Soil Science Extension
North Carolina State University

SOIL FERTILITY BASICS

NC Certified Crop Advisor Training

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Chapter 1 Basic Concepts

Introduction

Plants require at least 16 elements for normal growth and for completion of their life cycle. Those used in the largest amounts, carbon, hydrogen and oxygen, are **non-mineral elements** supplied by air and water. The other 13 elements are taken up by plants only in **mineral** form from the soil or must be added as fertilizers. Plants need relatively large amounts of nitrogen, phosphorus, and potassium. These nutrients are referred to as **primary** nutrients, and are the ones most frequently supplied to plants in fertilizers. The three **secondary** elements, calcium, magnesium, and sulfur, are required in smaller amounts than the primary nutrients. Calcium and magnesium are usually supplied with liming materials, and sulfur with fertilizer materials. Contaminants in rainfall also supply 10 to 20 pounds of nitrogen and sulfur per acre each year, depending on local air quality.

The **micronutrients** consist of seven essential elements: boron, copper, chlorine, iron, manganese, molybdenum, and zinc. These elements occur in very small amounts in both soils and plants, but their role is equally as important as the primary or secondary nutrients. A deficiency of one or more of the micronutrients can lead to severe depression in growth, yield, and crop quality. Some soils do not contain sufficient amounts of these nutrients to meet the plant's requirements for rapid growth and good production. In such cases, supplemental micronutrient applications in the form of commercial fertilizers or foliar sprays must be made.

Thus the soil supplies 13 of the 15 elements required for nutrition of higher plants. These elements must be available , continuously, and in balanced proportions to support photosynthesis and other metabolic processes of plants. If any one of these essential elements is missing, plant productivity will be limited, or the plant may cease to grow entirely. The **principle of limiting factors**, which states that the level of production can be no greater than that allowed by the most limiting of the essential plant growth factors, applies in both cropping systems and in natural ecosystems.

Plant Available Forms of Essential Elements

Plants absorb the essential elements through their root systems or their leaves in various forms. In general, the soil contains large amounts of all the elements, but only a very small percentage of these total amounts are actually plant available. For example, the actual total iron content of a soil may exceed 50,000 parts per million (ppm), however the portion available to plants may be less than 5 ppm. The availability of nutrients to plants is determined by the form and chemical properties of the element, the soil pH, interactions with soil colloids, microbial activity and soil physical conditions such as aeration, compaction, temperature, and moisture.

Table 1. Essential nutrient elements showing element, symbol and primary forms used by plants.

Element	Symbol	Primary Forms Used by Plants
NON-MINERAL ELEMENTS		
Carbon	C	CO_2 (g)
Hydrogen	H	H_2O (l), H^+
Oxygen	O	H_2O (l), O_2(g)
MINERAL ELEMENTS		
Major Nutrients		
Nitrogen	N	NH_4^+, NO_3^-
Phosphorous	P	HPO_4^{2-}, $H_2PO_4^-$
Potassium	K	K^+
Secondary Nutrients		
Calcium	Ca	Ca^{2+}
Magnesium	Mg	Mg^{2+}
Sulfur	S	SO_4^{2-}
Micronutrients		
Iron	Fe	Fe^{3+}, Fe^{2+}
Manganese	Mn	Mn^{2+}
Zinc	Zn	Zn^{2+}
Copper	Cu	Cu^{2+}
Boron	B	$B(OH)_3^o$ (Boric acid)
Molybdenum	Mo	MoO_4^{2-}
Chlorine	Cl	Cl^-

Essential elements can occur in one or more of three physical forms: solid, liquid or gas. We tend to deal primarily with solid and liquid forms of the elements in soils, but the non-mineral elements as well as nitrogen and sulfur can also occur in gaseous forms under certain soil conditions.

The chemical form of an element strongly influences how a nutrient reacts with other elements and compounds found in the soil. The nutrient elements can each occur in several forms, but we need to consider those which commonly occur in the soil (Table 1). Ions are elements or groups of elements which occur as charged particles. Cations are ions with positive charges, and anions have a negative charge. Sodium chloride, or table salt, is a common ionic solid which dissolves readily in water to release sodium cations and chloride anions. Ionic solids commonly found in the soil include silicate clays, iron and aluminum hydroxides and numerous compounds containing phosphorus and other essential elements. Obviously, these ionic solids are sparingly soluble, and do not readily release their ions when mixed with water. Because of their unique structure, silicate clays actually occur in the soil as solids with a net negative charge, a fact we will consider later when we discuss cation exchange capacity (CEC) in Chapter 2. Other nutrients, such as boron, occur as uncharged molecules which react very weakly with the soil.

Soil organic matter contains large amounts of carbon, which results in many complex types of structures and chemical properties. But basically, organic matter reacts in the soil like a tiny, spongy solid with a large amount of negative charge. Many of its complex structures also react strongly with smaller organic molecules, such as pesticides and root exudates.

Soil nitrogen is the most difficult nutrient to characterize: it occurs in organic and inorganic forms, in solution and as a gas, and as cation and an anion. Plant roots absorb only the inorganic forms. Common forms of N contained in fertilizers and fresh manures include ammonia, urea, ammonium and nitrate. Ammonia (NH_3), a gas, reacts rapidly with soil water to form the positively charged ammonium (NH_4^+) cation. Urea - $CO(NH_2)_2$ - is rapidly converted from the solid or liquid form by the urease enzyme to the ammonia form. When urea or fresh manure is applied to the soil surface, N loss as gaseous ammonia is possible, especially with warm, dry conditions and a soil high pH. If incorporated or watered into the soil, urea is changed in rapid succession ammonia and on to ammonium. The positive charged ammonium ion is held by the negative charges of the soil. This prevents ammonium leaching except in low CEC soils.

Potassium, calcium, magnesium, manganese, zinc, iron and copper also occur as cations. Potassium and ammonium both have a single positive charge, while the remaining cations have two or more positive charges. In general, the higher the charge of a cation, the more strongly it is attracted to the negative charge sites of the soil. When the sum of the positively charged nutrients exceeds the soil's capacity to hold nutrients, K^+ and NH_4^+ will leach before nutrients such as Ca^{++} and Mg^{++}. Leaching of K^+ occurs primarily in deep sands with low CEC. In addition to their high positive charge, the cationic micronutrients react in other ways with the soil to form very strong bonds. They are not subject to leaching under normal conditions.

Microorganisms convert ammonium to the nitrate (NO_3^-) anion. The negatively charged nitrate is repelled by the negative charges of the soil and is readily leached when water passes through the soil. Chloride (Cl^-) reacts similar to nitrate. Although elemental S may be added to the soil in fertilizers, and organic S is found in plant residues and soil organic matter, the sulfate anion (SO_4^{2-}) is the most common form taken up by plants. Microorganisms are also involved in the break down of elemental and organic S to the sulfate form. Because sulfate and molybdate (MoO_4^{2-}) have two negative charges, they are repelled by the charge of the soil. But they may react weakly with positively charged sites, such as occur on iron oxides. Even though these elements are not strongly bound under normal condition, they do not leach as readily as nitrate and chloride, and are frequently observed to increase in subsoil horizons having higher clay content and lower pH.

