Plant Nutrition

David Robson
University of Illinois

In early agricultural societies, it was observed that crop yields could be increased by adding animal manures or plant debris to soil. We continue this practice today with regular additions of organic matter. We have also learned that this simple practice provides a steady source of nutrients for plants, improves soil structure and tilth or looseness. Chemical sources through fertilizers have also been used to supply nutrients needed for plant growth and development.

Elements Required By Plants

Research has shown that 17 elements are necessary for most plants to grow and develop properly. Nine elements are used in relatively large quantities and they are referred to as major elements or **macronutrients**. The nine major elements are:

Carbon (C)
Hydrogen (H)
Oxygen (O)
Nitrogen (N)
Phosphorus (P)
Potassium (K)
Calcium (C)
Magnesium (Mg)
Sulfur (S)

The eight remaining elements are used by plants in small quantities and are called **trace elements**, **minor elements**, or **micronutrients**. Even though these minor elements are needed in small quantities, they are equally essential to plant growth and development. The micronutrients are:

Boron (B)
Zinc (Zn)
Manganese (Mn)
Copper (Cu)
Molybdenum (Mo)
Chlorine (Cl)
Iron (Fe)
Cobalt (Co)

Carbon, hydrogen and oxygen are the three elements used in the largest amounts and are the building blocks for plant growth, forming carbohydrates (sugars and starches) and oxygen forming carbon dioxide and water. Carbon, hydrogen and oxygen are obtained mainly from the air and water. Nitrogen, phosphorus and potassium are considered the **primary macronutrients**. Calcium, magnesium and sulfur are classified as **secondary macronutrients**.

Nitrogen gives plants their dark green color and increases leaf and stem growth. The crispness and quality of leafy vegetables such as lettuce and spinach is influenced by nitrogen levels. Plants deficient in nitrogen have light green to yellow leaves and appear stunted.

Phosphorus encourages root growth and establishment. Phosphorus is also crucial for plant flowering and fruiting, especially seed production. Most of the internal plant chemical reactions are dependent on phosphorus. Poor flowering and fruiting may be signs of the lack of phosphorus. Some plants, including corn and tomatoes, may exhibit red or purple leaves. Cold soils can prevent phosphorus uptake, even though the element is present.

Potassium or potash increases the plant's vigor, winter hardiness and resistance to diseases. Stems and stalks are stiffer. Plant seed or fruit yield is improved. Reduced vigor, susceptibility to diseases and thin skinned or small fruit may be signs of potassium deficiency.

Any material, organic or chemical, that provides any one or more of the 17 essential elements could be called a fertilizer. The definition of a fertilizer is a legal one. Even though a substance like compost provides most of the essential nutrients a plant needs, it cannot legally be sold as a fertilizer in most parts of this country. It is however the only source of nutrients in some third world countries.

While organic fertilizers usually release their nutrients more slowly than chemical sources, once the elements are released they are available for uptake by the roots. Nutrients are not absorbed directly into the roots, but absorbed in a water solution. Therefore, there is no preference of organic fertilizers over chemical fertilizers on the basis of ability of plants to use released elements. However, inorganic sources usually provide a faster plant growth response.

Fertilizers can be purchased as **slow-release** or **conventional**. Slow-release fertilizers require fewer applications and have less of a chance to burn the plant. Release rates can vary depending on the particular type. However, slow-release fertilizers usually cost more and are harder to find. The nutrient release rate is usually dependent on environmental conditions and not on plant need.

Burning occurs to plant roots and other plant parts that may come in contact with conventional fertilizers. Fertilizer elements are often in the form of salts. Like sugar and table salt, these materials are **hygroscopic**. This means that they will absorb moisture. This is why a salt shaker will clump up on a rainy day. If the level of salts, regardless of whether it is deicing salt or fertilizer salts, becomes too high in the soil, water is unable to enter the root. If the amount of salts in the soil continues to increase water is pulled out of the plant into the soil. Even though the soil feels moist, water is unable to enter the plant.

Conventional fertilizers are fast acting and relatively inexpensive. The nitrogen leaches more readily. The fertilizer can form clumps in the bag, making application tougher.

