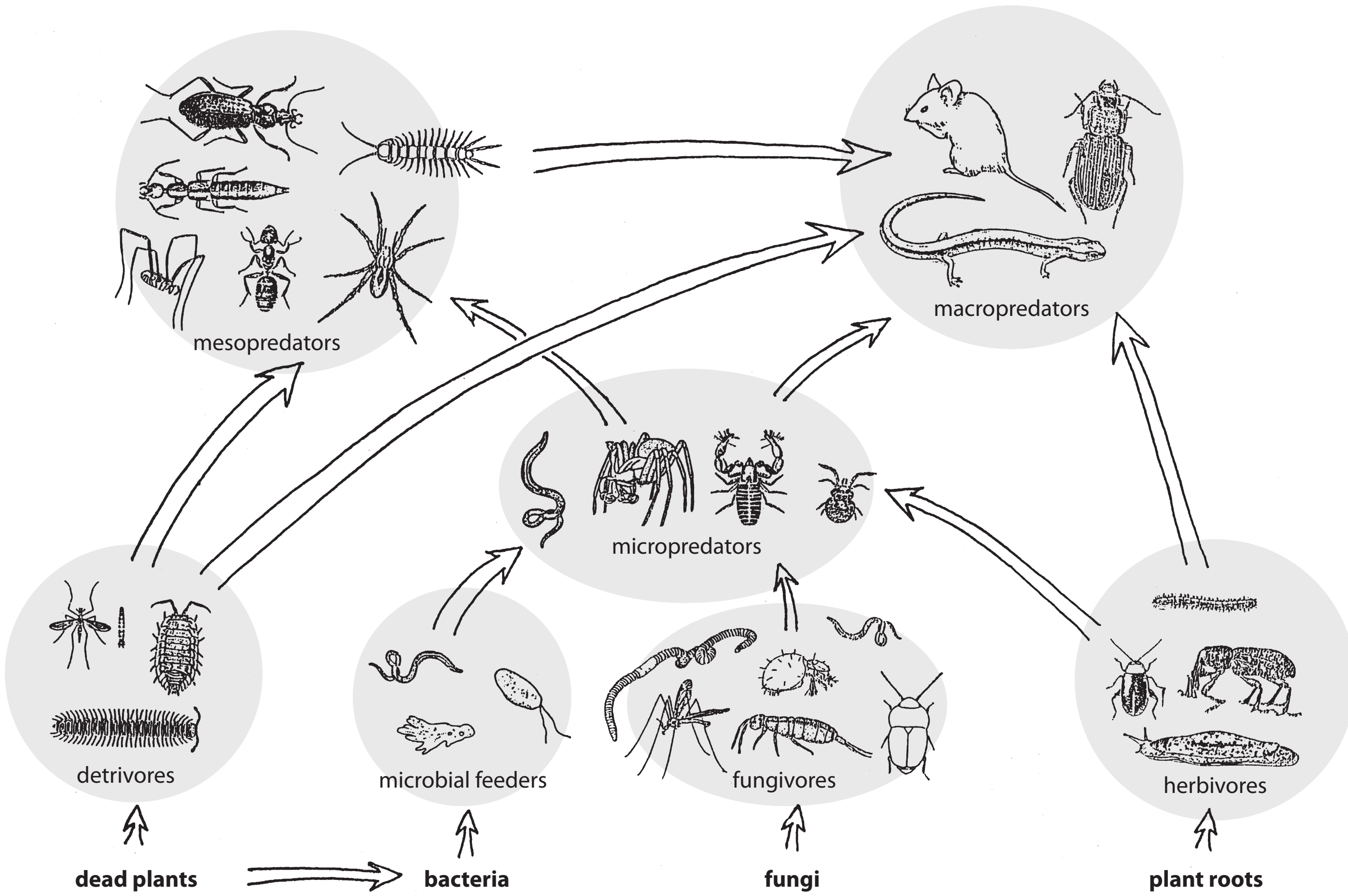
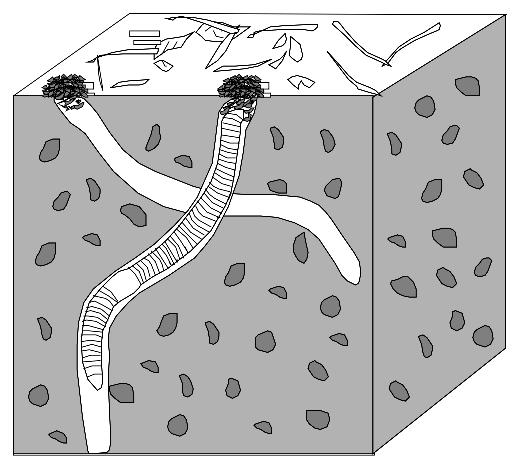


Figure 5. The soil food web.

Figure 6. Earthworm channels create macropores, which improve a soil's permeability and aeration.



Organisms ranging from tiny bacteria to insects and earthworms take part in a complex soil food web (Figure 5). Mammals such as moles and voles also are part of the food web, feeding on insects and earthworms and mixing organic matter throughout the soil profile. This mixing also improves soil structure.

Some soil organisms play other beneficial roles. Mycorrhizae are fungi that infect plant roots and increase their ability to take up nutrients from the soil. Rhizobia bacteria are responsible for converting atmospheric nitrogen to plant-available forms, a process known as nitrogen fixation. Earthworms mix large volumes of soil and create macropore channels that improve permeability and aeration (Figure 6). "Soil health" is often judged by the numbers of earthworms in the soil—the more earthworms, the better.

Not all soil organisms are beneficial. Some are pathogens, which cause diseases such as root rot of raspberries and scab on potatoes. Moles can damage crops and lawns, and slugs are a serious pest in many Kentucky 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° and 100°F, while earthworms are most active and abundant at about 50°F. Most organisms prefer moist soil. The relationships between gardening practices, microbial populations, and soil quality are complex and often poorly understood. 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.