Inorganic phosphorus (P) occurs as an anion with either one or two negative charges, depending on soil pH. While anions normally leach, P does not. Phosphorus reacts very strongly with Fe^{3+} , Al^{3+} and Ca^{2+} in soil solution, and with soil solids such as iron oxides, iron and aluminum hydroxides, broken edges of clays, and lime. The strength of these reactions limit the movement of P to less than a few inches even in very sandy soils. Boron occurs as a leachable, uncharged molecule (boric acid, H_3BO_3), which reacts very weakly with soil clays.

Soil Colloids

During soil formation, the soil parent material goes through many physical and chemical changes. Particle size is reduced, and many minerals are dissolved, and reformed as **secondary minerals** which are more stable under the current weathering conditions. Thus minerals such as feldspars, hornblende and micas are weathered to form new clay minerals, and in the case of mica, reduced to “clay-sized” particles of less than 2 micrometers in size. These extremely small particles are called **colloids**, and because of their large surface area to volume ratio, are extremely reactive. Colloids may be classed as **mineral** or **organic** in nature, although mineral colloids generally greatly exceed organic colloids in all but organic soils. Mineral and organic colloids account for essentially all of the charge and chemical reactivity of soils greatly affect the availability of nutrients. Because of the highly variable and often intermingled nature of sources in soils, the charges are sometimes referred to as the colloidal complex.

Mineral Colloids

The major soil mineral colloids are comprised of the alumino-silicate clays, and the oxides and hydroxides of Al and Fe. These minerals may contribute both negative and positive charges to the soil, but in soils of North Carolina, negative charge greatly exceeds positive charge, resulting in a net negative charge on soil colloids. Alumino-silicate clays exhibit negative charge as a result of alterations within their crystal structures. This type of charge is called **permanent charge**, and does not vary with soil conditions such as pH, salt content or content.. The amounts and kinds of clay minerals determine the quantity of negative charge contributed by the clay-sized fraction. (Table 2.1).

As soil pH increases, the quantity of negative charges increases. This increase is called **pH-dependent charge**, and results from neutralization of hydrogen ions from SOIL-OH (hydroxyl) groups at the broken edges of clay structures.

$$[\text{Clay -Al - OH}]^{o} + OH^{-} \quad => \quad [\text{Clay Al-O}]^{-} \quad + HOH_{[\text{water}].}$$

In more highly charged clays, the increase is insignificant, but clays such as kaolinite and oxides of iron and aluminum, the dominant clay minerals in most North Carolina soils, obtain most of their charge through this mechanism.

Table 1. Properties of selected soil colloids.

Component	Type	CEC	Surface Area	Swelling	pH Dependency	Colloidal Activity

		meq/100 g	g/m^2			
Vermiculite	2:1	120-150	600-800	Yes	Minor	High
Mica	2:1	20-40	70-120	No	Medium	Medium
Montmorillonite	2:1	80-120	600-800	Yes	Minor	Ex.. High
Kaolinite	1:1	1-10	10-20	No	Extensive	Low
Oxide & Hydroxides	-	1-10 (+ or -)	10-70	No	Extensive	Low to Medium
Organic Matter	-	100-300	800-900	-	Extensive	Medium

Organic Colloids

The soil humus, or organic colloidal fraction is composed of highly decomposed residues of plant and animal remains. Unlike mineral colloids, organic colloids are not crystalline. The structure of soil organic matter is extremely complex, with many different types of functional groups which can contribute negative charges as well as interact in other more specific ways with cations and organic molecules. Instead of silica and aluminum, these modified lignin, polyuronides and other constituents are composed of carbon, hydrogen and oxygen, along with minor amounts of nitrogen, phosphorous, sulfur and other elements

The nature of the functional groups and the amount of charge vary somewhat with the source of the organic material, the degree of decomposition and the soil pH. The increase in charge results primarily from neutralization of hydrogen ions on exposed OH and COOH groups:

$$[\text{R-COOH}]^{o} + \text{OH}^{-} \quad => \quad [\text{R-COO}]^{-} + \text{HOH}_{\text{[water]}}.$$

The charge and surface area of humus far exceeds that of its crystalline counterparts. It often contributes from 30 to 90% of the total charge present in the soil surface, even when present in relatively low amounts. Because of it complex and open structure, the ability of humus to pull water from the surrounding saturated atmosphere of the soils approaches 80 to 90% of its weight, as compared to 15 or 20% for soil clays. Soil organic matter is distinguished by its high moisture retention, low plasticity, low cohesion, and the dark color it imparts to the soil. These in turn lead to the favorable physical properties such as high water holding capacity, more stable structure, improved tilth, and more rapid water infiltration associated with mineral soils having significant organic matter content. Humus does not readily fix exchangeable cations, as do some clays, but maintains these ions in an easily exchangeable form. Mineralization of soil humus releases some amounts of nitrogen, phosphorous and sulfur from organic forms, and can dramatically influence the availability of micronutrients.

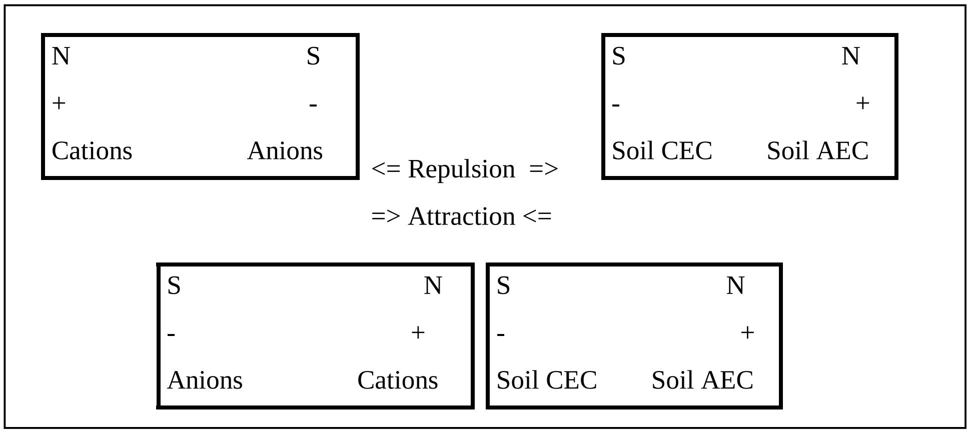
In soils of North Carolina, most mineral soils are inherently low in organic matter because warm temperatures and high rainfall speed decomposition. In cooler or wetter areas, it is possible for organic matter to accumulate, such as in the pocosins and bays of eastern North Carolina.

Cation Exchange Capacity

The extent and type of charge on the soil colloids determines the ability of a soil to retain essential plant nutrients against the forces of water moving through the soil profile. This in turn affects the capacity of the soil to supply nutrients over time.

