Plant Nutrition and Fertilizers

Robert Flynn, Associate Professor, Extension Agronomy and Soils

Many people confuse plant nutrition with plant fertilization. Plant nutrition refers to the chemical elements taken in by plants that are essential to their growth and development. Fertilization is the term used when these elements are supplied to the environment around the plants. Chemical change may occur before a plant nutrient supplied in a fertilizer can be taken up and used by the plants.

Plants need 16 elements for normal growth. Carbon, hydrogen, and oxygen are found in air and water. Nitrogen, phosphorus, potassium, magnesium, calcium, and sulfur are found in soil. These six elements are used in relatively large amounts by plants and are called macronutrients. These are further divided into primary (nitrogen, phosphorus, and potassium) and secondary nutrients. There are seven other elements known as micronutrients or trace elements that are used by plants in much smaller amounts but are still essential to their growth and development. These essential micronutrients are found in soil and include boron, chlorine, copper, iron, manganese, molybdenum, and zinc. All 16 elements, both macronutrients and micronutrients, are essential for plant growth. Other elements also associated with plant growth include cobalt, selenium, and silica.

Use of the Periodic Table of Elements

The elements required by plants are part of a table known as the "Periodic Table of Elements." Each plant nutrient element has a unique abbreviation. These abbreviations are put together in shorthand to describe fertilizers, such as ammonium sulfate, calcium nitrate, potassium chloride; and nonfertilizers, such as sodium chloride. Numbers that follow the element's abbreviation as a subscript refer to the number of that element in the molecule. Nitrate, for example, is abbreviated NO_3. There are three oxygen atoms that surround one nitrogen atom. The most common elements used in biology and their abbreviations are given below.

Boron (B)	Iron (Fe)	Potassium (K)
Calcium (Ca)	Magnesium (Mg)	Sulfur (S)
Carbon (C)	Manganese (Mn)	Zinc (Zn)
Chloride (Cl)	Nitrogen (N)	
Copper (Cu)	Oxygen (O)	
Hydrogen (H)	Phosphorus (P)	

Nutrient Absorption

Factors that affect nutrient absorption are type of ion, soil pH, solubility of ion pairs, water, soil oxygen, plant sugar supply, plant stress, temperature, and soil nutrient levels.

Most of the nutrients that a plant needs are dissolved in water and then absorbed by the roots. Ninety-eight percent of these plant nutrients are absorbed from the soil solution, and only about 2 percent are actually extracted from soil particles by the roots. Most nutrient elements are absorbed as charged particles (ions). Ions may be positively charged (cations) or negatively charged (anions). Positive and negative charges are equally paired so that there is no overall charge. For example, nitrogen may be absorbed as nitrate NO_3^-, which is an anion with one negative charge. The potassium ion (K^+) is a cation with one positive charge. Potassium nitrate (KNO_3) has one nitrate ion and one potassium ion and has a net charge of zero since 0 = +1 - 1. Calcium nitrate ($Ca(NO_3)_2$) has two negatively charged nitrate ions to balance the two positive charges associated with the calcium cation, which makes a total of no net charge. When two ions combine to make no net charge the result is usually a solid.

The balance of ions in the soil is very important. Just as ions of opposite charge attract each other, ions of similar charge compete for chemical interactions and reactions in the environment. Some ions are more active than others and compete better. For example, both calcium (Ca^{++}) and magnesium (Mg^{++}) are cations with two charges. Magnesium has a smaller size which tends to make it more active and compete more effectively for negative charges. If calcium and magnesium are in competition to be absorbed, the magnesium most likely will be absorbed. Although a soil test may indicate that there is sufficient calcium in the soil, the plant may still exhibit a calcium deficiency because of an excess of the more active magnesium. Therefore, what may be expressed as a deficiency of one micronutrient actually may be caused by an excess of another.

Ion size also can make a difference in what is absorbed by plants, even if the ions are of opposite charge. Phosphorus, for example, exists in the soil environment as a negatively charged orthophosphate ion (HPO_4^-) which has the same size as the positively charged zinc ion (Zn^{++}). If there is an excess of orthophosphate in the soil, a zinc deficiency can result because of the competition between these two elements.

For ions to be easily absorbed, they must first be dissolved in the soil solution. Some combinations of ions are dissolved easily, such as potassium nitrate. When other ions combine, they may precipitate or fall out of solution and thus become unavailable to the plant. Many of the micronutrients form complex combinations with phosphorus and calcium and precipitate out of the soil solution, so the nutrients cannot be taken up by the plant. Soil pH greatly affects these chemical reactions. If soil pH is extremely high (alkaline), many of the micronutrients precipitate out of solution and are unavailable to the plant. When soil pH is extremely low (acidic), some of the micronutrients become very soluble and ion levels may become high enough to injure the plant. The effect of pH varies with the ion, the types of ions in the soil, and the soil type. Therefore, not only is the amount of the nutrient important but also the soil pH.

Water and oxygen also must be available in the soil. Since nutrients are taken up with water, there must be sufficient water for the plant to absorb. Water is taken into the plant both passively and actively. Water that is taken in passively requires no energy output by the plant. It flows through the plant due to differences in concentration between the soil solution and the liquid within the cell. Water that is absorbed actively requires energy from the plant. If there is no oxygen available, sugar cannot be burned (oxidized) to produce energy and, therefore, water and nutrients cannot be absorbed.

Anything that lowers or prevents the production of sugars in the leaves can lower nutrient absorption. If the plant is under stress due to low light or extremes in temperature, nutrient deficiency problems may develop. The growth stage or level of plant activity also may affect the amount of nutrients absorbed. Many perennial plants go into a rest or dormancy during part of the year. During this rest period, very few nutrients are absorbed. Plants also may absorb different amounts of nutrients at different stages of growth, such as when flower buds begin to develop.