Organic sources of fertilizer such as manure, cottonseed or soybean meal, dried blood or bone meal, are slower acting and have a relatively low plant burn potential. These sources usually have some micronutrients available. Organic sources (manures and compost) can condition the soil as they break down further. On the other hand, many organic sources are bulky, expensive and can have an unpleasant odor.

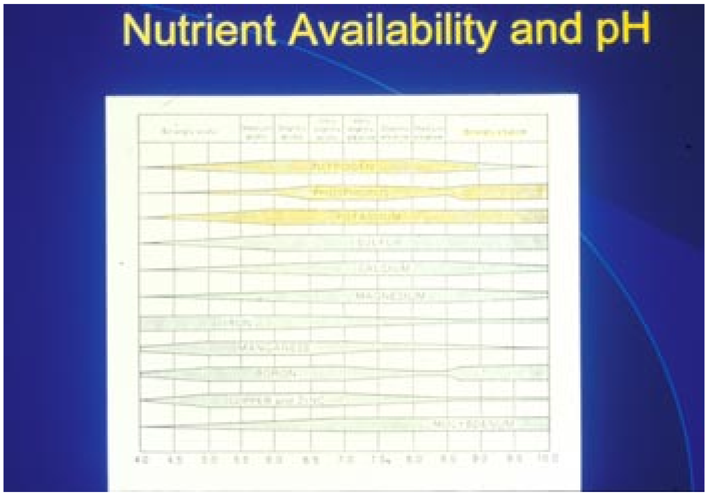
When we discuss the need to apply elements, generally we refer to major elements because they are used in greater quantity and may need to be replaced more frequently. Nitrogen, phosphorus and potassium, for example, are applied to lawns and gardens one or more times each season.

When sources for nitrogen, phosphorus and potassium are packaged together to be applied in a single application, the fertilizer is called a **complete fertilizer**. An **incomplete fertilizer** lacks one or two of the primary micronutrients. Examples include ammonium nitrate (33-0-0), urea (46-0-0), triple superphosphate (0-45-0) or muriate of potash (0-0-60).

In most areas of the U.S., minor elements are present in native soils in quantities sufficient for most plants. Applications of trace elements is usually not necessary.

SOIL pH

Soil pH refers to the acidity or alkalinity of a soil. **pH is the logarithm of the negative hydrogen ion concentration**. A 14-point scale is used to measure pH. 1.0 is as acid as something can get, 7.0 is neutral. Anything below 7 is classified as **acidic** and anything above 7 is **basic** or **alkaline**. Sometimes people will refer to acid soils as "sour" and basic soils as "sweet."


Nutrient Availability and pH

Most plants grow best in a slightly acid soil. At pH 6.5, the 17 essential elements can be taken up by plants if they are present in the soil. If the pH rises (becomes more basic) or lowers (becomes more acid), some elements become less available for plant uptake. Other elements become so readily available that they become toxic to plants. Therefore, it is possible for plant nutrients to be present in the soil, but unavailable for plant use because of an improper soil pH. Low pH soils are neutralized or brought up to 6.5 range by adding **limestone** (calcium carbonate) to the soil. Some limestone, such as **dolomitic limestone**, also contains magnesium (Mg). For all horticultural uses, agricultural ground limestone or ground dolomitic limestone is recommended.

High pH soils can be neutralized by adding an acid forming material such as finely ground **sulfur** (S), peat moss, or by using an acid forming fertilizer to the soil. When correcting soil pH, it is important to remember that pH is measured on a logarithmic scale. On a logarithmic scale everything moves in multiples of 10. For example, if it takes a pound of sulfur to lower the pH of a "pile" of soil from 7.0 to 6.0, then, in theory it will take 11 pounds to lower it from 7.0 to 5.0 (1 pound to get it to 6.0 plus 10 pounds to get it from 6.0 to 5.0). If we lower the pH from 7.0 to 4.0 it theoretically will take 111 pounds (1 pound plus 10 pounds plus 100 pounds). In reality, it is difficult or impossible to correct soil pH more than one unit (i.e. 7.0 to 6.0). Many soils are well buffered making them more difficult to adjust than other soils.

It is not possible to look at a soil and determine the pH. Soil test kits are available to get at least an approximate pH reading. For a reliable test, soils should be sent to a commercial or university testing laboratory. Not only will the laboratory give you the pH of the soil, the report will probably also include information on the amounts of other elements in the soil and how much fertilizer, limestone, etc. should be applied to the soil.

