Lesson 8: Soil Fertility

What is a fertile soil? A fertile soil produces high-yielding, healthy crops. A fertile soil has a balance and quantity of nutrients, but nutrients alone are not enough to make a soil fertile. There are soils that are rich in calcium (Ca), nitrogen (N), or potassium (K) that will not produce high yields of crops. In addition to nutrients, the soil texture, structure, rooting depth, organic matter content, available water capacity, aeration (porosity), and length of growing season must be favorable for maximum growth. Fertile soil also depends on physical support, such as good seed, timely planting and harvesting, erosion control practices, and good plant residue management.

Plant Nutrients

About 17 elements are necessary for plant growth, including 9 essential macronutrients. Three—carbon (C), hydrogen (H), and oxygen (O)—are supplied by water and air; 14 are found in the soil. Plant nutrients can be divided into six macronutrients that are needed in large amounts, and eight micronutrients that are needed in small or trace amounts. See Table 8.1.

Macronutrients

Six macronutrients are available in the soil. Calcium (Ca), magnesium (Mg), and potassium (K) are available mainly in mineral solids. Phosphorus (P) and sulfur (S) are available in both mineral solids and organic matter. Nitrogen (N) is available mostly in organic matter.

Soil air is necessary for plant roots to grow and to absorb nutrients. Plants may suffer deficiencies of some nutrients just because the oxygen (O) supply is limited. O is also necessary for the production of nitrate (NO_3) and the activity of bacteria.

For each macronutrient:
- ◊ The origin and natural form in the soil are given, along with ways it can be supplemented.
- ◊ Each nutrient's effect on plants is discussed.
- ◊ Signs of plant deficiencies are described.

Table 8.1 – Seventeen Essential Plant Nutrients

	NUTRIENTS		SOURCE
Macro	Ca	Calcium	Mineral solids
	Mg	Magnesium	
	K	Potassium	
	P	Phosphorus	Mineral solids, organic matter
	S	Sulphur	
	N	Nitrogen	Organic matter (primarily)
	C	Carbon	Water and air
	H	Hydrogen	
	O	Oxygen	
Micro	B	Boron	Naturally in soil; can be added with fertilizers
	Cl	Chlorine	
	Co	Cobalt	
	Fe	Iron	
	Mn	Manganese	
	Mo	Molybdenum	
	Zn	Zinc	
	Cu	Copper	

Calcium (Ca) – Calcium usually makes up more than 80 percent of the total bases present in the soil. Exchangeable Ca is important for changing the pH of the soil because Ca generally aids in the availability of other elements. However, a very high or low pHw may reduce the availability of some plant nutrients. A pH_w of 6.0 to 6.8 is considered the most desirable for most grain crops and grasses. Legumes, such as alfalfa, need a higher pH_w level (around 7.0). Ca can be supplied to the soil through agricultural limestone that is high in calcium carbonate ($CaCO_3$). Ca is essential for building cell walls in plants, new roots, and leaves.

Ca deficiencies do not show in definite colorations in plants as some other nutrient deficiencies do. Deficiencies result mostly in low production, even in soils that are adequately supplied with the other major nutrients.

Magnesium (Mg) – Magnesium makes up about 15 percent of the bases in the soil. Mg can be supplied to the soil through dolomitic limestone that is high in magnesium carbonate ($MgCO_3$). An Mg fertilizer is magnesium sulfate ($MgSO_4$), also known as epsom salts.

Mg is vital in the photosynthesis process. Most of the Mg in plants is in chlorophyll or in seed. Mg deficiencies do not show in definite colorations in plants, but result mostly in low production, even in soils that are adequately supplied with the other major nutrients.