Nutrients transported from the root to the cell by the vascular system move into the cell across a cell membrane. There are three different ways for this to happen. First, an entire molecule or ion pair may move through the membrane. If the cell is using energy to absorb the ions, then only one of the ions of the pair is pulled into the cell and is referred to as active transport. The other will follow to keep the number of positive and negative charges even. Most anions (negative charge) are absorbed actively.

The second way to keep the charges inside the cell balanced when absorbing a new ion is to exchange one charged ion for another of the same charge. The hydrogen ion (H^+) is often released from the cell so that the cell can absorb another positive ion, such as the potassium ion (K^+). Since this is a simple exchange or passive, absorption energy may not be required. Cations or positive ions may be absorbed passively by this method.

Both of the methods mentioned above may be passive or active. However, the third method, the carrier system, always is active absorption and requires energy. Scientists have discovered that within the cell membrane there are specialized chemicals that act as carriers. The carrier, through chemical changes, attracts an ion outside the cell membrane and releases it inside the cell. Once the ion is inside the cell, it is attached to other ions so that it does not move out of the cell. Complex chemical reactions are involved in the entire process. Although nutrients can be absorbed passively, research has shown that active absorption must take place if the plant is to grow and be healthy. Factors discussed earlier about absorption by the root also are true for absorption by the cell.

Foliar Absorption

Under normal growing conditions, plants absorb most nutrients from the soil, with the exception of carbon, hydrogen, and oxygen. Some nutrients also can be absorbed by the leaves, if a dilute solution is sprayed on the leaves. Factors affecting absorption are important, because the nutrient must enter the cell to be used by the plant. Care must be taken that the nutrient concentration is not too high or the leaf will be injured.

Also, the leaf is covered by a thin layer of wax called the cuticle. The nutrient must pass around or through the cuticle before it can enter the cell.

Fertilizers

Fertilizers are materials containing plant nutrients that are added to the environment around the plant. Generally, they are added to water or soil, but some also can be added to the air or sprayed on leaves. Fertilizers are not plant food! Although it is common for many fertilizers to be called plant food, this is a misnomer. Plants produce their own food using water, carbon dioxide, and energy from the sun. This food (sugars and carbohydrates) is combined with plant nutrients to produce proteins, enzymes, vitamins, and other elements essential to plant growth.

Fertilizer Macronutrients

Nitrogen (N)

Nitrogen is absorbed as NO_3^- or NH_4^+ from soil or foliage. Atmospheric nitrogen N_2 is fixed by legumes through a symbiotic relationship with bacteria. Nitrogen is mobile in plants, which results in yellow lower leaves if there is a deficiency. Nitrates NO_3^- can leach easily from soil if irrigation water or rain is in excess of plant needs. Too much nitrogen in a plant results in succulent growth, very dark green color, weak spindly growth, and not much fruit. It also may cause brittle growth, especially under high temperatures. Nitrogen deficiency symptoms include reduced growth, yellowing of leaves (chlorosis), and reduced lateral breaks. Reds and purples also may intensify with some plants. Deficiency symptoms appear first in old growth.

Corrective action for nitrogen deficiency includes fertilizing with a nitrate-based fertilizer. Soil test levels of nitrate should remain near 30 ppm during the active growing season.

Phosphorus (P)

Phosphorus is absorbed as the $H_2PO_4^-$ or $HPO_4^=$ ion. This complex does not leach readily from the soil and is mobile once in the plant. However, phosphorus may leach from soil that is high in bark or peat. Phosphorus is rapidly “fixed” with iron, magnesium, and aluminum on soil particles, when applied under acidic soil conditions. Under alkaline conditions, phosphorus is fixed with Ca and is unavailable to plants.

Plants actually use relatively small amounts of P when compared to N and K. Excess phosphorus can induce nitrogen and micronutrient deficiencies of Zn, Fe, or cobalt. Phosphorus is especially important for young plants and seedling growth. Phosphorus deficiency in plants generally is expressed in reduced growth, intense coloring, browning or purpling of foliage in some plants, thin stems, reduced lateral breaks, loss of lower leaves, and reduced flowering.

Potassium (K)

Potassium is absorbed as the ion K^+. Potassium is responsible for regulating the opening and closing of stomata by guard cells in the leaf. Potassium also is essential for translocating sugars and forming starch. Potassium encourages root growth and increases crop resistance to disease. Excess rain or irrigation can cause potassium to leach through the soil. Potassium is mobile once in the plant, meaning that deficiency symptoms will express in the old growth. Excess potassium can causes N deficiency in plants and may affect the uptake of other positive ions. Potassium deficiency results in reduced growth, short internodes, burned or scorched leaf margins, necrotic (dead) spots in the leaf, reduced lateral breaks, and a tendency to wilt readily.

Magnesium (Mg)

Magnesium is absorbed as the Mg^{++} ion and is used in the chlorophyll molecule which is essential to photosynthesis. Magnesium also serves as an enzyme activator for many plant growth processes. Magnesium can leach from soil with excess water but also is mobile in the plant. Excess magnesium interferes with Ca uptake. Excessive potassium may require the addition of magnesium to balance these nutrients for optimum uptake. Magnesium deficiency can cause reduced growth, marginal chlorosis, interveinal chlorosis (yellow between the veins), reduced seed production, and cupped leaves.

Epsom salts contain magnesium and can be applied at a rate of 1 teaspoon per gallon per 100 square feet as much as twice per year. Foliar applications also can be made if sprayed in a weak solution. Acidic soils are often amended with dolomitic limestone to supply magnesium to deficient soils.