The capacity for a soil to retain NH_4, K, Ca, Mg, Zn and Cu and other cations increases with increasing negative charge. The soil acts similar to a magnet, attracting and retaining oppositely charged ions, and holding them against the downward movement of water through the soil profile. The nutrients held by the soil in this manner are called "**exchangeable cations**" and can be displaced or exchanged only by other cations which take their place. Thus, the negative charge on a soil is call the cation exchange capacity (CEC). Soils with high CEC not only hold more nutrients, but they are better able to buffer, or avoid rapid changes in soil solution levels of these nutrients by replacing them as the solution becomes depleted. Generally, the inherent fertility, and long-term productivity of a soil is greatly influenced by its CEC. The CEC of a particular soil is expressed in units of milliequivalents per 100 grams (meq/100g) of soil.

The magnet analogy, showing attraction and repulsion by soil exchangers.



Implications of CEC on Management

The CEC affects the way a soil should be managed for crop production and environmental protection. For example, a soil with a low CEC (less than 5 meq/100g) generally has a low clay and organic matter content, has a low water holding capacity, requires more frequent lime and fertilizer additions, and is subject to leaching of NO_3, B, NH_4, K and perhaps Mg. Such soils will have lower yield potential than soils with higher CEC under the same level of management, but high productivity can be maintained by intensive management. These soils will usually be easier to cultivate than soils with higher CEC since they drain more rapidly, and added nutrients are highly available for plant uptake. Soils with CEC greater than 20 may have high clay content, moderate to high organic matter content, high water holding capacity, less frequent need for lime and fertilizers (except N), and low leaching potential for cationic nutrients. On the other hand, their physical properties may make it difficult for a farmer to cultivate, irrigate or maintain good aeration. Such soils are also more prone to K fixation unless soil K levels are inherently high.

CEC Calculations

Since the CEC can vary with pH, the method affects the results, and should be specified. The CEC value reported on the NCDA soil test report is the summation of the extractable K, Ca, Mg, and Acidity (Ac) values. The milliequivalents (me) of extractable acidity are determined directly using a buffer procedure, while the milliequivalents of K, Ca and Mg are determined by extraction. The equivalent weight of a cation is equal to its atomic weight in grams divided by the valence. The result yields the weight of one "equivalent" or one unit of charge for that ion. A milliequivalent is 1/1000th of an equivalent, and is thus usually expressed in milligrams rather than grams.

The meq weight of Ca would be calculated as:

$$\frac{40\text{ g/mole x }1000\text{ mg/g}}{2\text{ eq/mole x }1000\text{ meq/eq}} = 20\text{ mg/me}$$

The appropriate values for major soil cations are given in Table 2.2.

Table.2. Important soil cations and their milliequivalent weights.

Cation	Charge	Atomic Weight (g/mole)	Millequivalent Weight (mg/me)
Al^{3+}	3	27	9
H^{+}	1	1	1
Ca^{2+}	2	40	20
Mg^{2+}	2	24	12
K^{+}	1	39	39
NH4^{+}	1	18	18
Na^{+}	1	23	23

Example

If a soil was found to contain 80 mg of Ca in 100 grams of soil, the meq of Ca present would be:

$$\frac{80\text{ mg Ca/100 g soil}}{20\text{ mg/me}} = 4.0\text{ meq Ca/100 grams soil}$$

Conversely, if the meq of Ca/100 g is known, the mg/100 g can be calculated. For the example above, this would be:

$$4.0\text{ meq Ca/100g x }20\text{ mg/me} = 80\text{ mg/100g.}$$

We can convert 80 mg/100g to parts per million (ppm) by converting the top and bottom of the expression to the same units and multiply the top and bottom by 10/10:

$$\frac{80\text{ mg}}{100\text{ g}} = \frac{80\text{ mg}}{100{,}000\text{ g}} \text{ x } \frac{10}{10} = \frac{800\text{ mg}}{1{,}000{,}000\text{ mg}} = 800\text{ ppm.}$$

We generally assume the acre furrow slice (top 6-8 inches) of a soil weighs 2 million pounds. Thus, if Ca were present at a concentration of one part per million, and then the acre furrow slice would contain 2 lbs of Ca.

Base Saturation

The base cations include K, Ca, and Mg, (and Na, when present) and the **base saturation** is the proportion of the CEC occupied by these base cations. For a soil with 0.5 meq of K, 2.1 meq Ca, 0.4 meq of Mg and a CEC of 4.0 meq/100g , the base saturation is:

(0.5 meq K + 2.1 meq Ca + 0.4 meq Mg) / 4.0 meq CEC = 3.0/4.0 or 75%.

A relatively high base saturation of CEC (70 to 80%) should be maintained for most cropping systems, since the base saturation determines in large measure the availability of bases for plant uptake , and strongly influences soil pH as well. Low base saturation levels will result in very acid soils, and potentially toxic cations such as Al and Mn from the soil (Chapter 3).

Anion Exchange

Although the extent of positive charge on the soil is seldom as large as the negative charge, broken edges of kaolinite and iron and aluminum minerals in soils of the southeastern US can develop positively charged sites as the pH begins to drop below 5.5. These positively charged sites can be significant in the retention of sulfate and phosphate, especially in subsoil clay layers where pH is normally unaffected by liming.

Soil Solution

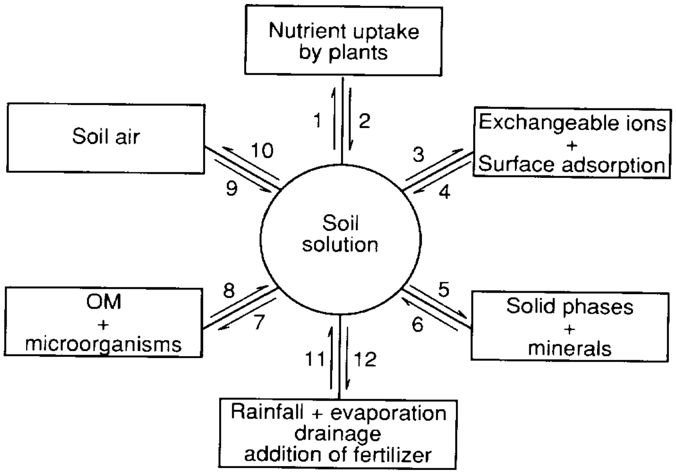
Plant nutrients are either bound to the soil or remain dissolved in the ***soil solution,*** the water which surrounds soil particles. From the standpoint of meeting the nutrient requirements of the plant, the soil solution is the most important place to look. Here, the nutrients are present in the appropriate ionic form, and readily taken up by the root system. But the soil solution can supply the nutrient demands for at most, a few days before it is depleted. In an acre of soil, less than 4 pounds of phosphorous may be present in the soil solution at any one time. Plants roots are in direct contact only a small portion of the available soil volume, and most estimates indicate less than 3% of the total uptake occurs through this mechanism. Instead, the soil solution in contact with the root system must be constantly replenished from the enormous reserves held by the soil colloids through the processes of equilibrium and transport.