Other Macronutrients

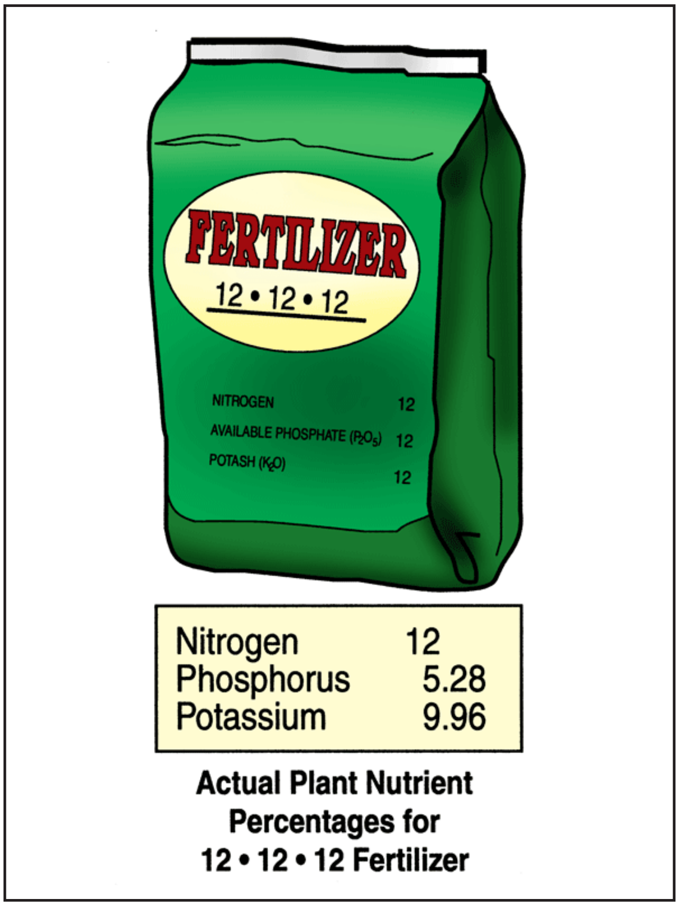
The other macronutrients are potassium (K), phosphorus (P), sulfur (S), and nitrogen (N); these are supplied in commercial fertilizers. Farmers (and even a few city people!) have used 12-12-12 fertilizer. Much of the fertilizer used for farm applications is now in the form of granular or liquid bulk mixes. Many fertilizer mixes are labeled P_2O_5 or K_2O to indicate the P or K. Neither of these compounds (P_2O_5 and K_2O) are actually contained in these fertilizers! The form of P mainly used by plants is dihydrogen phosphorus (H_2PO_4) and the form of K mainly used by plants is just the K^+ ion. See Figure 8.1.

To compare the prices of commercial fertilizer, the actual price of the N, the P, and the K must be determined. Most commercially mixed fertilizers give the actual percentage of N. P_2O_5 actually contains 44 percent P. K_2O actually contains 83 percent K. To determine the actual P and K in a 12-12-12 fertilizer, multiply the appropriate number in the fertilizer (12-12-12 = N-P-K) by the percent, for example, 12 x .44 = 5.28 lbs of P, and 12 x .83 = 9.96 lbs of K.

Potassium (K) – Potassium is the third element in all complete fertilizers. For example, in 3-12-24 fertilizer, the stated make-up is 3 lbs of N, 12 lbs of P_2O_5, and 24 lbs of K_2O. (To find the actual amounts of P and K, follow the example above.)

The upper 7-inch layer of topsoil contains, on the average, about 30,000 lbs of K, but the exchangeable ion K makes up only 200-500 lbs per acre, or one percent of the total. Plants use K in this K^+ ion form. A good crop of alfalfa may use more than 25 percent of the available K in the soil in one year. Because only a small percentage of the K

Figure 8.1 – Contents of a Bag of Fertilizer



in the soil is available to plants and because plants absorb large amounts of K, the K level can be depleted rather quickly, especially when growing high forage-producing crops. Additions of K fertilizer on a regular basis are very important. The most commonly used K fertilizer is potassium chloride (KCl), also known as muriate of potash. Many commercial fertilizers, however, still use an old term for potash, expressed as K_2O. There is actually no K_2O compound in the fertilizer.

K helps in the uptake of other nutrients, it assists in many enzyme systems affecting metabolism and photosynthesis, and it is important in the formation of carbohydrates. K helps to regulate the opening and closing of stomata in the leaves (openings or slits in the outside of leaves that allow for breathing and the transportation of water) and the uptake of water in root cells. K is important for strong brace roots in corn and helps to prevent the plant from falling over (lodging in small grain). If the soil is too wet and aeration is inadequate, K cannot be absorbed by plant roots. Plant deficiencies can be detected by comparing deficient and healthy plants. The edges of older leaves and areas between the veins first turn yellow, then brown. Small brown spots develop while the veins are still green.