Calcium (Ca)

Calcium is absorbed as the Ca^{++} ion. Calcium is an essential part of cell wall structure and must be present for new cells to form. Calcium is moderately leachable in soil but is usually present in sufficient amounts as not to warrant application. Calcium generally is considered nonmobile in the plant, which results in new growth expressing deficiency symptoms. Deficiency symptoms include death of growing points (including roots), abnormal dark green foliage, premature shedding of blossoms and buds, weakened stems, and fruit disorders (blossom end rot, bitter pit of apple). Water stress, too much or too little, can affect Ca relations within the plant, causing deficiency in the location where Ca was needed at the time of stress. High levels of Ca in the soil usually implies high pH, which causes many of the micronutrients to precipitate and become unavailable to the plant.

Sulfur (S)

Sulfur is absorbed as the $S0_4^{=}$ ion. Sulfur is a constituent of three amino acids, which are building blocks for essential proteins in the plant. Sulfur is essential for nodule formation on legume roots. Sulfur is not mobile in the plant. Deficiency symptoms include a light green to yellowish color of young leaves, small and spindly plants, retarded growth rate, and delayed maturity. Sulfur can be leached from soil with excess rain and irrigation. Sulfur also can be absorbed by the leaves. Industrial pollutants can provide some of the sulfur needs of plants. Many synthetic fertilizers also have sulfur present in the formulation or as contaminants in the process.

Micronutrients

The majority of micronutrients are not mobile in the plant, which results in deficiency symptoms associated with new growth. Their availability in the soil is highly dependent upon pH and the presence of other ions. The proper balance between the ions present is important, since many micronutrients are antagonistic to each other. This is especially true of the heavy metals—an excess of one element may show up as a deficiency of another. If pH is maintained at the proper level and a fertilizer containing micronutrients is used once a year, deficiency symptoms are rarely associated with indoor plants, with the exception of iron. Most micronutrients are enzyme activators, which control the formation of specific proteins and other compounds that control plant growth.

Iron (Fe)

Iron is absorbed as either the Fe^{++} or Fe^{+++} ion. Iron is required for chlorophyll formation and other biochemical processes. Excess manganese and high lime levels in the soil can cause iron deficiency. Interveinal chlorosis primarily on young tissue, which may develop to white and dead tissue, is the most common deficiency symptom. Poorly drained soils that are oxygen deficient often show signs of iron deficiency. Iron should be added to a soil in a chelated form. The type of chelate needed depends on the soil pH. Soils with a pH of less than 7.2 can benefit from an EDTA (ethylenediaminetetraacetic acid) chelate, while soils above 7.2 should be amended with FeDTPA (diethylenetriaminepentaacetic acid) or FeEDDHA (ethylenediaminedi(o-hydroxy-phenylacetic acid). Foliar treatments can be made as well. Iron toxicities usually only occur on flooded soils.

Boron (B)

Boron is absorbed as soluble boric acid H_3BO_3 in soil with pH below 9.0. Without boron, plant cells may continue to divide, but they will not know what they are suppose to be (leaf, stem, flower). Boron also regulates carbohydrate metabolism. Deficiencies include failure to set seed; soft or necrotic spots in fruit or tubers; thickened, curled, wilted, and chlorotic leaves; internal breakdown; apical bud death; and death of terminal growth causing lateral buds to develop for a "witches' broom" effect. Excess boron causes blackening or death of tissue between veins.

Zinc (Zn)

Zinc is absorbed as the Zn^{++} ion. Zinc deficiency includes "little leaf" (a reduction in size of leaves), short internodes, distorted or puckered leaf margins, and interveinal chlorosis of new growth. Excessive zinc can appear as Fe deficiency. Zinc also can interfere with Mg uptake by the plant. Excessive phosphorus also can induce zinc deficiency.

Copper (Cu)

Copper is absorbed as the Cu^{+} or Cu^{++} ion. Copper rarely is deficient in soils, but symptoms may include wilting of the plant even with adequate soil moisture, and small, misshapen, or wilted new growth. Deficiencies can be found in some peat soils. Soil testing is the best way to ascertain the potential for a deficiency. Excess copper can occur at low pH and shows up as Fe deficiency.

Manganese (Mn)

Manganese is absorbed as the Mn^{++} ion. Manganese deficiency is expressed as interveinal chlorosis of leaves followed by brown spots producing a checkered effect. There lacks a sharp distinction between green veins and yellow interveinal areas as seen with iron deficiency. Excess manganese can reduce plant growth, cause brown spotting on leaves, and can show up as Fe deficiency. Excess iron can induce manganese deficiency.

Molybdenum (Mo)

Molybdenum is absorbed as MoO_4. Molybdenum is required for nitrogen use. Plants cannot transform nitrate nitrogen into amino acids without molybdenum. Molybdenum deficiency occurs as interveinal chlorosis on older or midstem leaves, and twisted leaves (whiptail) on acid soils. There can be marginal scorching, but it often is similar to nitrogen deficiency due to their relationship.

Chlorine (Cl)

Chlorine is absorbed as the chloride (Cl^-) ion. Choride is required for photosynthesis reactions in the plant. Deficiency symptoms include wilted leaves, which become chlorotic; excessive branching of lateral roots; leaf bronzing; chlorosis and necrosis in tomatoes and barley; and leaf spot lesion in wheat. Chloride toxicity is much more of a problem in western areas with overhead irrigation. Excess chloride causes leaf burn and may increase succulence in some plants. Many fertilizers contain chloride, especially potash fertilizers.

Cobalt (Co)

Cobalt is absorbed as the Co^{++} ion. This element only recently has been established as essential for nitrogen fixation in legumes. Little is known about deficiency or toxicity symptoms.