It is not possible to look at a soil and determine the pH. Soil test kits are available to get at least an approximate pH reading. For a reliable test, soils should be sent to a commercial or university testing laboratory. Not only will the laboratory give you the pH of the soil, the report will probably also include information on the amounts of other elements in the soil and how much fertilizer, limestone, etc. should be applied to the soil.

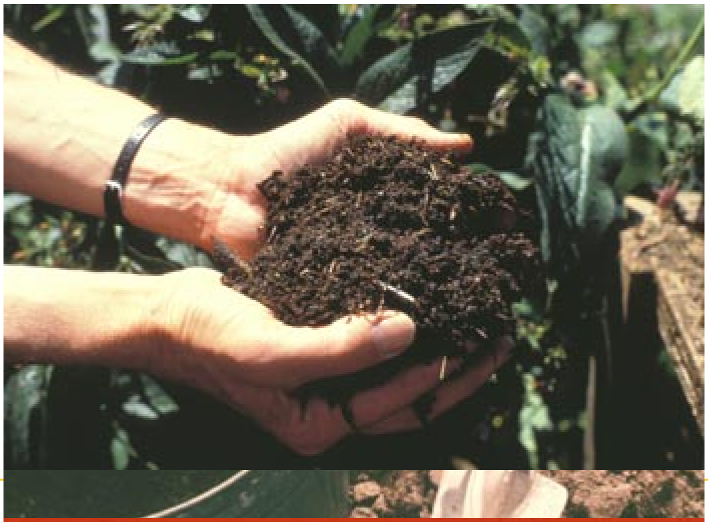
It is certainly worthwhile to invest the time and small amount of money to have a soil test made at least every three years. Basic soil testing usually gives pH, phosphorus and potassium levels. Nitrogen readings are seldom accurate due to the potential for leaching during testing.

In recent years, leaf analysis, petiole analysis and tissue analysis has been used to detect nutrient deficiencies. These tests are particularly helpful in detecting micronutrient deficiencies. The tissue should be collected in midseason and representative leaves and/or petioles should be taken from the midshoot region. The laboratory doing the tests will provide specific sampling procedures. This test is commonly used on fruit crops since a nutrient imbalance can prevent maximum flowering and/or fruit development.

Nutrient Holding Capacity of Soils

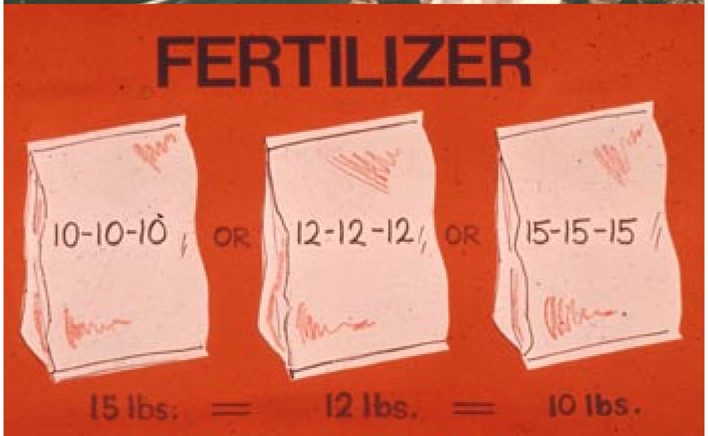
Soil particles, even sand, can attract small quantities of elements and hold them by surface attraction; however, elements or nutrients are held tighter and in much larger quantities by clay particles and **humus**. Humus is well broken down organic matter. Soils with moderate to large quantities of clay and soils rich in organic matter have higher nutrient holding capacities.

Benefits of Organic Matter



Organic matter provides some nutrients for plants as it decomposes, increasing the **nutrient holding capacity** of the soil significantly. After it completely decomposes, it "glues" soil particles together. This **aggregation of particles** results in a soil with improved **soil structure**, one that is loose, crumbly and not compacted. A soil with good structure allows water and air to move more freely through the root zone resulting in improved root and plant growth.

What Is in the Fertilizer Bag?