Phosphorus (P) – All P comes originally from rock. P in the soil forms complex anions with O. The solubility of P is low, making it less available to plants. This often causes P deficiencies in plants. The availability of P to plants is very complex and is related to the pH level, soil moisture, the amount of N in the soil, and other chemical properties. One positive factor about the low solubility of P is that unlike N, P is not readily leached from the soil.

Phosphorus in soil comes in both organic and inorganic forms. The organic form accounts for about one-half of the P in the soil. It is held very tightly in the soil and usually is not available to plants. Microorganisms break down organic forms of P into inorganic forms that plants can use (H_2PO_4 and HPO_4). This process develops best in warm, well-aerated soils where bacteria are most active. The amount of available P in the soil depends to a large extent on the soil pH, the types of P fertilizers added, and how they are applied. Application needs should be determined by soil test recommendations. P can be added to the soil by applying finely ground P rock, super phosphate, or mixed fertilizers containing P.

Phosphorus is a component of every living cell. In plants it is concentrated in seeds and in the growing parts. P is needed for energy and root development and aids in the maturing of crops. Low temperatures stop the availability of P. P is second only to N in fertilizer usage.

Phosphorus deficiencies in plants result in stunting and late maturity. The lack of P results in slow conversation of sugar to starches and cellulose. The excess sugar causes the formation of anthocyanins, which result in purple spots and streaks in the leaf tissues.

Sulfur (S) – Plants adsorb S as a sulfate (SO_4^{--}) ion or from the air as sulfur dioxide (SO_2^{--}). It is also available through organic matter. Sulfur is a vital part of all plant proteins and some hormones. Plants use about as much S as P. Sulfur can be applied in the form of ferrous sulfate or aluminum sulfate (alum). Sulfur can also be added to reduce high pH levels. The amount of sulfur needed can be calculated in the same way as the lime (Ca) requirement is calculated.

Sulfur deficiencies slow down protein synthesis and the formation of amino acids. S deficiencies in plants resemble N deficiencies (e.g., leaves turn yellow during dry periods).

Nitrogen (N) – Nitrogen is a major component of the atmosphere. About 78 percent of the atmosphere is made up of N gas (N_2). N is also found in soil. Organic matter releases N in the soil through the activity of microbes. N is one of the most critical elements for plant growth. Plants use two forms of N: ammonium (NH_4^+) and nitrate (NO_3^-). NH_4 is held mostly on the soil colloid and NO_3 is in the soil water and leaches out easily. There is also some NH_4 in the soil water that leaches out.