Equilibrium and Buffering

The soil solution holds most nutrients - especially cations - in proportion to the amounts held on the soil solids. Plants absorb both cations and anions from the soil solution , and release small quantities of ions such as H^+, OH^-, and HCO_3^-. These reactions cause changes in the soil solution such that the ions in soil solution are no longer in **equilibrium** , or balance with ions on the soil solids.

For example, when a plant removes a cation such as K^+ from solution, this causes an imbalance of K^+ in soil solution relative to that found on the soil. As a result, K^+ ions are desorbed from the soil surface, or dissolved from soil minerals to restore the balance. This equilibrium process, somewhat like balancing a see-saw, is often called **buffering**, and is the reason that soil solution levels change relatively slowly. The buffering of soil solution concentrations depends greatly on the nature of the soil with which it is in contact. Soils with low amounts of clay are more rapidly depleted of their soil reserves, and thus have less buffering capacity than soils with higher clay contents. Certain clay minerals have higher buffering capacity than others. For this reason, we also need to closely examine the nature of the soil colloids.

Soil solution can be affected by a factors other than plant uptake and exchange reactions. Factors which can cause changes in solution concentrations include reactions involving soil air, soil organisms, soil organic matter, rainfall and evapotranspiration, mineral dissolution and precipitation, and addition of plant nutrients as fertilizers and manures (Fig. 1).



Nutrient Transport

Buffering is important in maintaining the supply of nutrients in soil solution. Ions must however, still move from the exchange sites or from mineral surfaces to the point of uptake, since studies show only a small percentage of the uptake occurs by actual root contact with soil surfaces. Two pathways account for most of the movement. The first is illustrated by the movement of fertilizer salts from the surface to the subsoil during a rain. This process, called **mass flow**, moves ions rapidly through the soil with the free water present in soil pores. In soils with low water holding capacity, mass flow can result in **leaching** of nutrients from the root zone. Mass flow depends on the concentration of the particular nutrient, the type of interaction between the nutrient and soil colloids, the water holding capacity of the soil, and the degree of water saturation.

The second process can be illustrated by the movement of fertilizers salts from a band of fertilizer in a soil at less than field capacity. All soil particles are coated with a thin layer of water through which ions in solution may move. And just as a drop of ink placed in a glass of water will eventually spread from a concentrated drop to form a uniformly colored solution, ions in soil solution will diffuse from points of high concentration to areas of low concentration. **Diffusion** is a much slower process than mass flow, but is an extremely important pathway in the replenishment of the soil solution, especially for nutrients which react strongly with the soil colloids.

Chapter 2 Nitrogen

Nitrogen in the Plant

Nitrogen (N) is an essential nutrient used in relatively large amounts by all living things. It is critically important to plants because it is a fundamental part of the chlorophyll molecule and is essential in the formation of amino acids and proteins. Plants obtain their N as inorganic nitrate and ammonium ions in the soil solution but N is not a natural constituent of rocks or minerals. Rather, the natural state of N is as N_2 gas in the atmosphere. 78% of the air we breath is N by volume. It is estimated that there are 31,250 tons of N over every acre on earth. The difficulty from a plant's point of view is that the N_2 in the atmosphere is very non-reactive and is not plant-available. The N_2 molecule has a triple bond and is the most stable diatomic molecule known to science. Plants obtain all the Oxygen and Carbon they need from the air, but they get no N. Very special circumstances are required to convert N_2 into forms plants can use.

Once in the plant, ammonium can be used directly but nitrate is transformed to the ammonium form using energy derived from photosynthesis. The ammonium ions are combined with carbon ions to form glutamic acid which is then used by the plant to produce a large number of possible amino acids. Amino acids are joined together to form proteins. The proteins which are formed act primarily to control plant growth processes through enzymatic action. A good supply of N is associated with vigorous growth and a deep green color. Plants deficient in N become stunted and yellow (chlorotic) in appearance. Since plants can remobilize N from older tissue to provide N to younger tissue, chlorosis usually appears on the lower leaves first while the upper leaves remain green.

Excess N may cause plants to remain in a vegetative growth stage and delay initiation of flowering or fruiting, resulting in lowered yields of some crops. Excess N can also encourage tender, succulent plant growth that may be more susceptible to certain plant diseases. An example of this is Glume blotch (Septoria nodorum) which can infect the heads of wheat and cause severe yield reductions. Plants with excess N may also be more susceptible to lodging and breakage than plants without excess N and very often are more likely to be damaged by freezing temperatures. Most perennial plants should not be fertilized with N in the late summer of fall in order that they can "harden off" before cold weather occurs. Likewise, N applied too early in the spring can result in tender growth that is more prone to cold damage.

In general, N is a scarce under natural conditions and organisms quickly use up all that is available at any given time. In other words, under natural conditions, N is a limiting growth factor in nature. Historically the availability of N was a major limiting factor for crop production, especially in the Southeast. Only recently have N fertilizers become plentiful and relatively inexpensive. Under natural circumstances there is roughly a balance between the atmospheric N and soil N. Gains in soil N by microbial fixation and return of nitrates and ammonium by precipitation are balanced by losses to crop removal, leaching, and volatilization. The natural N balance has been upset by man. We now chemically convert atmospheric N_2 into usable N compounds and use them for fertilizers and other products. In 1982 it was estimated that N from all sources was being introduced into the biosphere at the rate of 92 million metric tons per year. The total denitrified, or converted back to gaseous N, was estimated at about 83 million metric tons per year. That leaves a balance of 9 million metric tons per year that accumulates. Nitrogen that accumulates in the wrong place can be pollutant.

Nitrogen Forms

In general, N is classified as either inorganic or organic. At any given time, most of the N in the soil is in the organic form. Inorganic N compounds are unstable and N is constantly returning to the atmosphere in gaseous forms. The conversion of N_2 to N compounds and from N compounds back to N_2 is called the NITROGEN CYCLE. It has been estimated that it takes from 44 to 220 million years for all N to pass through the cycle. The N cycle is illustrated by Figure 1.