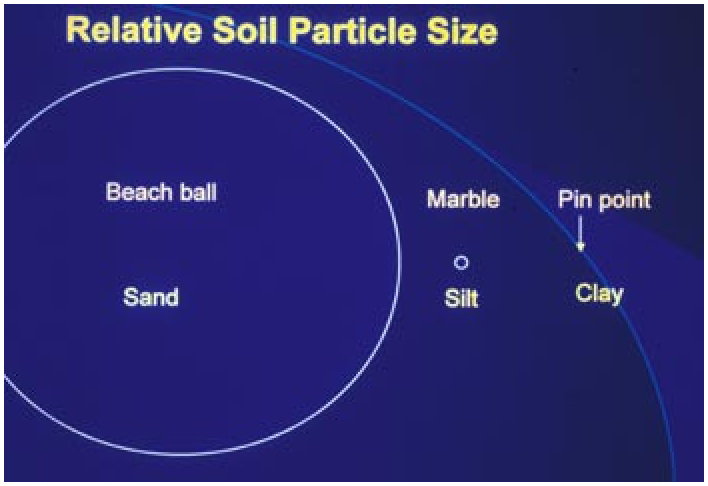
You have seen many different brands and kinds of fertilizers at garden centers, nurseries and other retail stores. By law they all have three numbers boldly listed on the front of the fertilizer bag (e.g. 10-6-4, 5-10-5, 38-0-0). These numbers represent the percentage by weight of nitrogen, phosphorus (as P2O5) and potassium (as K2O) in a bag. The order (N, P and K) is always the same. So with a 50 pound bag of 10-6-4, we know that 5 pounds (10% of 50 pounds) is N, 3 pounds is P2O5 and 2 pounds is K2O. So there is a total of 10 pounds of plant nutrients in this 50 pound bag (5 lbs N + 3 lbs P2O5 + 2 lbs K2O). The remaining 40 pounds is filler such as ground corn cobs, sawdust, talc, vermiculite, or clay which makes it easier for you to apply the product evenly over your lawn or garden.

In most instances, fertilizer applications are made on the basis of the nitrogen required. Frequently, it is one pound of actual nitrogen per 1000 sq feet (square feet) or 43 pounds of N per acre. (There are 43,560 sq feet in an acre) How much of the following fertilizers are required to place one pound of nitrogen on a garden that is 1000 sq feet?

- 10-6-4 (10%N)
  to calculate divide 1 pound nitrogen by the percent nitrogen in the fertilizer: 1/.10 = 10 lbs of 10-6-4 per 1000 sq feet
- 5-10-5 (5% N)
  1/.05 = 20 lbs of 5-10-5 per 1000 sq feet
- 20-10-10 (20% N)
  1/.20 = 5 lbs of 20-10-10 per 1000 sq feet

Application rates of fertilizers are important. Excessive amounts may damage plants by burning roots or foliage or may prevent another element from being absorbed from the soil. Insufficient amounts may lower the potential crop yield or cause the plant not to grow or develop and complete its life cycle properly. It is especially important to be careful when applying micronutrients since they are applied in relatively small quantities. How would you apply one teaspoon per 1000 sq feet? Perhaps you could mix the nutrient thoroughly in a bucket of soil or sand and then apply the material evenly over the 1000 sq feet. In this case, the bucket of soil becomes the filler to allow for easier, more accurate application.