Types of Fertilizers

Based on their primary nutrient content (N, P, K), fertilizers are designated as single nutrient or multinutrient. Single nutrient fertilizers also are referred to as simple fertilizers or materials for building multinutrient fertilizers. Multinutrient fertilizers are referred to as mixed or complex fertilizers.

All fertilizers sold as plant nutrients have three numbers fixed to their bag which represent their grade. The first number is the percent by weight nitrogen, the second is percent by weight phosphorus expressed as P_2O_5, and the third is percent by weight potassium expressed as K_2O. If other nutrients are guaranteed to be in the fertilizer, then the three primary numbers are followed with the percent by weight of the element with its abbreviation. For example, if we have a 100-pound bag of fertilizer labeled 10-10-10, there are 10 pounds of N, 10 pounds of P_2O_5 and 10 pounds of K_2O. If it were 10-10-10-3 Fe, the fertilizer includes 3 percent water soluble iron by weight. Keep in mind that P and K are reported as their oxide form. This is an old method from days when fertilizers were burned and analyzed for their oxide content. To convert the P_2O_5 to actual phosphorus, multiply it by 0.43; to convert K_2O to actual potassium, multiply it by 0.83.

In a 100-pound bag of 10-10-10 fertilizer, there are 30 pounds of fertilizer and 70 pounds of filler or carrier. Filler or carrier helps to evenly spread the fertilizer and avoids burning plants with too much fertilizer. A 100-pound bag of fertilizer labeled 0-20-10 would have 0 pounds of N, 20 pounds of P_2O_5, 10 pounds of K_2O, and 70 pounds of filler or carrier.

A number of states have adopted a model label law for classifying fertilizers. The law establishes minimum allowable levels of nutrients and provides specific labeling requirements. To date, model label legislation has not met with total acceptance, so there still are differences from state to state regarding what constitutes a fertilizer and the type of information required on labels. Even so, the information contained on fertilizer labels has been well-standardized, and the consumer is protected by state laws requiring manufacturers to guarantee the claimed nutrients.

The law only requires that the manufacturer guarantee what is claimed on the label. So in some cases, a fertil-

Table 1. Common incomplete fertilizers or farm-type fertilizers.

	% Nitrogen	% Phosphorus	% Potassium
	N	R_2O_5	K_2O
Ammonium nitrate	33	0	0
Ammonium sulfate	21	0	0
Mono-ammonium phosp	11	52	0
Muriate of potash (potassium chloride)	0	0	60
Potassium sulfate	0	0	52
Super phosphate	0	20	0
Triple super phosphate	0	46	0
Urea	42-45	0	0
Diamonium phosphate	18	46	0
Slow Release			
Urea-formaldehyde	38	0	0
Sulfur-coated urea	22-17	0	0
IIBDU	31	0	0

izer will contain secondary nutrients or micronutrients not listed on the label, because the manufacturer does not want to guarantee their exact amounts. The gardener/consumer can rest assured that nutrients listed on the label actually are contained in the fertilizer.

The best fertilizer grade to use depends on many factors, such as what nutrients are needed, what the soil structure and chemistry are, and the method of applying the fertilizer.

Complete Versus Incomplete Fertilizers

A fertilizer is said to be complete when it contains nitrogen, phosphorus, and potassium. The manufacturers of commercial fertilizers are required to state nutrient amounts on the container as a guaranteed analysis. Examples of complete fertilizers are 10-10-10, 15-5-10, 20-10-5. An incomplete fertilizer will be missing one of the major components (table 1).

A complete fertilizer can be made from a blend of incomplete fertilizers. If 100 pounds of urea (45-0-0) were combined with 100 pounds of triple super phosphate (0-45-0), and 100 pounds of muriate of potash (0-0-60), a fertilizer grade of 15-15-20 would result.

Urea, a nitrogen source, has 45 lb of nitrogen per 100 pounds of urea. Triple super phosphate has 45 pounds of phosphorus, and muriate of potash has 60 pounds of potash. When these three quantities are combined, each quantity is diluted by the other two by one-third, provided each bag has equal weight.

The fertilizer ratio indicates the proportion of nitrogen, phosphate, and potash contained in the fertilizer. The specific fertilizer ratio needed depends on the soil nutrient level. For example, a 1-1-1 ratio (10-10-10, 15-15-15, 20-20-20) is widely used to establish lawns. But established lawns generally respond better to fertilizer ratios high in nitrogen. Three of the most common complete fertilizers used by homeowners are 10-10-10, 19-5-9 and 15-5-10.

Special-Purpose Fertilizers

When shopping for fertilizer, you will find that some are packaged for certain uses or types of plants, such as camellia food, rhododendron and azalea food, or rose food. The camellia and rhododendron, or azalea fertilizers are well known acidic plant foods. Some of the compounds used in these fertilizers are chosen, because they have an acid reaction. They are especially beneficial to acid-loving plants in soil that is naturally neutral or slightly alkaline. This does not mean that azaleas, blueberries, or other acid-loving plants will grow on an alkaline soil. More often than not these types of plants will die if placed in many of New Mexico's soils. Acid-loving plants should remain potted. The effectiveness of other fertilizers packaged for certain plants has not been established. Compare, for example, the fertilizer ratios of three different brands of rose food on any garden center shelf.

Other special-purpose fertilizers, which continue to be marketed extensively, claim to promote increased blooming of vegetable and ornamental plants. These fertilizers contain high amounts of phosphorous. Although phosphorous is a macronutrient and needed by the plant for proper blooming and root growth, the addition of high doses of phosphorous does not guarantee increased blooming. Most New Mexico soils have phosphorous in them, and occasional additions of a complete lawn or garden fertilizer generally is adequate.

A soil test should be performed before purchasing any expensive, special-purpose fertilizer. There is no one fertilizer that is best for every area of the state. While different plants use different nutrients at different rates, nutrient reserves already in the soil is unknown. This changes with every soil type and every location.