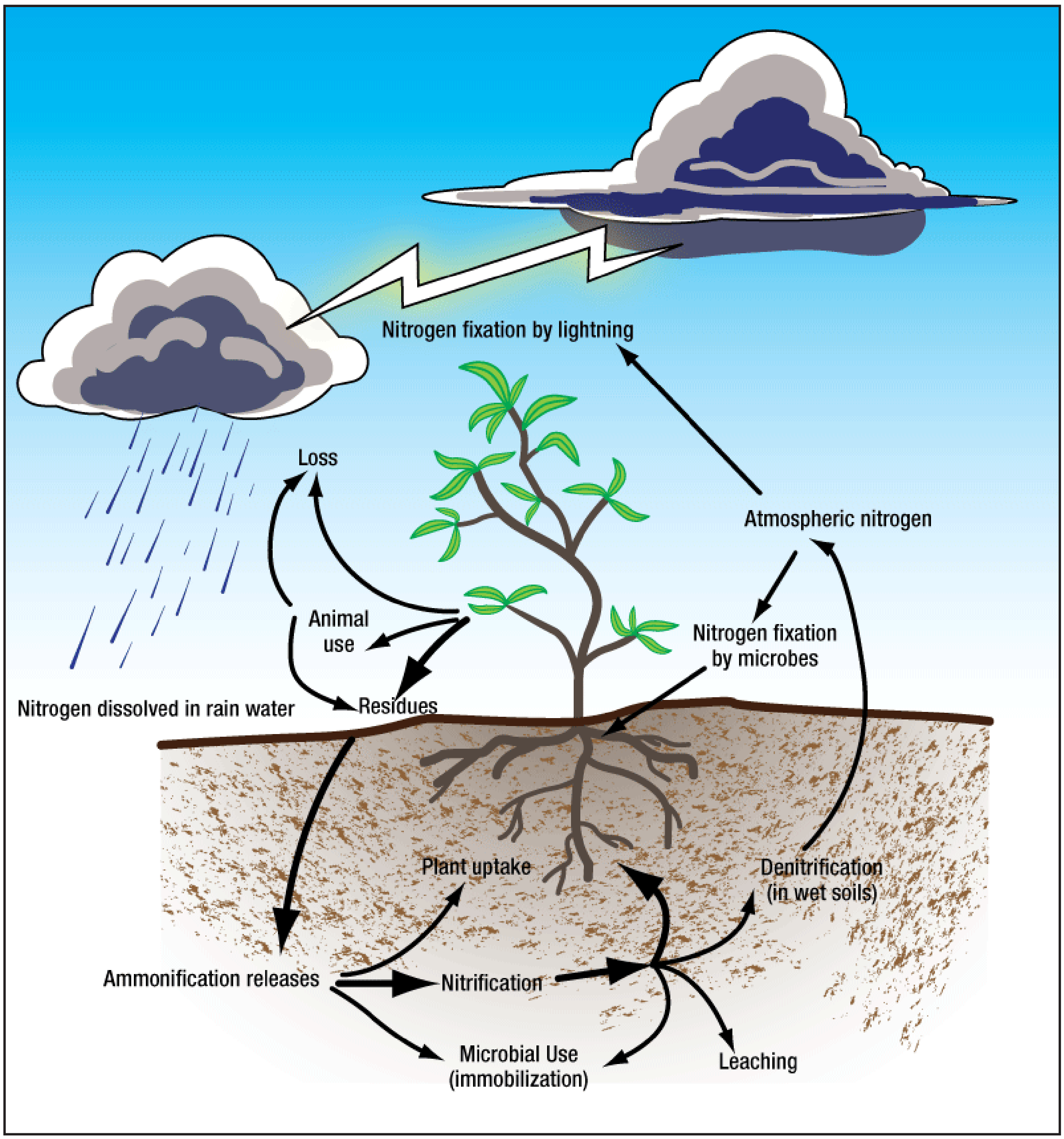
Organic matter may contain up to 2,000–3,000 lbs of N per acre, but only a very small percent becomes available each year. Each percent of organic matter in the soil will supply only about 20 lbs of N per acre each year. This is not usually sufficient for most crops, so N is added to the soil in fertilizer.

Many of the compounds in plants, such as amino acids and enzymes, contain N. Each molecule of chlorophyll contains four atoms of N. Chlorophyll is needed for the production of carbohydrates by photosynthesis. Plants also need N to form cells, and especially for root development.

Nitrogen not only is a very important plant nutrient, but it is equally important in the breakdown of the complex raw organic materials to humus by microbes. A fixed ratio of carbon and nitrogen (C:N ratio of 32:1) is necessary for microbes to decompose residues. If microbes run out of N, they stop working. This can be noticed when crop residue (like corn stalks) do not decompose within a year in the soil. N cycles through various forms as it moves from the soil to microbes and back to the soil. N can enter or leave the cycle in different ways and places. Figure 8.2 shows the nitrogen cycle.

Nitrogen is to plants as gas is to a car. Just as a car will not run with an empty gas tank, soil will not produce

Figure 8.2 – Nitrogen Cycle



without N. Most of the N applied to soils is in fertilizers, such as ammonium nitrate, anhydrous ammonia, urea, and ammonium sulfate.

Abundant N results in a dark green, lush growth. The pale green color of N-deficient plants results from a shortage of chlorophyll. The N deficiency is caused mainly by inadequate soil moisture, even though adequate amounts of N may have been supplied. N deficiencies are most noticeable during long dry periods. For example, the center of corn leaves may turn yellow and die during extended dry periods. Therefore, N should be applied deeply enough in the soil so that roots can get adequate supplies during dry periods.

Micronutrients

The eight micronutrients are:

1. Boron (B)
2. Chlorine (Cl)
3. Cobalt (Co)
4. Copper (Cu)
5. Iron (Fe)
6. Manganese (Mn)
7. Molybdenum* (Mo)
8. Zinc (Zn)

*(muh-lib-deh-num)

These elements are sometimes referred to as trace elements or minor elements. However, a much more appropriate term is **micronutrient**. Some plants absorb large amounts of Na and Cl just because they are abundant in the soil, but only a small amount is necessary to the plants.