Nutrients

Soil supplies 13 essential plant nutrients. Each nutrient plays one or more specific roles in plants. 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 lot 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 primary nutrient (macronutrient), secondary nutrient, or micronutrient, based on the amount of the nutrient needed by plants (Table 2). If a soil's nutrient supply is deficient, fertilizers can provide the additional nutrients needed for healthy plant growth.

Table 2. Essential plant nutrients.

Primary nutrients (macronutrients)		Secondary nutrients		Micronutrients (trace nutrients)	
Name	**Chemical symbol**	**Name**	**Chemical symbol**	**Name**	**Chemical symbol**
Nitrogen	N	Sulfur	S	Zinc	Zn
Phosphorus	P	Calcium	Ca	Iron	Fe
Potassium	K	Magnesium	Mg	Copper	Cu
				Manganese	Mn
				Boron	B
				Molybdenum	Mo
				Chlorine	Cl

Deficiencies

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

Secondary nutrients also are deficient in some Kentucky soils, but not very often. The secondary nutrients are calcium (Ca), magnesium (Mg), and sulfur (S). Micronutrient deficiencies do occur in Kentucky, but to a limited extent.

Except for boron and zinc, micronutrients are rarely deficient. Boron deficiencies occur most often in root crops, brassica crops (e.g., broccoli), and caneberries (e.g., raspberries). Zinc deficiency usually is associated with high P levels and high pH soils and most often affects tree fruits and corn.

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

Because most soil in the Central and Outer Bluegrass region of Kentucky have been formed from limestone that is naturally high in phosphorous, plant-available phosphorus is very high (exceeding 200 lb/acre), and these fields may never need phosphorus fertilization. Adding fertilizer phosphorus in this region simply increases the chances for eutrophication (algal blooms which may cause fish kills) and can diminish the uptake of other essential plant nutrients like zinc. Since fertilizer analysis is given in percent of N, P_20_5, and K_20, make certain that the center number in a fertilizer product is 0 (example 23-0-30) when soils are already high in phosphorus .

Long-term use of complete fertilizers or animal manures can also increase P concentrations to levels so that no additional P is required, which is another reason to soil test when applying nutrients—so you will know what nutrients are needed and the correct amount to add.

Excess Nutrients

Excess nutrients can be a problem for plants and the environment. Excesses usually occur because too much of a nutrient is applied or it is applied at the wrong time.

Too much boron is toxic to plants. Too much nitrogen can lead to excessive foliage production, increasing the risk of disease; wind damage; and delayed flowering, fruiting, and dormancy. Available nitrogen left in the soil at the end of the growing season can leach into groundwater and threaten drinking water quality.

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 take up only nutrients that are in solution (dissolved in soil water). Most soil nutrients are not in solution but instead are tied up in soil mineral and organic matter in insoluble forms. These nutrients become available to plants only after they are converted to soluble forms and dissolve in the soil solution.

This process occurs through weathering of mineral matter and biological decomposition of organic matter. Weathering of mineral matter is a very slow process that releases small amounts of nutrients each year. The rate of nutrient release from soil organic matter is somewhat faster and depends on the amount of 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. 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, meaning they have either positive or negative charges. Positively charged ions are cations, of which potassium, calcium, and magnesium are examples. Negatively charged ions are anions. Chlorine is an example of an anion.

Clay particles and soil organic matter have negative charges on their surfaces and can attract cations. They hold nutrient cations in ready reserve for rapid release into soil solution to replace nutrients taken up by plant roots. This reserve supply of nutrients contributes to a soil's fertility. A soil's capacity to hold cations is called its cation exchange capacity, or CEC.

The Nitrogen Cycle

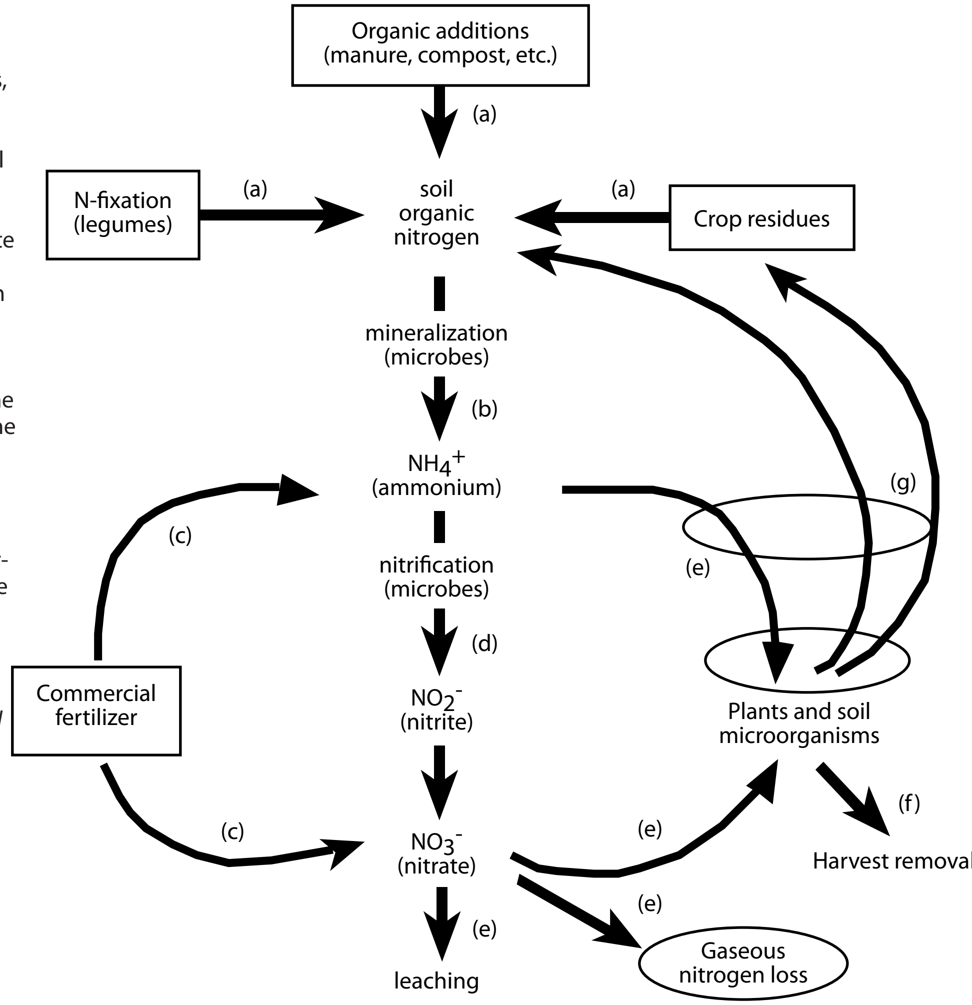
Managing nitrogen is a key part of growing a productive and environmentally friendly garden. Nitrogen is the nutrient needed in the largest amount by plants, but excess nitrogen can harm plants and degrade water quality. Understanding how the nitrogen cycle affects nitrogen availability can help you become a better nutrient manager (Figure 7).