Slow-Release Fertilizers

Since plants can take up fertilizers continuously, it is beneficial to provide them with a balance of nutrients throughout their growth period. Perhaps the most efficient way to achieve this is to apply a slow-release fertilizer, which is designed to release nutrients at the same rate they are taken up by the plants. Slow-release fertilizers contain one or more essential elements. These elements are released or made available to the plant over an extended time.

Slow-release fertilizers can be categorized by the way in which they are released. The three major nutrient release types include: materials that dissolve slowly, materials from which the nitrogen is released by microorganisms, and granular materials with membranes made of resin or sulfur that control the rate of nutrient release into the soil. These nutrient release systems may be used in combination with one another.

Sulfur-coated urea is a slow-release fertilizer with a covering of sulfur around each urea particle. Different thicknesses of sulfur control the nitrogen release rate, which becomes more rapid as temperature increases. Watering does not affect its release rate. When applied to the soil surface, sulfur-coated urea releases more slowly than if it is incorporated into the soil. This material generally costs less than other slow-release fertilizers and it supplies the essential element sulfur as well as nitrogen.

When fertilizer products coated with multiple layers of resin come into contact with water, the layers swell and increase the pore size in the resin so that the dissolved fertilizer can move into the soil. Release rate depends on coating thickness, temperature, and soil water content. There is often a large release of fertilizer during the first 2 or 3 days after application. Depending on the coating, release timing can extend up to 12 months.

Slow-release fertilizers need not be applied as frequently as other fertilizers, and higher amounts can be applied without danger of burning. Plants may use the nitrogen in slow-release fertilizers more efficiently than in other forms, since it is released continually over a longer period of time. Slow-release fertilizers generally are more expensive than other types. The real benefit, however, is the frequency of application, which is much lower than with conventional fertilizers.

Urea formaldehyde and sulfur-coated urea have been used as turf fertilizer, while resin-coated fertilizers predominantly are used in container media.

Caution should be used in applying slow-release fertilizers around trees or shrubs in the summer as they may keep the plant in growth late in summer. Late season growth may not harden off completely and excessive winter damage may occur. Table 2 compares slow-release fertilizers and conventional fertilizers.

Sometimes there are initials or designations (W.I.N. and W.S.N.) on fertilizer labels. These stand for water insoluble nitrogen and water soluble nitrogen, respectively. Water soluble nitrogen dissolves readily and is usually in a very simple form, such as ammoniacal nitrogen (ammonia) or nitrate nitrogen. Nitrogen that will not dissolve readily may exist in other forms in the fertilizer. These usually are organic forms of nitrogen (with the exception of urea) that must be broken down into simpler forms before it can be used. Water insoluble nitrogen is referred to as a slow-release nitrogen source and delivers nitrogen at different rates, according to the amount and kind of material in the composition. Also, if a fertilizer includes iron, look for water soluble iron and not total iron. Total iron may include certain metals that will never go into soil solution and thus not be a plant nutrient.

Organic Fertilizers

The word "organic" used with fertilizers simply means that the nutrients contained in the product are derived solely from the remains (or a by-product) of

Table 2. Advantages and disadvantages of slow-release, conventional, and organic fertilizers.

	Advantages	Disadvantages
Slow-Release Fertilizer	• Fewer applications • Low burn potential • Release rates vary depending on fertilizer characteristics • Comparatively slow release rate	• Unit cost is high • Availability limited • Release rate governed by factors other than plant need
Conventional Fertilizer	• Fast-acting • Some are acid-forming • Low cost	• Greater bum potential • Solidifies in the bag when wet • Nitrogen leaches readily
Manures or Sewage Sludge	• Low burn potential • Relatively slow release • Contains micronutrients • Conditions soil	• Salt may be a problem • Bulky; difficult to handle • Odor • Expensive per pound of active nutrient • Weed seeds a problem • Heavy metals may be present in sewage sludge (frequent in sludge from large cities)

a once-living organism. Urea is a synthetic, organic fertilizer, an organic substance manufactured from inorganic materials. Cottonseed meal, blood meal, bonemeal, hoof and horn meal, and all manures are examples of organic fertilizers. Most of these products packaged as fertilizers will have the fertilizer ratios stated on the package labels.

Some organic materials, particularly composted manures and sludge, are sold as soil conditioners and do not have a nutrient guarantee even though small amounts of nutrients are present. Most are high in one of the three major nutrients and low or zero in the other two, although some may be fortified with nitrogen, phosphorus, or potash for a higher analysis. Many are low in all three. In general, organic fertilizers release nutrients over a fairly long period. The potential drawback is that they may not release enough of their principal nutrient at the proper time to give the plant what it needs for optimum growth. Because organic fertilizers depend on soil organisms to break them down and release nutrients, most of them are effective only when the soil is moist and soil temperature is warm enough for the soil organisms to be active.

Cottonseed meal is a by-product of cotton manufacturing. As a fertilizer, it is somewhat acidic. Formulas vary slightly, but they generally contain 7 percent nitrogen, 3 percent phosphorus, and 2 percent potash. Cottonseed meal is available more readily to plants in warm soils, and there is little danger of burn. For general garden use, apply 2 to 5 pounds per 1,000 square feet. Cottonseed meal frequently is used to fertilize acid-loving plants, such as azaleas, camellias, and rhododendrons. Keep in mind that these acid-loving plants also should be planted in acid soils.

Blood meal is dried, powdered blood collected from cattle slaughterhouses. It is a rich source of nitrogen. So rich, in fact, that it may do harm if used in excess. The gardener must be careful not to exceed the recommended amount suggested on the label. In addition to nitrogen, blood meal supplies some essential trace elements including iron.