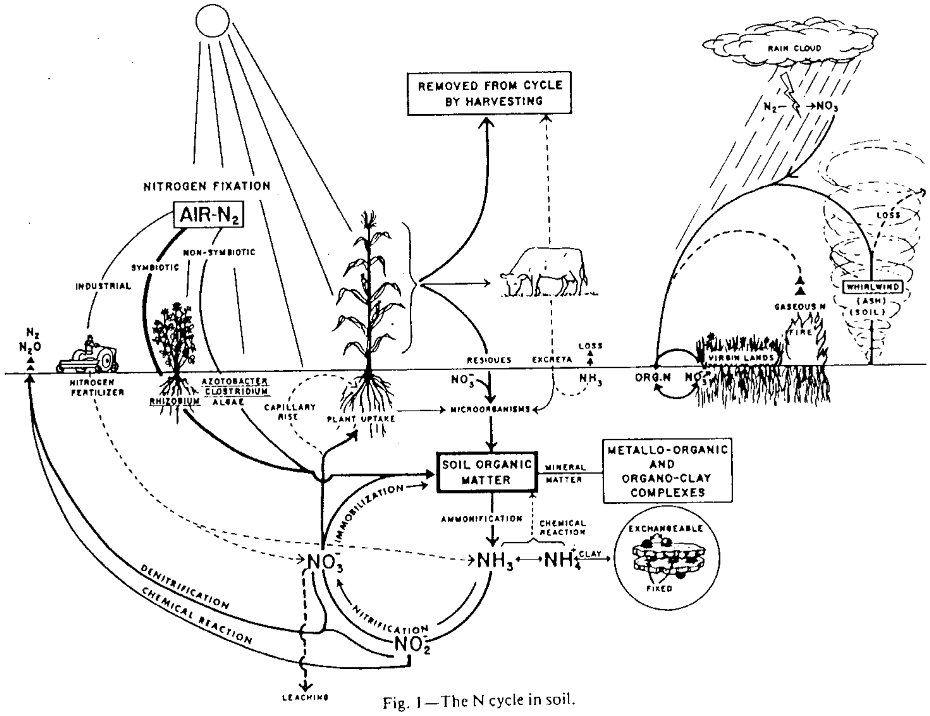


Fig. 1—The N cycle in soil.

Inorganic Sources of Nitrogen

N_2: Inert N gas found in the atmosphere

NO_x: Nitrous oxide, is found in the atmosphere and is a component of automobile exhaust and industrial processes.

NH_3: Ammonia, is a volatile gas and often is lost from soil applied ammonium fertilizer into the atmosphere.

NH4+: Ammonium, is a positively charge cation found in the soil

NO_2^-: Nitrite, is a negatively charged anion found in the soil.

NO_3^-: Nitrate, is a negatively charged anion found in the soil and at times in the atmosphere.

Plants absorb most of their N in the ammonium (NH_4^+) or (NO_3^-) forms. The availability of these two forms of N for plant uptake largely depends on the liberation of inorganic N from organic sources or the application of fertilizers which contain either NH_4^+ or NO_3^-.

Note: The proper way to express nitrate concentration is as NO_3-N, the concentration of elemental N that was measured in the nitrate form. The following conversions are based upon molecular weights:

To convert NO_3^- - N to NO_3^-:

$$NO_3^- N \times 4.4 = NO_3^-$$

To convert NO_3^- to NO_3^- -N:

$$NO_3^- \times 0.23 = NO_3^- \text{-} N$$

Organic Sources of Nitrogen

Organic sources of N include Amino Acids, Proteins, Amino Sugars, and other complex, generally unidentified compounds.

Immobilization and Mineralization of Soil Nitrogen

Soil N is very dynamic and is constantly shifting back and forth between inorganic and organic forms. The "IMMOBILIZATION" of N refers to the absorption of plant-available N forms (NH_4^+ and NO_3^-) by plants and microbes and their transformation into amino acids and proteins. This form of N is no longer available for plant or microbial uptake and has been "immobilized" within the plant or microorganism tissue.

At some future time these organic N compounds will undergo a decomposition process by bacteria, fungi, and other organisms to liberate plant available inorganic N forms (NH_4^+, NO_2^- and NO_3^-). This process of decomposition and liberation of NH_4^+, NO_2^- and NO_3^- from plant tissues is known as "MINERALIZATION" because mineral forms of N are liberated. Both immobilization and mineralization are on-going processes in the soil and generally are in balance with one another. That is, just as much nitrogen is being liberated into the soil by mineralization (organic matter decomposition) as is being immobilized (absorbed by plants). However, this balance can easily be disrupted by the incorporation into the soil system of organic residues which have high carbon to nitrogen ratios (C/N). The rate at which organic matter decomposes to release N depends on the relative proportions of easily decomposed versus more difficult to decompose organic compounds.

Organic residues which have high C/N ratios are very difficult to decompose because of their high carbon content. These include materials such as hay straw, pine needles, corn stalks, dry leaves, saw dust, etc. Some of these materials may have C/N ratios in excess of 100:1. The more difficult to decompose organic N compounds include cellulose, lignin, oils, fats, and resins.

Organic residues which have low C/N ratios decompose relatively easy. These include alfalfa, clover, manures, sludge, immature grasses, etc. Generally, the more immature the plant material, the lower C/N ratio. These materials can decompose rapidly and in many cases actually contribute to soil N levels. Easily decomposed organic N compounds include sugars, starches, proteins, and hemicellulose.

Shortly after the soil incorporation of organic residues which have a high C/N ratio, soil microorganisms begin to attack and decompose the material. The soil microorganisms utilize the carbon components of the residue as an energy source and require available N in order to form proteins for their bodies.

There is extreme competition between the microorganisms for a limited amount of soil N. These microorganisms not only compete between themselves for this N, but also compete against crops for this vital nutrient. During the decomposition process, available soil N levels drastically decrease and the carbon in the organic material is liberated as CO_2 into the atmosphere. Once the materials are decomposed, the microorganisms no longer have a food source and begin to die off. The decomposition of these microorganisms once again mineralizes the protein in their bodies and liberates plant available NH_4^+ and NO_3^-.

This biological process can take a great deal of time and is dependent on soil conditions. The process can be accelerated by applying N fertilizer sources at the time of incorporation of the residues to supply sufficient N to maintain the activity of the microorganisms.

In the mineralization process, complex organic compounds become simpler organic compounds, and simple organic compounds eventually lose all their carbon to become inorganic NH_4^+ which can be converted to NO_3^-. The mineralization process takes place step-wise by the processes of AMINIZATION, AMMONIFICATION, and NITRIFICATION. Aminization and ammonification are performed by heterotrophic microorganisms and nitrification is brought about mainly by autotrophic soil bacteria. Heterotrophs require organic carbon compounds for their energy source. Autotrophic organisms get their energy from the oxidation of organic salts and their carbon from the carbon dioxide in the air.

AMINIZATION

Heterotrophic soil microorganisms are diverse and include numerous groups of bacteria and fungi. Each group is responsible for one or more steps in the many reactions that result in organic matter decomposition. The end products of the activities of one group furnish the substrate for the next, and so on down the line until the material is decomposed. Aminization is one of the final steps in the decomposition of nitrogenous materials. Simple proteins are hydrolyzed (bonds are broken and water molecules added) to form amines and amino acids. The process can be represented as follows:

$$\text{proteins} = R\text{-}NH_2 + CO_2 + \text{energy} + \text{other products}$$

AMMONIFICATION

The amines and amino acids released by aminization are used by other soil heterotrophs and broken down further to ammoniacal compounds. This process, called ammonification, can be represented as follows:

$$R\text{-}NH_2 + HOH = NH_3 + R\text{-}OH + \text{energy}$$

The ammonia produced by this process may be used in several ways in the soil.

1. Be converted to nitrite and nitrate by the process of nitrification.
2. Be used directly by plants.
3. Be used by soil microorganisms.
4. Be tied up by certain types of soil clays.