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

Most nitrogen in soil is tied up in organic matter and plant, animal, and microbial biomass. 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 (NH_4^+). Any nitrogen source that contains ammonium or has an ammonium intermediary is acid forming. Urea $(NH_2)_2CO$ will form NH4+ when applied to the soil. When the soil is warm, a group of microbes called nitrifiers convert the

Figure 7. 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.

(Note: An alternate schematic of the nitrogen cycle is illustrated in Chapter 11, *Your Yard and Water Quality*.)



ammonium to nitrate (NO_3^-). When the nitrifiers convert the NH_4^+ to NO_3^-, they release H^+ (acidity), which will lower soil pH. On the other hand, nitrate forms (NO_3^-) are not acid forming. Ammonium, retained by the soil due to its positive charge, is a soluble ion that is available to plants and soil microbes. 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 lost readily by leaching. Nitrate remaining in the soil at the end of the growing season will leach 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 to nitrogen gases, which diffuse back into the atmosphere.

Table 3. Common forms of nitrogen in soil.

Form of nitrogen	Characteristics
Organic N	Primary form of N in soil. Found in proteins, lignin, amino acids, humus, etc. Not available to plants. Mineralized to ammonium by soil microorganisms.
Ammonium N (NH_4^+)	Inorganic, soluble form. Available to plants. Converted to nitrate by soil microorganisms.
Nitrate (NO_3^-)	Inorganic, soluble form. Available to plants. Can be lost by leaching. Converted to gases in wet soils.
Atmospheric N (N_2)	Makes up about 80% of the soil atmosphere. Source of N for N-fixing plants. Not available to other plants.

Note: Any nitrogen source that contains ammonium or has an ammonium intermediary is acid forming

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 available forms.

The nitrogen cycle is a leaky one, with losses to leaching and 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 is a natural process involving certain plants and Rhizobia bacteria. The Rhizobia form nodules in the plant roots, and through these nodules they are able to take atmospheric nitrogen (N_2 gas) from the soil air and convert it to available N within the plant. Legumes (plants that produce seeds in pods) such as peas, beans, alfalfa, and clover are common nitrogen fixers. The Kentucky coffeetree, the honey locust, redbuds, and Alder trees also fix nitrogen. Growing legumes as a cover crop will supply nitrogen to future crops.

Understanding 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.

You can use processed fertilizers, organic fertilizers, or a combination of the two to supply soil nutrients. Plants do not prefer one source of nutrients over another, but the nutrients' behavior in the soil often differs (Table 4).

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 are immediately available to plants.

Organic fertilizers are natural materials that have undergone little or no processing. They include both biological (plant and animal) materials and mineral materials.

Once in the soil, organic fertilizers release nutrients through natural processes, including chemical weathering of mineral materials and biological breakdown of organic matter. The released nutrients are available to plants in water-soluble forms. These soluble forms of 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. That means larger amounts of organic fertilizers are needed, but their effects last longer.

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

Choosing organic fertilizers involves trade-offs in cost or convenience.

Farmyard manure usually is inexpensive or free, but can be inconvenient to apply. Packaged organic blends, on the other hand, are convenient but often expensive.

Table 4. 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, 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 almost immediately available to plants
Nutrient content	Usually low	Usually high

Nutrient Release

Nutrients in most processed fertilizers are available almost 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 no longer can 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. Fresh manure, biosolids, and fish emulsion are examples of organic fertilizers containing available nutrients.

We assume that in manures, 100% of postassium (potash) is available the first year, 80% of phosphorus, and about 50% of the nitrogen. Remember that nitrogen values vary depending on the type of manure, the environmental conditions during the growing season, and when during the season the manure was applied.

As manure ages, the most readily available nutrients are lost into the air or leached into the soil, leaving slow-release material in the aged manure.

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. In the long run, this nutrient supply decreases the need for supplemental fertilizer.

Fertilizer Labels

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

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

$$1 \text{ lb P} = 2.29 \text{ lb } P_2O_5.$$

For potassium, the conversion is:

$$1 \text{ lb K} = 1.2 \text{ lb } K_2O.$$

Thus, a bag of fertilizer labeled 5-10-10 contains 5% nitrogen, 10% phosphorus expressed as P_2O_5, and 10% potassium expressed as K2O. This information is called a fertilizer analysis.

The analysis for processed fertilizers guarantees the amount of available nutrients in the fertilizer. The analysis for organic fertilizers represents the total amount of nutrients rather than available nutrients. Because nutrients in most organic fertilizers are released slowly, the amount of immediately available nutrients is less than the total.

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 include those listed in Table 5.

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. The potassium in sylvinite is already in soluble form, but the sylvinite is treated to remove the sodium salts to make it suitable for use as a fertilizer. Some other potassium fertilizers are made from potassium sulfate salts, which supply sulfur as well as potassium. Table 6 lists examples of processed phosphorus and potassium fertilizers.