Fish emulsion, a well-rounded fertilizer, is a partially decomposed blend of finely pulverized fish. No matter how little is used, the odor is intense. But it dissipates within a day or two. Fish emulsion is high in nitrogen and is a source of several trace elements. In late spring, when garden plants have sprouted, an application of fish emulsion followed by deep watering will boost the plant's early growth spurt. Contrary to popular belief, too strong a solution of fish emulsion can burn plants, particularly in containers.

Manure is a complete fertilizer, but it is low in the amounts of nutrients it can supply. Manures vary in nutrient content according to the animal source and what the animal has been eating. However, a fertil-

Table 3. Nutrient content of selected organic sources and their suggested application rates.

Type of Manure or Fertilizer	N%	P%	K%	Suggested Rates per 1,000 sq. ft. of Bed Area*
Chicken manure, dry	2.0-4.5	4.6-6.0	1.2-2.4	125
Steer manure, dry	1.0-2.5	0.9-1.6	2.4-3.6	450
Dairy manure, dry	0.6-2.1	0.7-1.1	2.4-3.6	600

*Cut rates by 50 percent if soils are saline or water has medium to high salinity hazard.

izer ratio of 1-1-1 is typical. Manures are best used as soil conditioners instead of nutrient suppliers. Commonly available manures include horse, cow, pig, chicken and sheep. The actual nutrient content varies widely; the highest concentration of nutrients is found when manures are fresh. As it is aged, leached, or composted, nutrient content is reduced.

Even though fresh manures have the highest amount of nutrients, most gardeners use composted forms of manure to ensure a smaller amount of salts, thereby reducing the chance of burning plants. Fresh manure should not be used when it will contact tender plant roots. Typical rates of manure applications vary from a moderate 70 pounds per 1,000 square feet to as much as 1 ton per 1,000 square feet.

Sewage sludge is a recycled product of municipal sewage treatment plants. Two forms are commonly available: activated and composted. Activated sludge has higher concentrations of nutrients (approximately 6-3-0) than composted sludge and is usually sold in a dry, granular form for use as a general purpose, long-lasting, nonburning fertilizer. Composted sludge primarily is used as a soil amendment and has a lower nutrient content (approximately 1-2-0). There is some question about the long-term effect of using sewage sludge products in the garden, particularly around edible crops. Heavy metals, such as cadmium, are sometimes present in the sludge and may build up in the soil. Possible negative effects vary according to the sludge's origin and the characteristics of the soil. If cadmium, lead, arsenic, or other heavy metals may be suspected in the sludge then an analysis should be done on both the soil and the sludge for these elements.

Table 3 shows the approximate nutrient content of manures and suggested yearly rates of application per 1,000 square feet of garden area. Rates given are for materials used singly; if combinations of two or more materials are used, the rate should be reduced accordingly.

Table 4 provides a more exhaustive list of organic fertilizers and their analyses. Compared to synthetic fertilizer formulations, organic fertilizers contain relatively low concentrations of actual nutrients. But they perform other important functions that the synthetic formulations do not. These functions include increasing the soil's organic content, improving physical structure of the soil, and increasing bacterial and fungal activity, particularly the mycorrhiza fungus, which alone makes other nutrients more available to plants.

Lawn Fertilizers Combined with Herbicides

The major reason for buying a lawn fertilizer combined with an herbicide is convenience. It is very convenient to combine everything you need in one application, but it also can be ineffective or even harmful to the trees and shrubs in the lawn area. Sometimes, a fertilizer-herbicide combination may actually fertilize the weeds targeted for control. Perhaps an even greater concern with "weed and feed" fertilizers is that the herbicide used may actually be taken up by the trees and shrubs in the lawn area. The result can be a severely damaged or dead tree or shrub hedge.

Applying Fertilizer

Computing the amount of fertilizer needed for a given area is rather tricky at first, but it becomes easier with time. Examples 1 and 2 show fertilizer determinations for lawns and gardens.

Table 4. Total N, P, and K content of selected amendments with comments regarding their suitability for gardening purposes.

Category	Amendment Name	% N	% P	% K	Remarks
Misc.	Alfalfa meal	3	2	2	
	Blood meal	13	-	-	Accelerates compost heap. Good for corn.
	Bone meal	1	13	0	Very slow-release phosphorus.
	Bone meal, steamed				
	Corn gluten	10	0	0	Good N source, but do not apply at planting.
	Cotton seed meal	6	1	1	Best N source next to blood meal. Acidifies.
	Compost, mushroom	1	1	1	Decomposes quickly but can be saline.
	Compost, yard trimmings	1	0.5	1	6-month longevity.
	Crab meal	5	2	0.5	Enhances composting process.
	Grass clippings	3	0.3	2	Decomposes quickly.
	Kelp or seaweed meal	-	-	-	Source of micronutrients and potassium.
	Leaf mold	0.9	-	-	6-month longevity.
	Newsprint	0.1	-	-	Best when shredded.
	Rice hulls	0.3	-	-	Increases porosity. 10-year soil life.
	Rock phosphate	0	3	0	Very low available phosphorus.
	Sawdust, pine	0.17	0.02	0.04	High N requirement for soil/compost.
	Wood ash	0.04	0.34	2.42	Avoid on high pH soils.
	Wood bark	0.2	-	-	Fir bark reportedly good for turf.
	Yuccah	-	-	-	A microbial activator that supposedly decomposes quickly.
Manures					
	Cattle, feedlot steer	2.4	0.5	1.5	
	Chicken, laying	3.7	2.7	3.1	High ammonia content. Avoid at planting.
	Dairy, stockpiled	1.4	0.4	1.5	
	Horse	3.1	0.8	1.1	
	Sheep	2.7	0.3	1.2	
	Swine	3.1	1.6	2.2	
	Peats				General term. Hydrophobic when dry.
	Moss	-	-	-	Surface of bog.
	Moss peat (peat moss)	-	-	-	Layer under moss from bog.
	Sphagnum peat/ green sand	-	-	-	Fe-K silicate (glauconite). Holds water.
	Sedge peat	-	-	-	More fibrous than sphagnum peat.
	Hypnum peat	-	-	-	Muck. Not used in horticulture.
Sludges					
	Biosolids, activated	3.8	1.7	0.1	Class A sludges from wastewater treatment plants suitable for land application.
	Biosolids, composted	2.5	1.8	0.8	

Example 1. Determine the amount of ammonium sulfate a 5,000-square-foot lawn needs, if the lawn requires 1 pound of nitrogen per 1,000 square feet.