Shortages of micronutrients were not noticed much until the use of very high-analysis fertilizers became common. Adequate levels of micronutrients could be maintained in the soil in the past when crop yields were low. But with the heavy applications of fertilizers that are now generally applied, micronutrients are quickly depleted. The effect of small amounts of micronutrients is remarkable. A deficiency may have a devastating effect on plant growth, even though the plant requires only a minute amount.

Some micronutrients are a part of the enzyme molecules or act as an aid in the function of the enzyme. Others function in the processes of plant metabolism. Some micronutrients, such as Cu and Fe, aid in the formation of chlorophyll. The amount of micronutrients needed usually is only a few pounds per acre; therefore, they generally can be included in other complete fertilizer mixes. It is very important that micronutrients are mixed thoroughly because only a small amount is needed and it must be applied evenly over the field. Overdoses can be toxic to plants, perhaps killing them or making them unfit for human consumption. It should be noted that plants also absorb varying amounts of several nonessential elements just because they are available, but the plants apparently show no adverse side-effects.

Organic Matter

An abundance of organic matter makes the soil black. Most people associate this with a fertile soil. If organic matter does nothing else, it makes a person who owns a garden spot or farm just feel good to know the soil is, or appears to be, fertile! However, there are other important factors in favor of a soil that has a high organic matter content. Organic matter improves soil structure. Good soil structure enhances aeration and healthy root development. Organic matter supplies N. In fact, it supplies nearly all the N to plants unless N fertilizer is added to the soil. Organic matter also contains P and may account for about one-half of the P in the soil. Organic matter adds to the total CEC of the soil, of which it may make up 25–50 percent, depending on the amount of montmorillonite, kaolinite, or other minerals in the soil.

Summary

A fertile soil produces high-yielding, healthy crops. Although a fertile soil has nutrient balance and quantity, nutrients alone are not sufficient to make a soil fertile. Fertile soil depends on soil texture, structure, rooting depth, organic matter content, available water capacity, aeration, length of growing season, and physical support.

There are nine essential macronutrients: three are supplied by water and air (carbon, hydrogen, and oxygen); six are supplied by soil mineral solids or organic matter (calcium, magnesium, potassium, phosphorus, sulfur, and nitrogen). Calcium (Ca) makes up more than 80 percent of the bases, so it is very important in changing soil pH and making other nutrients available to plants. Calcium deficiencies usually result in low production, even if soils have adequate supplies of other major nutrients.

Magnesium makes up about 15 percent of the bases in the soil. It is vital in the photosynthesis process (chlorophyll contains Mg). Magnesium deficiencies usually result in low production, even though soils have adequate supplies of the other major nutrients.

Potassium is the third element in all complete fertilizers. Regular additions of potassium fertilizer are very important because only a small amount of the potassium in the soil is available to plants, and it is depleted rather quickly. Potassium is absorbed in large amounts by plants. It helps in the uptake of other nutrients and assists in many enzyme systems that affect metabolism and photosynthesis. Plant deficiencies are evident when leaf edges yellow and then brown, or small brown spots develop while veins are still green.

Phosphorus is a component of every living cell. It helps in root development and aids in the maturing of crops. Phosphorus deficiencies in plants result in stunting and late maturity. An absence of phosphorus causes purple spots and streaks.

Sulfur is a vital part of all plant proteins and some hormones. Sulfur deficiencies turn leaves yellow during dry periods.

The nitrogen in the soil that is available to plants is usually insufficient for most crops, so nitrogen is generally added to the soil in fertilizer. Nitrogen is one of the most critical elements for plant growth. It has an effect on many compounds in plants, such as amino acids and enzymes. Deficiencies are evident in a pale green plant color, which is a result of a shortage of chlorophyll.

The eight essential micronutrients are boron, chlorine, cobalt, copper, iron, manganese, molybdenum, and zinc. Only a small amount of these elements is necessary for good plant growth, but deficiencies can have a devastating effect. Organic matter is important because it supplies most of the nitrogen that is naturally present in the soil, and may account for about half of the phosphorus. It also aids in good soil aeration, healthy root development, the formation of soil structure, and the soil's total CEC.

Credits

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