Mixed, or complete, fertilizers

Mixed, or complete, fertilizers contain all three primary nutrients. The ratios can vary. Fertilizers for annual gardens typically have $N:P_2O_5:K_2O$ ratios in the range of 1:1:1 or 1:2:2. Examples include 8-8-8 and 10-20-20 blends. Fertilizer blends for starting plants usually have a higher proportion of phosphorus. Lawn fertilizers are higher in nitrogen; an example is a 12-4-8 blend.

Common Organic Fertilizers

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

Animal manures vary widely in nutrient content and nutrient availability, depending on the type of animal that produced the manure and the manure's age and handling. For example:

- Fresh manure has higher nutrient levels than aged manure.
- Manure diluted with large amounts of bedding has fewer nutrients than undiluted manure.
- Exposure to rain leaches nutrients.
- Composting under cover retains more nutrients but reduces nutrient availability.

Table 5. 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.
Diammonium phosphate	18-46-0	Used in mixed fertilizers as a source of nitrogen and phosphorus.
Sulfur-coated urea (SCU)	35-0-0	Sulfur coating slows release of available N, making this a slow-release fertilizer.

Table 6. 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 nitrogen and phosphorus.
Diammonium phosphate	18-46-0	Used in mixed fertilizers as a source of nitrogen and phosphorus.
Potassium chloride	0-0-60	High salt index.
Potassium magnesium sulfate	0-0-22	Also contains 11% magnesium and 18% sulfur.
Potassium sulfate	0-0-50	Also contains 18% sulfur.

Table 7 compares average nutrient contents of typical manure products.

It doesn't take much fresh manure to fertilize a garden. One 5-gallon bucket of fresh cow manure is enough for about 50 square feet of garden. The same amount of fresh poultry manure covers 100-150 square feet. Larger amounts can harm crops and leach nitrogen into groundwater.

Fresh manure can carry disease-causing pathogens. Be sure to refer to the information on manure safety below before using fresh manure.

It takes larger amounts of aged, diluted, or leached manure to provide the same amount of nutrients as fresh manure. If you're using it, increase the amount applied based on how much it is aged, diluted, and/or leached. Composted manure solids from dairy farms also have low nutrient availability, so you can apply them at higher rates than fresh manure. Use these manures as much for the organic matter they supply as for nutrients. You can add as much as 1 to 2 inches of manure and still have very low nutrient availability.

To fine-tune your application rate, experiment with the amount you apply and observe your crops' performance. It's better to be conservative and add more nutrients later if crops seem deficient than to risk overfertilizing.

Table 7. Typical nitrogen, phosphate, and potash content (%) of some manures and tobacco stalks.

Animal Manures[1]	Water (%)	% nutrients		
		N[2]	P_2O_5	K_2O
Dairy Cattle	80	0.55	0.45	0.60
Swine	80	0.45	0.45	0.40
Beef	80	0.55	0.35	0.50
Broiler litter	20	2.75	2.75	2.25
Broiler layers	40	1.75	2.75	1.50
Broiler pullets	30	2.00	2.25	2.00
Goat	70	1.10	0.25	0.75
Horse	80	0.60	0.30	0.60
Tobacco Stalks	20	1.50	0.50	3.50

1 Animal manures contain chloride, which can reduce the quality of some crops.
2 Plant-available N can range from 20 to 80% of the total N in the year of application. See UK Cooperative Extension publication *Using Animal Manures as Nutrient Sources* (AGR-146) for more details.
This table was taken from UK Cooperative Extension publication *Lime and Fertilizer Recommendations* (AGR-1).

To use manure, simply spread it over the soil and turn it in if you wish.

The best time to apply manure is in the spring before planting. You also can apply manure in the fall, but environmental risks of leaching and runoff increase in winter. If you do apply manure in the fall, apply it early and plant a cover crop to help capture nutrients and prevent runoff. See "Green Manure (Cover Crops)" later in this chapter for more information.

Using Manure Safely

Fresh manure sometimes contains disease-causing pathogens that can contaminate garden produce. *Salmonella* bacteria are among the most serious pathogens found in animal manure. Pathogenic strains of *E. coli* bacteria also can be present in cattle manure. Manure from swine, dogs, cats, and other 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 to the leaves or fruit of low-growing crops. The risk is greatest for root crops (for example, carrots and radishes) or leaf crops (such as lettuce), where the edible part touches the soil. The risk is negligible for crops such as sweet corn, which do not contact the soil, or for any crop that is thoroughly cooked. Avoid using fresh manure where you grow high-risk crops.

Cooking destroys pathogens, but raw food carries a risk. Washing and peeling raw produce removes most pathogens, but some may remain.

Composting manure at high temperatures kills pathogens, but it is very hard to maintain rigorous composting conditions in a backyard 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 manure should not contain them. Helminths in dog, cat, or pig manure can persist for years, however, so do not add these manures to your garden or compost pile.

Biosolids

Biosolids are a by-product of wastewater treatment. Most of the biosolids produced in Kentucky are used to fertilize agricultural and forest crops. Biosolids also are available to gardeners from some wastewater treatment plants.

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 as well as small amounts of potassium and trace elements. Some of the nitrogen in biosolids is immediately available to plants. The rest is released slowly. A 5-gallon bucket of biosolids cake is enough to fertilize 50 square feet of garden. Apply biosolids as you would apply manure.

Biosolids also are an ingredient in some commercial composts. Like other composts, biosolid compost releases nutrients very slowly (other than the immediately-released nitrogen). It is a good source of organic matter and provides small amounts of nutrients to plants.

Use only biosolids that are free of disease-causing pathogens (Class A biosolids). Examples include biosolids compost and some heat-treated biosolids. Class B biosolids have not been treated to the same extent and may contain pathogens, including some that are long-lived in the soil. Check with the wastewater treatment plant offering biosolids to find out whether its biosolids meet Class A requirements and are available for home use.

Biosolids contain small amounts of trace elements. Some trace elements are micronutrients, which can be beneficial to crops. However, large amounts can be toxic to crops, animals, or humans. When you apply biosolids at proper rates to provide nutrients, the risk of applying harmful amounts of trace elements is negligible.