Lawn: 5,000 square feet
Fertilizer: ammonium sulfate (21-0-0)
Rate: 1= pound of nitrogen per 1,000 square feet

(1) Ammonium sulfate is 21 percent nitrogen (round to 20 percent).

(2) 20 percent is the same as 0.20 or one-fifth.

(3) This means that for every 5 pounds of fertilizer, there is 1 pound of nitrogen; therefore, 5 pounds of fertilizer 1 pound of nitrogen.

(4) We need 1 pound of nitrogen for every 1,000 square feet. Since 1 pound nitrogen = 5 pounds fertilizer, 5 pounds fertilizer = 1 pound nitrogen per 1,000 square feet.

(5) We are fertilizing 5,000 square feet (5 x 1,000 square feet). 5 units of area x 5 pounds of fertilizer per unit area = 25 pounds of fertilizer.

$$\textbf{Total fertilizer needed} = \frac{\text{N application rate (lb./1,000 sq. ft.)}}{\text{\% N content of fertilizer as decimal}} \times \frac{\text{lawn size (sq. ft.)}}{1{,}000}$$

$$\frac{1}{0.20} \quad \frac{5{,}000}{1{,}000} \quad \frac{5}{0.20} = 25 \text{ lb. fertilizer}$$

Example 2. Determine how much 20-10-5 needs to be applied to get 2 pounds of phosphorus per 1,000 square feet in a garden that measures 20 X 10 feet.

Garden: 20 X 10 = 200 square feet
Fertilizer: 20-10-5 = 10 percent phosphorus
Rate: 2 pounds of phosphorus per 1,000 square feet

$$\textbf{Total P needed} = \frac{\text{2 lb. phosphorus}}{0.10} \times \frac{\text{200 sq. ft.}}{1{,}000}$$

20 X 0.20 = 4 lb. 20-10-5

Table 5. Application rates of selected fertilizers to supply a constant N rate.

Formula	Pounds Per 100 Square Feet
5-10-10	3.50
6-18-6	2.80
8-12-4	2
12-6-6	1.40
16-16-16	1

Recommendations for fertilizing vegetables and annual flowers are usually stated: "Apply 3 to 4 pounds of 5-10-10 fertilizer per 100 square feet of garden space." This works as long as the 5-10-10 formula is used. If the fertilizer has a different formula, perhaps with a higher nitrogen content as indicated by the first number in the formula, the application rate should be reduced to avoid nitrogen burn. A high phosphorus fertilizer, such as 6-18-6, is often recommended for vegetables as a starter food. Table 5 shows how the amount to be applied decreases as the percentage of nitrogen increases. The percentage of nitrogen is indicated by the first number in each series.

Soluble Salts

Nitrogen fertilizers do not burn or damage plants, if they are applied correctly. Fertilizers are salts, much like our familiar table salt, except that they contain various plant nutrients. When a fertilizer (salt) is applied to soil, nearby water begins to very gradually move toward the area where the fertilizer has been applied. Salts and fertilizer begin to diffuse or move away from the place where they were applied. This dilutes the fertilizer and distributes it throughout a much larger area. If tender plant roots are close to the fertilizer, water is drawn from these roots as well as from surrounding soil. The more salt or fertilizer applied, the more water is drawn from nearby roots. As water is drawn from the roots, plant cells begin to dehydrate and collapse, and the plant roots burn or dehydrate beyond recovery. If soil moisture is limited, most of the water drawn toward the salt will come from plant roots and the damage will be severe.

Keep in mind two rules when applying a fertilizer during hot weather when soil moisture is limited.

1. Do not overapply nitrogen fertilizers.
2. Make sure adequate moisture is present after applying fertilizers that are high in salts.

Table 6 lists commonly used garden fertilizers that are high in salt content or burn potential. The last column is the practical measure of relative salinity. A higher number indicates greater salinity.

Soluble salts will accumulate on top of the soil in a container and form a yellow or white crust. A ring of salt deposits may form around the pot at the soil line or around the drainage hole. Salts also will build up on the outside of clay pots.

Soluble salts build up when fertilizer is applied repeatedly without sufficient water to leach or wash the old fertilizer or salts through the soil. It also occurs when water evaporates from the soil, leaving minerals or salts behind. As salts in the soil become more concentrated, plants find it harder to take up water. If salts build to an extremely high level, water can be taken out of the root tips, causing them to die.

Soluble salt problems commonly occur on plants grown in containers but rarely occur in the garden. Correct watering is the best way to avoid soluble salt injury by preventing salts from accumulating. When water is applied, allow some to drain through, and then empty the drip plate. Water equal to one-tenth the volume of the pot should drain through each time water is applied. The pot should not be allowed to sit in water. If drained water is allowed to be absorbed by the soil, the salts that were washed out are taken back into the soil. Salts can be reabsorbed through the drainage hole or directly through a clay pot.