NITRIFICATION:

The conversion of ammonium to nitrate is called nitrification. It is an oxidation process and releases energy for the use of soil microorganisms. The conversion is a two step process in which ammonium is first converted to nitrite (NO_2) and nitrite is converted to nitrate (NO_3). The conversion of ammonium to nitrite is performed by a number of soil microorganisms but the most important is a group of obligate autotrophic bacteria known as NITROSOMONAS. This process can be represented as follows:

$$2\ NH_4^+ + 3\ O_2 = 2\ NO_2^- + 2\ H_2O + 4\ H^+$$

The conversion of nitrite to nitrate is also performed by a number of soil microorganisms but is performed mainly by another group of obligate autotrophic bacteria known as NITROBACTER. This process can be represented as follows:

$$2\ NO_2^- + O_2 = 2\ NO_3^-$$

The resulting NO_3^- is highly mobile in soils and is easily lost from the soil with water that moves downward laterally through a soil profile. This NO_3^- is a potential pollutant if it reaches surface and ground water supplies.

It is important to remember that these processes require molecular oxygen; that is, they take place most rapidly in well-aerated soils. Poor aeration due to soil wetness or lack of pore space will slow or stop the mineralization process. Also, since living soil microorganisms are responsible for the processes, the rate of reaction is very dependent on soil environmental conditions. These include soil temperature, soil moisture, soil pH, tillage system, cropping system, and the presence of other nutrients. This has practical implications when organic wastes are soil-applied as fertilizers. The rate at which N is released by organic wastes is dependent on the soil environment as well as the characteristics of the waste itself.

The Acidification of Soil Through Nitrification

During the nitrification process, two H^+ cations are liberated which can accumulate and significantly reduce the pH of the soil. The application of any fertilizer which carries part of its N in the ammonium form will ultimately decrease the soil pH due to the nitrification process. The continued use of ammonium sulfate will drastically reduce the soil pH of agricultural soils. Ammonium nitrate and urea will also cause a decrease in soil pH, but not to the same degree as ammonium sulfate. In order to not induce problems with soil acidity through the use of ammonium fertilizers, it is recommended that a well planned liming program be an integral part of the farming enterprise.

Denitrification

Denitrification is the biological reduction of soil nitrates under anaerobic conditions. If nitrates are present in the soil and the soil is waterlogged, nitrates can be transformed into N_2 and N_2O gases. These gases can then escape to the atmosphere. Denitrification losses vary with degree of soil saturation, duration of saturation, organic matter content and soil pH. Obviously the greater the soil saturation and the longer the time of saturation favors denitrification. Alkaline soil pH also favors the denitrification process. From a practical viewpoint, the best way to prevent nitrate losses from denitrification is to promote farming practices that encourage adequate soil aeration, reduce soil water logging, and maintain soil pH in the 5.5 to 7.0 range.

Nitrogen Fixation

Nitrogen can be fixed from the atmosphere either by natural or by synthetic processes. In either case, N_2 gas is transformed into forms which are plant available such as NH_{4+} or NO_{3-}.

Biological processes:

Biological fixation may be symbiotic or non-symbiotic. Symbiotic N fixation refers to microorganisms fixing N while growing in association with a host plant. Both the plant and the microorganisms benefit from this relationship. The most widely known example of such a symbiotic association is between Rhizobium bacteria and plants such as soybean, peanut and alfalfa. These bacteria infect the plant's roots and form nodules. The bacteria within these nodules fix N_2 from the atmosphere and make it available to the plant. The legume in turn provides carbohydrates which the bacteria use as an energy source. The quantity of symbiotic N which may be fixed ranges from a few pounds per acre to over 500 lbs/acre/year in some cases, with values of 200 lbs/acre/year being common.

From a nutrient management point of view, it makes good sense to give credit for residual N following a legume crop. Not only is pollution potential reduced, but less fertilizer applied means lower fertilizer costs, and better management of N-sensitive crops.

Non-symbiotic N fixation is carried out by free-living bacteria and blue-green algae in the soil. The amount of N fixed by these organisms is much less than the amount fixed symbiotically. Some estimates of the N fixed by these organisms range from 20 to 45 lb/A, but generally accepted figure is about 6 lb/A. From an agronomic standpoint, these sources of N are not very significant.

Fixation of Nitrogen from Lightning:

Nitrogen may be fixed by the electrical discharge of lightning in the atmosphere. The heat from lightning can form NO_3--N, which is then brought to the earth through rainfall. Industrial pollution may also contribute to the N level of rain or snow, which may be important at the local level. However, the amounts of N generally brought the soil through these processes is probably on the order of 5 to 10/lbs/acre/year.

Synthetic or Industrial Processes of Nitrogen Fixation:

Industrial processes can very efficiently fix N in plant available forms. The most important process synthesizes ammonia (NH_3) from N and hydrogen (H), shown as follows:

$$N_2 + 3\,H_2 \text{ ---------> } 2\,NH_3$$

The hydrogen (H_2) is usually obtained from natural gas and the nitrogen (N_2) comes directly from the atmosphere. Once in the ammonia form (NH_3), it serves as the raw material for many other materials that contain nitrogen, such as ammonium nitrate, ammonium sulfate, sodium nitrate, urea aqua ammonia, nitrogen solutions and ammonium phosphates. Essentially all commercially available N fertilizers originate as NH_3 formed from atmospheric N.

Losses of Nitrogen

Nitrogen can be easily lost from an agricultural system by various pathways. Those pathways include volatilization, leaching and runoff, and crop removal.

VOLATILIZATION, or the gaseous loss of ammonia, may occur under certain conditions with ammonium fertilizers. In situations where the soil is pH alkaline, or where limestone has recently been applied on acid soils, applications of ammonium sulfate, urea or ammonium nitrate may result in the transformation of the ammonium (NH_4) to ammonia (NH_3) which may be lost to the atmosphere. This situation can be avoided by incorporating these fertilizers into the soil in the case of soils with alkaline pH, or waiting at least a month after limestone applications to surface apply ammonium fertilizers.

UREA prills are particularly prone to volatilize if left on the surface of any soil and there is sufficient moisture and adequate temperatures. This material should always be incorporated or banded into the soil to reduce volatilization losses. Irrigation immediately after the soil application of urea is very effective in reducing losses. Some studies indicate that under optimal conditions, if not properly incorporated into the soil, N losses could exceed 16% of the nitrogen contained in the urea.

ANHYDROUS AMMONIA is a gaseous form of N and is very prone to volatilization if handled improperly. This material must be knifed into the soil at sufficient depth to prevent loss. Soil moisture is important, and the soil should be moist but not saturated. Sandy and low CEC soils need deeper application than finer textured soil types.

LEACHING AND RUNOFF are other important sources of N loss. Leaching occurs when inorganic forms of N, particularly nitrite (NO_2-) and nitrate (NO_3-) are solubilized and carried with water through the soil profile or with surface waters. Apart from being an economic loss to the farmer, these nitrites and nitrates are potential pollutants to ground water and surface water resources. Factors which contribute to nitrite and nitrate leaching or runoff include the following.

- Heavy, one-time applications of N fertilizers on sandy textured soils.
- Over applications of manures or sludge to land.
- Improperly timed applications of N fertilizer.
- Poorly designed or non-existent soil conservation measures.
- Periods of exceptionally heavy rain.