Because biosolids come from the wastewater treatment process, they contain synthetic materials that were present in the wastewater or added during treatment. Biosolids are not certified as organic fertilizers.

Biosolids do have two important characteristics common to organic fertilizers:

- Their nutrients are released slowly from the organic form by natural processes in the soil.
- They are a product of the waste stream that can benefit crop growth.

Salinity

Salts from irrigation water, fertilizer, compost, and manure applications can accumulate to the point where they harm plant growth. In areas where rainfall exceeds evaportranspiration, salts are leached from the soil and do not accumulate in the root zone.

A salinity test measures the total soluble salts in a soil. Table 8 shows how to interpret a salinity test. Soil salinity problems are rare in Kentucky.

You can leach salts from soil by applying irrigation water in excess of the water-holding capacity of the soil. The excess water must drain down through the soil to carry away excess salts. When leaching, apply water slowly enough so that it drains freely through the subsoil. Three inches of excess water removes about half of the soluble salts in a soil. Five inches of water removes about 90%.

Table 8. Soil salinity measured in conductivity units (millimhos/cm) and potential effects on plants.

Conductivity (mmho/cm)	Interpretation
4 or above	Severe accumulation of salts. May restrict growth of many vegetables and ornamental plants. Reduce salt by leaching.
2 to 4	Moderate accumulation of salts. Will not restrict plant growth but may require more frequent irrigation to prevent wilting.
Less than 2	Low salt accumulation. Will not affect plants.

Commercial Organic Fertilizers

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

Table 9 shows that most organic fertilizer materials contain one main nutrient. The other nutrients are present in smaller amounts, which means that although organic fertilizers contain a variety of nutrients, they may not be present in the proportions needed by plants. Several companies produce balanced organic fertilizers by blending these materials into a single product that provides all of the primary nutrients in balanced proportions.

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 because of convenience. They are most economical for small gardens where little fertilizer is 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.

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

Material	Nitrogen (%)	P_2O_5 (%)	K_2O (%)
Cottonseed meal	6–7	2	1
Blood meal[1]	12–15	1	1
Alfalfa	2	0.5	2
Bat guano[1]	10	3	1
Fish meal[1]	10	4	0
Fish emulsion[1]	3–5	1	1
Bone meal	1–4	12–24	0
Rock phosphate[2]	0	25–30	0
Greensand	0	0	3–7
Kelp meal	1	0.1	2–5

[1] Contains a substantial amount of quickly available nitrogen that plants can use early in the season.
[2] Very low P availability (only 2–3%). Useful only in acid soils.

How Much Fertilizer to 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 use of Cooperative Extension publications can help you estimate fertilizer needs.

Soil Tests

A soil test gives information on the levels of nutrients in your soil and recommends how much fertilizer to add each year based on the test results and the crops you grow. You don't need to test your soil every year; every three to five years is enough.

A garden soil test typically includes the nutrients phosphorus, potassium, calcium, magnesium, and zinc. The test also includes soil pH and recommends lime if it's needed to raise pH. In areas with historically high manure applications, a test for soluble salts can be worthwhile.

Soil test labs don't routinely test for nitrogen because there is no simple way to predict nitrogen availability. The lab will give a general nitrogen recommendation, however, based on the plants you are growing and on information you provide about the soil (such as whether there is a history of manure applications, which would increase soil-available nitrogen).

To take a soil sample, first collect subsamples from at least 10 different spots in your garden. Avoid any unusual areas, such as the site of an old trash dump, burn pile, or rabbit hutch. Sample the top 6 inches of soil (0 to 6 inches) if the soil has been tilled and 0 to 4 inches for non-tilled soil and lawns. Air-dry the samples and mix them together well. Send about a pint of the mixed sample to the lab.

If you're planting different crops but the area has had similar previous fertilizer additions, it's probably not necessary to submit more than one soil sample. Instead, use the fertilizer recommendations for the various crops.

Before choosing a lab, call to make sure it tests and make recommendations for garden soils. Ask a lab representative the following questions:

- Do you routinely test garden soils for plant nutrients and pH?
- Do you use Kentucky test methods and fertilizer guides?
- Do you give recommendations for garden fertilizer applications?
- Are there forms to fill out? What information do you need?
- How much does a test cost?
- How quickly will you send results?

Cooperative Extension Publications

Soil testing is highly recommended, but if you are unable to submit a sample for testing, you can use Cooperative Extension publications to estimate your needed fertilizer additions. These publications usually give recommendations for processed fertilizers, but some give guidelines for organic fertilizers as well. Kentucky has published fertilizer recommendations for a variety of crops. See "For More Information" at the end of this chapter. Also see other chapters in this series for information on specific crops.

A typical extension recommendations is for 2 lb of nitrogen per 1,000 square feet of garden, usually applied in a mixed fertilizer with a 1:1:1 ratio. Gardens with a history of fertilizer application may need less phosphorus and potassium than this rate supplies—you won't know if you don't test. (Fast-growing crops such as sweet corn need more nitrogen.) The best way to know what your garden or lawn needs is to soil test.

Estimating Organic Fertilizer Rates

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

- Organic fertilizers with large proportions of available nutrients (such as bat guano and fish emulsion) can be substituted for processed fertilizers on a one-to-one basis. Use the same quantity called for in the processed fertilizer recommendation.
- Apply other packaged fertilizers according to their nutrient availability. Composts, rock phosphate, and plant residues generally have lower nutrient availability than more concentrated animal products (for example, blood meal, bone meal, and chicken manure). The recommended application rates on packaged organic fertilizers are a good guideline. Check these recommendations against other products to make sure they seem reasonable.
- Nutrient concentration and availability in farmyard manures vary widely, depending on the type of manure and its age and handling. Application rates range from 5 gallons per 100-150 square feet for high-nitrogen chicken manure to 1-2 inches deep for cow or horse manure composted with bedding. Estimate application rates based on the type of manure.
- Observe your crops carefully. Lush plant growth and delayed flowering and fruiting are signs of high amounts of available nitrogen and may indicate overfertilization.
- Experiment with different fertilizer rates in different parts of a row, and see whether you notice differences in crop performance. Plan your experiment carefully so you are confident that differences are the result of different fertilizer rates rather than differences in soil, water, sunlight, or management practices.
- Soil testing is valuable in understanding your soil's nutrient status. Many established gardens have high levels of soil fertility, so that crops grow well with little fertilizer.