Container plants should be leached every 2 to 4 months. Leach a plant before fertilizing to avoid washing away all of the newly added fertilizer. Leaching is done by pouring a large amount of water on the soil and letting it completely drain. The amount of water used for leaching should equal twice the volume of the pot. A 6-inch pot will hold 10 cups of water, so 20 cups of water are used for leaching. Keep the water running through the soil to wash out the salts. If a layer of salts has formed a crust on the soil, remove the salt crust before leaching. Do not remove more than 1/4-inch of soil. It is best not to add more soil to the top of the pot. If the soluble salt level is extremely high or the pot has no drainage, repot the plant.

The level of salts that will cause injury varies with the type of plant and how it is grown. A plant grown in the home may be injured by salts at a concentration

Table 6. Examples of high-salt content fertilizers

Material	Nutrient Level	Relative Salinity per Weight of Nutrient
Ammonium nitrate	33% nitrogen	1.49
Ammonium sulfate	21% nitrogen	1.63
Potassium nitrate	14% nitrogen	2.67
Natural organic fertilizer	5% nitrogen	0.40
Urea formaldehyde	38% nitrogen	0.13
Urea	45% nitrogen	1.81
Superphosphate	20% phosphorus	0.20
Potassium chloride	60% potash	0.87
Potassium sulfate	50% potash	0.43
Dolomite	30% calcium	
	20% magnesium	
Gypsum	33% calcium	0.12
Epsom salts	16% magnesium	1.38

of 200 parts per million (ppm). If the same plant is in a greenhouse where light and drainage are good, it will grow with salts 10 times that level or 2,000 ppm. Some nurseries and plant shops leach plants to remove excess salts before the plant is sold. If you are not sure what has been done, leach a newly purchased plant the first time you water it.

Timing Fertilizer Applications

Soil type is one factor that dictates the frequency of fertilizer application. Sandy soils require more frequent applications of nitrogen and other nutrients than clay soils. Other factors affecting frequency of application include plant type, plant expectations, the frequency and amount of nitrogen or water applied, and the type of fertilizer and its release rate.

The plants being grown influence the timing and frequency of fertilizer application since certain plants feed more heavily on some nutrients than others. For example, in the vegetable garden, root crops require less nitrogen than leafy crops. Corn feeds heavily on nitrogen, while most trees and shrubs are generally light feeders. Corn may require nitrogen fertilization every 4 weeks, while most trees and shrubs perform nicely with a single, well-placed application every year. Turfgrasses are heavy feeders of nitrogen, requiring at least two applications per year. A general rule of thumb is that nitrogen is for leafy top growth, phosphorus is for root and fruit production, and potassium is for cold hardiness, disease resistance, and general durability.

Late fertilization (after August 1) of trees and shrubs can cause new flushes of growth to occur on woody plants that would normally be adjusting themselves for the coming winter. This may delay dormancy in woody plants and cause severe winter dieback of new growth.

Table 5 suggests general guides for groups of garden plants. Gardeners should be aware that individual species within these groups vary considerably. After each group of plants, the primary nutrient (nitrogen, phosphorus, and potassium) requirement is indicated as high, medium, or low.

Application Methods

There are different methods of applying fertilizer, depending on the formulation and the plant requirements.

Broadcasting. A recommended rate is spread over the growing area and left to filter into the soil, or it is incorporated into the soil with a rototiller or spade. Broadcasting is used over large garden or lawn areas when time or labor are limited.

Banding. Narrow bands of fertilizer are applied in furrows 2 to 3 inches from vegetable garden seeds and 1 to 2 inches deeper than the seeds or plants that are to be planted. Careless placement of the fertilizer band too close to the seeds will burn seedling roots. The best technique is to stretch a string where the seed row is to be planted. With the corner of a hoe, dig a furrow 3 inches deep and 3 inches to one side of and parallel to the string. Spread fertilizer in the furrow and cover with soil. Repeat the banding operation on the other side of the string, and then sow seeds underneath the string.

For widely spaced plants, such as tomatoes, fertilizers can be placed in bands 6 inches long for each plant or in a circle around the plant. Place the bands 4 inches from the plant base. If used in the hole itself, place fertilizer at the bottom of the hole. Work it into the soil, placing a layer of soil about 2 inches deep over the fertilized soil; then put the plant in the hole.

As the first roots develop, banding is one way to satisfy the phosphorus needs of many plants, especially tomatoes. When fertilizer is broadcast and worked into soil, much of the phosphorus is locked up by the soil and is not immediately available to the plant. By concentrating the phosphorus in a band, the plant is given what it needs even though much of the phosphorus stays in the soil.

Starter solutions. Another way to satisfy the need for phosphorus when setting out tomato, onion, eggplant, pepper, or cabbage transplants is by using a liquid fertilizer that is high in phosphorus as a starter solution. Follow directions on the label.

Side dressing. Dry fertilizer is applied as a side dressing after plants are up and growing. Scatter fertilizer on both sides of the row, 6 to 8 inches from the plants. Rake it into the soil and water thoroughly.

Foliar feeding. This is used when a quick growth response is wanted, micronutrients (iron or zinc) are locked in the soil, or the soil is too cold for the plants to extract or use the fertilizer applied to the soil. Foliar-applied nutrients are absorbed and used by the plant quite rapidly. Absorption begins within minutes after application and is completed within 1 to 2 days with most nutrients. Foliar nutrition can be a supplement to soil nutrition at a critical time for the plant, but it is not a substitute. At transplanting, applying a phosphorus spray will help establish the young plant in cold soils. For perennial plants, early spring growth usually is limited by cold soil, even when the air is warm. Under such conditions, soil microorganisms are not active enough to convert nutrients into forms available for roots to absorb. Yet, if the nutrients were available, the plants could grow. A nutrient spray for the foliage will provide the needed nutrients to the plants immediately allowing them to begin growing.

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