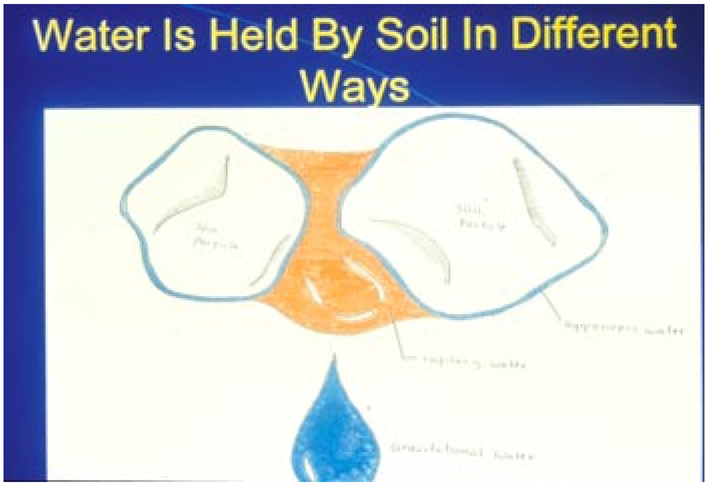
Soil Particle Size Comparison



Soil is a natural body composed of organic and mineral materials. Every soil is made up of mineral matter, organic materials, air and water. The mineral portion is made up of various particle sizes called **sand**, **silt** and **clay** . Sand and silt particles are the result of breakdown of larger rocks, a process known as weathering. During this **weathering** process, the elements which make up the larger materials are released and made available for plant uptake. Clay particles have been synthesized or put together by physical and chemical processes over a long period of time. These clay particles are in plate-like layers and have internal spaces between the layers that allows the clay particles to hold more nutrients.

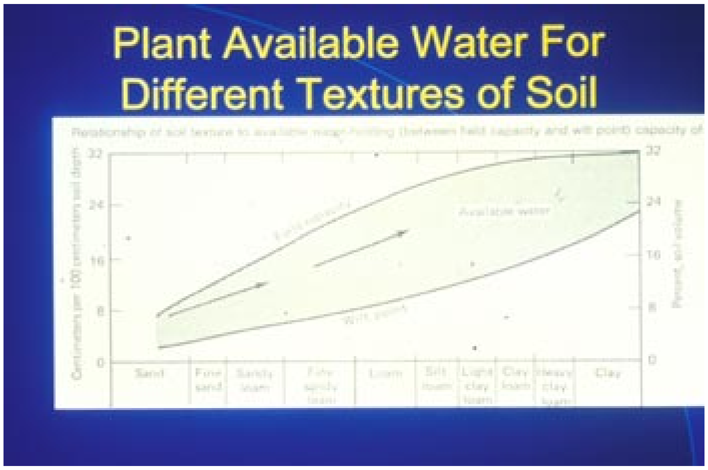
Heavy clay soil structures can be modified by the addition of organic matter that increases the soil tilth or looseness. Gypsum is sometimes used to break apart the clay structure; however, soil chemistry is usually altered negatively. Organic matter such as compost, leaf mold, or peat moss added to sandy soils helps retain water.

Approximately 50% of a soil is made up of solids (45% mineral and 5% organic matter) and the other 50 percent is pore space. The pore space is made up of the spaces between particles. If the soil particles are aggregated or glued together with broken down organic matter, about 50% of the soil volume will be **pore space**. On the average, half of the space should be occupied by water and half by air. In order to achieve this balance between air and water, the water level will fluctuate from a saturated level to a fairly dry level.


Water Is Held By Soil In Different Ways

When all of the pore space is filled with water, the soil is saturated and a poor environment for plant growth results because of insufficient air in the root zone. Roots rot, nutrients are not absorbed due to a lack of oxygen and loss of nitrogen into the air can occur. After several hours, gravity will carry excess water down through the soil; this water is referred to as **gravitational water**. Plant nutrients such as nitrogen are water soluble and carried away or **leached** with this gravitational water. Gravitational water also carries away excess fertilizers that may damage plants. This flushing is one way to minimize winter salt damage to plants. Not all elements are carried off easily with gravitational water. Calcium and phosphorus, for example, are quite immobile in the soil.

The amount of water remaining in the pore space after the force of gravity has drawn off the excess is called **field capacity**. At this point, considerably more than 25 percent of the pore space is occupied by water. As water is used by plants and evaporates from the soil surface, the pore space has less and less water until it gets so dry that plants cannot absorb any more water from it. At this point, most of the pore space is occupied by air. At this point moisture in the soil is referred to as being at the **wilting point**.


Plant Available Water For Different Textures of Soil

Between field capacity and the wilting point, the water available for plant use is referred to as available or capillary water. Research shows that moisture within this available range is equally available to plants, so there is no advantage to keeping the water level in the soil high. In fact this would be detrimental to plants since too little air would be in the pore space.

On many hot summer afternoons, plants wilt. However, this condition is not usually related to low soil moisture (wilting point) but rather to a situation where the plant is using (losing) water more rapidly than the roots can absorb it and transport it to the leaves.

If soils dry below the wilting point, a level is reached called hygroscopic water. **Hygroscopic water** is not available to plants and is held so tightly by soil particles (especially clay) that it can only be removed by heating.