How to Calibrate a Fertilizer Spreader by the Volume Method

1. Based on the fertilizer analysis, determine the amount of actual fertilizer that needs to be spread per 1,000 ft^2. (1.5 lbs N/1,000 ft^2 needs 30 lb of 5-5-5 to get this rate of nutrient, or 15 lb of 10-10-10).
2. Start with a known amount of fertilizer (for example, a 50-lb bag) and a known volume (for example, two 5-gal buckets of same size).
3. Pour the fertilizer into the buckets and measure the total height, leveled. If the measurement is in inches, there will be a known amount of fertilizer (50 lb) per so many inches. For example, if 50 lb measures 31 inches total in the two buckets, 50 lb/31 inches = 1.6 lb/inch of bucket height. This standard calculation will allow determination of a weight if scales are not available.
4. Determine the width of the fertilizer spread pattern, then the total area.

(Known width x distance = total area)

5. Set the spreader's gate to manufacturer's recommendation. Most fertilizers will have a different flow pattern and density, so one factory setting will not work for all fertilizers.
6. Measure a known distance—for example, 50 feet. Apply the fertilizer to the 50-ft line. Do not collect the fertilizer. Pour fertilizer remaining fertilizer in the spreader back into the bucket, and measure the height. (Remember that for this example, 1 inch in the bucket weighs 1.6 lb.)

Example:

With a 10-ft spread width and 50-ft length, total area = 500 ft^2

For this area, we want 1.5 lbs N/1,000ft^2, or 15 lb of 10-10-10.

- After spreading 50 ft of fertilizer at a 10-foot width, pour the remaining fertilizer back into the bucket and measure and assume you measure 7 inches.
- Based on the previous determination of a fertilizer weight of 1.6 lb/inch, 7 inches x 1.6 lb/inch = 11.2 lb of fertilizer.
- Because calibration is on 500 ft^2 and the recommendation is for 1,000 ft^2, multiply by 2, which = 22.4 lb fertilizer/1,000ft^2.
- Amount of 10-10-10 to achieve the 1.5 lb of N/acre is 15 lb and our calculations show that 22.4 lb was applied; therefore, we are applying too much and need to reduce the amount coming out of the spreader and calibrate again.
- Continue using this procedure until you have the desired rate.

When to Fertilize

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. Not only is nutrient loss inefficient, it 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, earlier for spring plantings of lettuce and other greens. Plants also need available nutrients (especially phosphorus) 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 organic fertilizers, a single application usually is adequate, because nutrient release usually is fastest just before plant demand is greatest.

For perennial plants, timing depends on the plant's growth cycle. Blueberries, for example, benefit most from fertilizer applied early in the season at bud break, while June-bearing strawberries are fertilized after harvest. Refer to other chapters in this manual and to other extension publications for information on timing fertilizer applications for specific crops.

Adding Organic Matter

Organic matter builds and stabilizes soil structure, thus reducing erosion and improving soil porosity, infiltration, and drainage. It holds water and nutrients for plants and soil organisms. It also is a long-term, slow-release storehouse of nitrogen, phosphorus, and sulfur, which continuously become available as soil microorganisms break down the organic matter.

The value of organic materials varies, depending on their nitrogen content (more specifically, their carbon to nitrogen, or C:N, ratio). Organic materials with a low C:N ratio, such as undiluted manure or blood meal, are rich in nitrogen. They are a good source of nutrients but must be used sparingly to avoid over-fertilization.

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, you can add them 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 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. If you use materials with a high C:N ratio in your garden, add extra nitrogen fertilizer to compensate for immobilization. The best use for these materials is for mulches around perennial crops or in walkways. They do not cause nitrogen immobilization until you mix them into the soil.

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. You can make compost at home or buy commercially prepared compost.

Making compost

The key to composting is to supply a balance of air, 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). You don't need additives to stimulate your compost pile. You just need to provide conditions favorable for natural composting organisms.

You can compost in the following ways:

- Hot (fast) composting produces high-quality, finished compost in six to eight weeks. To maintain a hot compost pile, mix together balanced volumes of energy materials and bulking agents, keep the pile moist, and turn it frequently to keep it aerated.
- Cold (slow) composting requires less work than hot composting. Build the pile and leave it until it decomposes. This process may take months or longer. Cold composting does not kill weed seeds or pathogens. Rats and other pests can be attracted to edible wastes in cold compost piles.
- You can compost fruit and vegetable scraps in a worm bin. This method works well for urban gardeners who have little space.
- You can bury fruit and vegetable scraps and allow them to decompose in the soil.

Commercial compost

Yard debris is the major raw material in most commercial compost sold in Kentucky. 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

Adding 1 to 2 inches of compost each year helps build a productive garden soil. You can till or dig compost directly into your garden or use it as a mulch before turning it into the soil. One cubic yard of compost covers about 300 square feet to 1 inch deep. In the first 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 (poor growth or yellow leaves), add extra nitrogen fertilizer (either organic or inorganic). In subsequent years, most compost contributes small amounts of available nitrogen to the soil.

It is important to know the source of composted materials derived from grass clippings or animal manure used as fertilizer amendments on your garden or landscape plants. Herbicide residues could be present that can cause injury to sensitive garden plants such as tomatoes and other broadleaf plants. Active ingredients in certain herbicide products applied to lawns can be retained in grass clippings, or animals consuming herbicide-treated pastures and hay can pass the material through the digestive system, so that the herbicide in the manure persists at concentrations that will cause injury to sensitive crops. Furthermore, the composting process may not fully degrade these herbicide compounds. To be safe, make sure that composted grass clippings and manure used on your garden or landscape areas have not been indirectly exposed to herbicides.