CROP REMOVAL is a very important, but often overlooked, way that N is lost. Many crop materials contain 2 to 4% N on a dry weight basis. If these crop materials are exported from the farm in the form of grains, forages, meat, etc. there is a net loss to the farm's balance sheet for N. However, if crop residues and manures are saved and returned to the soil, some of the N will be recycled for future crops. The N content of many crops is shown in SoilFacts AG-439-16 "Nutrient Removal by Crops in North Carolina".

Chapter 3 Phosphorus

Phosphorus in the Plant

Although phosphorus is required in lower amounts than other major nutrients, it is critical in the early developmental stages of growth, and in energy transfer within the plant throughout the growing season.. Typical phosphorus contents of plants range between 0.1 to 0.46 percent P on a dry weight basis, approximately ten times less than for nitrogen or potassium. Phosphorus apparently stimulates young root development and earlier fruiting (earliness). It is essential in several biochemicals that control photosynthesis, respiration, cell division, and many other plant growth and development processes. Phosphorus is concentrated in the seed and fruit, and strongly affects seed formation. Since the primary functions of P involve energy and growth regulation, deficiencies affect vegetative growth and yield more than quality, but in seed crops, quality can also be affected.

Uptake of P occurs primarily in the form of HPO_4^{2-} and $H_2PO_4^-$ (orthophosphate) forms. The particular form depends on pH, with the $H_2PO_4^-$ form most common in acid soils. Other forms can be taken up by plants, but in much smaller quantities. Within the plant, concentrations of P are highest in the youngest, actively growing tissue. As crops mature, P tends to move and be concentrated in the fruit or seeds.

Deficiencies of P so strongly affect overall growth rates that foliar symptoms are not very dramatic when compared to those seen with N or K. Only when P is very low or and other nutrients are well supplied are symptoms distinctive. Plants will appear stunted, and abnormally dark green in color. In severe cases, especially in cool soils, the foliage, stems or stalk may exhibit reddish-purple pigment. Phosphorus translocates from older tissue to new, actively growing tissue quite readily, so discoloration tends to appear on older tissue first. Phosphorus deficiency is often difficult to diagnose correctly from visual symptoms alone. Soil and plant tissue analyses are required to confirm this deficiency.

Phosphorus in the Soil

Phosphorus is unique among the anions in that it has low mobility and availability in soils. It is difficult to manage because it reacts so strongly with both solution and solid phases of the soil. As a result, mobility through the soil is extremely limited in all but organic soils or white bleached sands with extremely low CEC's. While P occurs in a multitude of inorganic and organic forms in the soil, the plant available forms of phosphorus are limited primarily to solution HPO_4^{-2} and $H_2PO_4^-$, with the dominant form determined by the soil pH. In soils with pH values greater than 7.0 the HPO_4^{-2} form predominates, while in soils with pH between 4.3 and 7.0, the H_2PO_4- form predominates. Regardless of the form, the concentration of soluble P in soil solution is very low.

The plow layer of most agricultural soils contain about 400 to 1600 pounds per acre of total P, mostly in unavailable forms. The primary source of P in native soils is apatite, a calcium phosphate that also contains hydroxides or fluorides. This is the mineral which is found in bones and teeth. Other sources include decaying plant and animal residues, humus, and microorganisms. In acid soils, iron and aluminum in solution and in oxide and hydroxide forms react strongly with added P, binding it so that it is unavailable to plants. Higher organic matter levels can help reduce P “fixation” reactions, by binding Al, Fe and Ca., and forming soluble complexes with P. In alkaline soils, phosphorus readily reacts with calcium to form sparingly soluble calcium phosphates. Phosphorus availability in the highly weathered soils of the southeastern U.S. peaks within the range from of 5.5 to 6.5. Not all the P added as fertilizer will remain available to the first crop, however, the residual will remain in the soil to be taken up by later crops

Since P is strongly bound by the soil, it moves primarily through diffusion. The rates of diffusion are very slow, such that it may move less than one-fourth of an inch in the course of a cropping season. In dry soils, the rate of diffusion may be even slower. Thus the importance of placing P within the root zone cannot be overlooked.

Only a small portion of the total P in the soil is in solution at any one time - usually less than four pounds per acre. Concentrations in soil solution range from less than 0.1 to around 5 ppm. Most crops respond to P additions when soil solution levels are less than 0.1 to 0.2 ppm.. Solution P levels must be constantly replaced, as often as twice a day during the peak uptake period of the growing season. The processes of equilibrium (exchange and dissolution) as well as organic matter decay and fertilizer additions account for the movement of P from the enormous soil reserves to the solution form.

Even though phosphorus is not easily leached from soils, it can be a potential pollutant of surface waters. Phosphorus enters surface water through soil erosion. Even though bound tightly to soil surfaces under aerated conditions, P availability can dramatically increase once deposited in water. Thus erosion results not only in loss of the most productive and fertile soil, it can contribute to water quality problems through enrichment of ecosystems developed under low P conditions.

Prior to cultivation, soils of the southeast had inherently low available P levels. Years of intensive fertilization for cash crops such as tobacco, cotton and peanuts, and the increase in land application of manures and biosolids, have raised soil test levels to high or very high for large areas within the region. As a result, these soils have adequate P to supply crops for 10 or more years. Agronomically and economically, there is little justification for further P additions on these soils, except for replacement of P removed with the crop, or for starter fertilizers on responsive crops such as corn or cotton. With the possible exception of P-induced Zn deficiencies on soils with near-threshold levels of

Zn, current research has, for the moment, presented little evidence that excessive soil P levels are directly harmful to the crop or the environment. But even minimal soil erosion losses can move P enriched surface soils into surface waters, where environmental impacts may be profound. Sludge and manure applications to soils high in available P should be based on agronomic needs.

Fertilizer Sources

Source	**% P_2O_5**	**Water Soluble %**
Normal superphosphate	16-22	90
Concentrated superphosphate	44-52	95-98
Monoammonium phosphate	48-61	100
Diammonium phosphate	48-53	100
Ammonium polyphosphate	34-37	100
Phosphoric Acid	55	100
Super phosphoric acid	76-85	100
Rock phosphate	3-26	0
Bone Meal	22-28	--

Water soluble P is dissolved readily in water only. **Citrate soluble P** is the additional P extracted by the neutral, normal citrate, a weak complexing agent. The sum of water soluble and citrate soluble P is called **available -P**. The P remaining after extraction with water and citrate is called **citrate insoluble P**, and although it may be released eventually, it is not readily available to the first crop grown after application.

Phosphorus does not actually occur as P_2O_5, in the fertilizer or the soil. Most scientific literature now uses percent of elemental P (%P) instead. To convert from % P_2O_5 to %P, multiply by 0.44.

Factors Affecting Availability

Phosphorus availability depends on several soil conditions. Some of these are related to interactions with soil components, and others affect the ability of the root to take P from the soil.