Green Manure (Cover Crops)

Green manures are cover crops grown specifically to be tilled or dug 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, however. They also can do the following:

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

Roots from cover crops, especially crops that produce taproots, can penetrate a moderately compacted zone and help distribute nutrients deeper into the soil profile.

No one cover crop provides all of these benefits. Deciding which cover crop or combination to grow depends on which benefits are most important to you and which cover crops best fit into your garden plan (Table 10). With the exception of buckwheat, all of the cover crops listed in Table 10 are suitable for fall planting and spring tillage.

Gardeners usually plant cover crops in the fall and till them into the soil before planting in the spring. The earlier cover crops are planted, the more benefits they provide.

Table 10. Examples of cover crops for Kentucky.

Cover Crop	Characteristics
Annual ryegrass	Hardy, tolerates wet soils, can be difficult to control if seeds
Austrian winter peas	Legume, does not compete well with winter weeds, must establish early fall
Buckwheat	Rapid germination and growth, frost sensitive, drought tolerant
Cereal rye	Hardy, rapid growth, matures rapidly in spring
Crimson clover	Legume, grows more slowly than vetch
Hairy vetch	Legume, slow initial growth, grows quickly in the spring, can be difficult to kill
Winter triticale	Produces more vegetation than cereal rye or winter wheat
Winter wheat	Most common cover crop, covers soil well, matures slowly
Turnip/Mustard greens	Grow well in fall, strong taproots to break compacted layers, edible

Note: All legumes fix nitrogen.

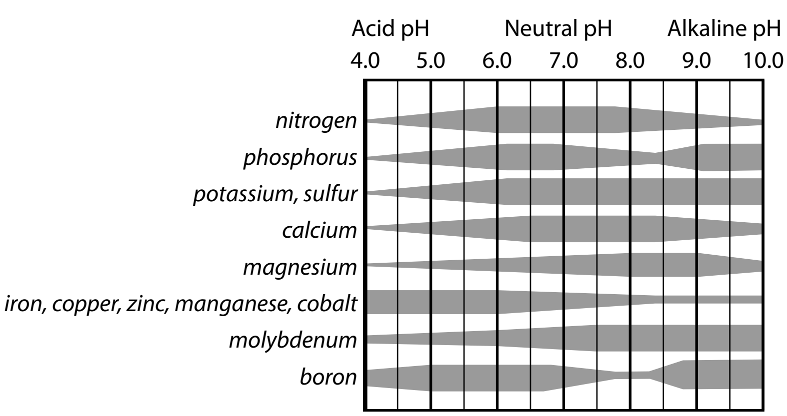
Legumes such as vetch and crimson clover need an early start to achieve enough growth to cover the soil before cold weather arrives.

If your garden contains crops into November or December, it will not be possible to plant early cover crops over the entire area. In this case, plant cover crops in areas you harvest early and use mulch in those you harvest 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 you remove the crop in November. You also can start cover crops between rows of late crops if space allows.

Till or dig cover crops into the soil before they flower. After flowering, plants become woody and decline in quality. Also, digging plants into the soil becomes quite difficult if they grow too large. If you cannot till a cover crop before it blooms, cut it off and compost it for later use. You will still get the short-term benefit of organic matter from the crowns and roots when you till your garden.

The organic matter benefits of cover crops last only about one year, so make cover crops an annual part of your garden rotation. If they do not fit into your garden plan, you can use winter mulches as a substitute.

Figure 8. Effect of soil pH on the availability of plant nutrients.



Soil pH

Soil pH measures 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 rainfall. Soils in arid areas tend to be alkaline, and those in rainy areas tend to be acid. Gardening and farming also affect soil pH; for example, many nitrogen fertilizers tend to reduce pH, while liming increases pH.

Soil pH influences plant growth in three ways, affecting the following:

- availability of plant nutrients (Figure 8)
- availability of toxic metals
- 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.

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, and what is present causes no problems for plants. As pH declines and aluminum availability increases, aluminum toxicity can become a problem.

Microbes also are affected by soil pH. 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.

Many garden crops perform best in soil with pH of 5.5 to 7.5, but some (such as blueberries and rhododendrons) 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

The most common way to increase soil pH is to add lime, which is ground limestone, a rock containing calcium carbonate. It is an organic (natural) amendment, suitable for use by organic gardeners.

Lime raises the pH of acid soils and supplies calcium, an essential nutrient. Dolomitic lime contains magnesium as well as calcium.

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.

Lime is a slow-release material. Apply it in the fall to benefit spring crops.

Wood ashes are a readily available source of potassium, calcium, and magnesium. Like lime, they also raise soil pH. High rates of wood ashes may cause short-term salt injury, so apply less than 15 to 25 pounds per 1,000 square feet. We do not recommend using wood ashes in alkaline soils.

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 structure only when poor structure results from excess sodium in the soil, a rare condition in Kentucky. Use organic amendments to improve soil structure, as described earlier under "Adding Organic Matter."

Some composts can increase soil pH, as can poultry litter, due to diet and amendments added to bedding material.

Decreasing Soil pH

You may need to decrease soil pH if you wish to grow acid-loving plants. Elemental sulfur lowers soil pH. Soil testing is the best way to determine whether sulfur is needed and, if so, how much. Refer to Table 11 to determine the amount of sulfur needed when lowering soil pH.

Table 11. Materials required to lower soil pH to specific levels. Use the following table for each 100 sq ft.[1] Multiply by 436 for lb/A.

	Add		
To Change pH from:	**Wettable Sulfur (lb)**	**or**	**Aluminum[3] Sulfate (lb)**
8.0 to 7.0	2		3.0
8.0 to 6.5	3		4.5
8.0 to 6.0	4		6.0[2]
8.0 to 5.5	5		7.5[2]
8.0 to 5.0	6		9.0[2]
7.5 to 7.0	1		1.5
7.5 to 6.5	2		3.0
7.5 to 6.0	3		4.5
7.5 to 5.5	4		6.0[2]
7.5 to 5.0	5		7.5[2]
7.5 to 4.5	6		9.0[2]
7.0 to 6.5	1		1.5
7.0 to 6.0	2		3.0
7.0 to 5.5	3		4.5
7.0 to 5.0	4		6.0[2]
7.0 to 4.5	5		7.5[2]
6.5 to 6.0	1		1.5
6.5 to 5.5	2		3.0
6.5 to 5.0	3		4.5
6.5 to 4.5	4		6.0[2]
6.0 to 5.5	1		1.5
6.0 to 5.0	2		3.0
6.0 to 4.5	3		4.5
5.5 to 5.0	1		1.5
5.5 to 4.5	2		3.0
5.0 to 4.5	1		1.5

[1] Aluminum sulfate is faster in reaction than sulfur. The two materials may be applied together (half of each). Incorporate into the top 6 inches of the soil.

[2] Rates higher than 4.5 lb. per 100 sq ft can cause excess soluble salt problems. Split the amount in half and apply in the spring and fall.

[3] Aluminum sulfate is much less effective in reducing pH than wettable sulfur but is quicker acting than flowers of sulfate and is usually available. More frequent applications may be necessary.

Prepared by Kathy Keeney, McCracken County extension agent for horticulture.

Ammonium sulfate fertilizer also lowers pH, but it takes longer than sulfur to have an effect. All nitrogen fertilizers that contain ammonium (NH_4^+) also reduces pH slowly, as do some organic fertilizers.

Soils and Fertilizer Terminology

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 (NO^{-3}), phosphate ($H_2PO_4^-$), and sulfate (SO_4^{2-}).

Aspect—Direction of exposure to sunlight.

Biosolids—A by-product of wastewater treatment sometimes used as a fertilizer.

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 (Ca^{++}) and potassium (K^+).

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

Clay—The smallest type of 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 are good bulking agents in compost piles, while those with a low C:N ratio are good energy sources.

Cold composting—A slow composting process of simply building a pile and leaving it until it decomposes. This process may take months 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—The product created by the breakdown of organic materials under conditions manipulated by humans.

Cover crop—A crop that is dug into the soil to return organic matter and nitrogen to the soil. Also called green manure. It is planted to reduce soil loss and capture nutrients not used during the growing season.

Decomposition—The breakdown of organic materials by microorganisms.

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

Fertilizer analysis—The amount of nitrogen, phosphorus (as P_2O_5), and potassium (as K_2O) in a fertilizer expressed as a percent of total fertilizer weight. Nitrogen (N) always is listed first, phosphorus (P) second, and potassium (K) third.

Green manure—Same as cover crop.

Hot composting—A fast composting process that produces finished compost in six to eight weeks. High temperatures are maintained by mixing balanced volumes of energy materials and bulking agents, keeping the pile moist, and turning it frequently to keep it aerated.

Humus—The stable end product of decomposed animal and plant remains of unrecognizable origin, their partial decomposition products, and waste for soil biomass. Same as soil organic 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 positive or negative charges.

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 control a soil's permeability and aeration and include earthworm and root channels.

Micronutrient—A nutrient used by plants in small amounts (iron, zinc, molybdenum, manganese, boron, copper, and chlorine). Also called a trace element.

Micropore—A fine 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 the plants' ability to take up nutrients from the soil, particularly phosphorus.

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. Can include plant, animal, and/or mineral materials.

Organic materials—Recognizable materials originating from living organisms, the precursors to soil organic matter.

Organic matter—Plant remains of unrecognizable origin, their partial decomposition products, and waste for soil biomass. See *Humus*.

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 acidity or alkalinity. Values from 0 to 7 indicate acidity, a value of 7 is neutral, and values from 7 to 14 indicate alkalinity. Most soils have a pH between 4.5 and 9.

Phosphate—The form of phosphorus listed in most fertilizer analyses (P_20_5).

Potash—The form of potassium listed in most fertilizer analyses (K_20).

Primary nutrient—A nutrient required by plants in a relatively large amount (nitrogen, phosphorus, and potassium). See Macronutrient.

Processed fertilizer—A fertilizer that is manufactured or is refined from natural ingredients to be more concentrated and 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 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 type of soil particle that is intermediate in size between sand and clay (0.002 to 0.05 mm in diameter).

Slow-release fertilizer—A fertilizer material that must be 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—A measure of the total soluble salts in a soil.

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.

Soluble salt—A compound often remaining in soil from irrigation water, fertilizer, compost, or manure applications.

Water-holding capacity—The ability of a soil's micropores to hold water for plant use.

For More Information

For more information, contact your county extension agent. You may also refer to the following publications:

ID-128 *Home Vegetable Gardening* (http://www.ca.uky.edu/agc/pubs/id/id128/id128.pdf)

Bohn, H.L., B.L. McNeal, and G.A. O'Connor. *Soil Chemistry, 3rd edition (John Wiley & Sons, New York, 2001).*

Brady, N.C., and R.R. Weil. *The Nature and Properties of Soils, 14th edition* (Prentice-Hall., New York, 2007).

Craul, P.J. *Urban Soil in Landscape Design* (John Wiley & Sons, New York, 1992).

Donahue, R.L., R.W. Miller, and J.C. Shickluna. *Soils: An Introduction to Soils and Plant Growth* (Prentice-Hall, Inc., Englewood Cliffs, NJ, 1990).

Kentucky Cooperative Extension Service. *Home Composting: A Guide to Managing Home Yard Waste* (HO-75). http://www.ca.uky.edu/agc/pubs/ho/ho75/ho75.pdf.

Kentucky Cooperative Extension Service. *Winter Cover Crops for Kentucky Gardens and Fields* (ID-113). http://www.ca.uky.edu/agc/pubs/id/id113/id113.htm

Kentucky Cooperative Extension Service. Organic Manures and Fertilizers for Vegetable Crop http://www.uky.edu/Ag/Horticulture/manures.htms.

Tisdale, S.L., and W.L. Nelson. *Soil Fertility and Fertilizers (Macmillan Publishing Co., Inc., New York, 1985).*

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