1. Amount of Clay - increased clay content results in greater retention of P by the soil.
2. Type of Clay - kaolinite and iron oxides retain more P than 2:1 clays
3. Soil pH - determines the form of P, and the levels of Al, Fe and Ca in soil solution. Also affects pH dependent charge.
4. Soil P Levels - soils very high in P will eventually saturated binding sites and tend to release higher concentrations of P to soil solution.
5. Temperature - at low and high temperatures, ability of the plant to remove P is decreased

6. Compaction - limits root penetration and volume of the soil contacted by the root system
7. Aeration - poorly aerated, and poorly drained soils can limit root system development
8. Moisture - low moisture limits movement of P and affects crop development, excess moisture affects rooting and limits P uptake
9. Time and Method of Application - Increasing the time of contact increases the amount of P retained by the soil in unavailable forms. On soils with high P retention, banded applications may provide more available P to the crop when soil P levels are low. As soil fertility levels increase, the banding advantage decreases., although starter fertilizers frequently result in improved yields due to improved early season development in some crops. Broadcast applications are more rapid and cheaper to apply, can provide larger rates without crop injury, and can result in better mixing within the entire root zone which over time can increase rooting depth.
10. Solubility and/or Particle Size - -Retention tends to increases as the solubility increases and as particle size of the applied P decreases.
11. Incorporation vs. Surface Application - surface applied P is usually the least efficient method of placing P. Incorporation throughout the plow layer leads to improved rooting depth and more effective uptake over time. In no-till situations, incorporation is not possible. Building good P levels prior to initiating a no-till system is strongly recommended. As residues build on the soil surface, natural P cycling in the soil by animals, and movement through macropores, surface applications of can supply the needs of the crop.
12. Other nutrients - Although P availability is little affected by the presence of other essential nutrients within normal ranges, the presence of these nutrients can stimulate P uptake.

Phosphorous and the Environment

Release of P from the field can cause **eutrophication**, or an excessive increase in fertility and productivity of natural waters which contain low levels of native P. Accelerated growth of algae and water plants can cause surface scums of algae, foul odors, insect problems, impeded water flow and boating due to excessive weed growth, and disappearance of desirable fish species as oxygen levels are depleted by decaying vegetation. Natural waters which are sensitive to P can be dramatically affected by inputs of P from agriculture, industry, sewage and urban runoff.

From the agricultural standpoint, release of P is greatly reduced when soil erosion is reduced. Best management practices that reduce P release include practices which decrease runoff and soil erosion such as tillage practices, terraces, grassed waterways, buffer strips, proper application timing, and incorporation of manure and fertilizers to coincide with crop removal, and reduce P runoff.

Chapter 4 Potassium

Potassium in the Plant

Potassium is required by plants in approximately the same or slightly larger amounts as nitrogen. Uptake of K occurs in the K^+ form. Most of the functions of K in the plant are indirect in that K is necessary for other chemical reactions to operate properly. Some 60 enzymes require the presence of K, with high concentrations of K found in the active growing points and immature seeds. Potassium forms no organic compounds within the plant, but remains in the ionic K^+ form. The plant uses K in photosynthesis, in carbohydrate transport, in water regulation, and in protein synthesis. The benefits of proper K nutrition include improved disease resistance, vigorous vegetative growth, increased drought tolerance, improved winter hardiness of forages, and decreased lodging. As a result, potassium fertilization is frequently associated with improved crop quality as well as better handling and storage properties.

Plants deficient in potassium are stunted and develop poor root systems. Deficiency symptoms are most obvious on the older, lower leaves since this element is readily translocated within the plant. Symptoms begin as interveinal chlorosis or "bronzing" near the edges of lower leaves, and develop into a firing or scorch as the deficiency continues. This firing moves inward until the entire leaf dies and is shed. Since K deficiency can result in leaf shedding, it reduces the ability of the plant to produce carbohydrates, and ultimately, yields. Plants, especially small grains and corn, are prone to lodging when they are deficient in potassium. Severe deficiency causes premature defoliation, delayed maturity, and plant death.

Potassium in the Soil

The availability of soil potassium depends primarily on the types and amounts of soil minerals present. **Unavailable potassium** found in rocks and primary minerals becomes available only after these minerals begin to decompose. Soil clays which can collapse around the potassium ion are capable of "fixing" K so that it is no longer free to exchange with other cations in solution. This pool of potassium is termed **slowly available,** and can be very important in soils containing vermiculite and some montmorillonite in their clay fractions. Slowly available K is released by acid weathering of the clay or by cycles of wetting and drying. Soil solution and exchangeable K are considered **readily available** for plant uptake. Soil solution rarely holds more than 8 to 10 pound per acre of available K, which for many crops is less than a three day supply.

Potassium does not move readily in most soils. In these soils, movement I primarily through diffusion. It is much less mobile than nitrate nitrogen, but more mobile than phosphorus. However, on sandy soils with low CEC, potassium can move by mass flow, and loss from the surface soil can be significant, especially after periods of heavy rainfall.

The fate of applied K depends on the CEC and clay minerals present. Potassium may be leached from the root zone before it interacts with soil solids (minimal), or it can exchange for other cations on the exchange complex, and be held in a readily available form for future use by plant roots. If vermiculites or strongly charged montmorillonite clays are present, K may be fixed in interlayer region of these 2:1 clays, and be slowly released as the minerals are subjected to wetting and drying cycles, or acid weathering.

Potassium is not known to cause any environmental problems at this time. But from the standpoint of economics, it makes good sense to manage K in a way that minimizes losses. Loss of K is minimized by implementing good erosion control practices, maintain good soil pH to increase soil CEC, building soil organic residues where possible, and using split applications to reduce leaching losses on soils with low CEC.

Potassium Sources

There are many unrefined and manufactured sources of potassium, but plants always absorb potassium in the same form, K^+. Some of the most commonly used potassium sources are potassium chloride (60% K_2O), potassium sulfate (50% K2O), potassium-magnesium sulfate (22% K_2O), potassium nitrate (44% K_2O), and animal manures (1-2% K_2O).

Fertilizer content of potassium is usually expressed as K_2O even though potassium does not exist in this form in the fertilizer. To calculate the amount of K_2O, simply multiply K by 1.2; to calculate the amount of K from K_2O, multiply by 0.83.

	Percent Composition			
Material	K_2O	Mg	S	N
Potassium chloride	60-62	-	-	-
Potassium sulfate	50	-	16	-
Potassium, magnesium sulfate	22	11	22	-
Potassium nitrate	44	-	-	13

Chapter 5 Secondary Nutrients

Calcium in the Plant

Calcium, a structural component of plant cell walls, is most abundant in plant leaves. It is involved in cell growth, both at the plant terminal and at the root tips, and apparently enhances uptake of nitrate-N. Calcium is not translocated within the plant, so an adequate supply throughout the season is important for sustained terminal and root growth. Cotton roots will not grow into a soil area unless it has adequate Ca.

Calcium deficiency results in poorly developed root systems and relatively little fruit of poor quality. Foliage symptoms are extremely variable. Since Ca is immobile in the plant, affected plants may display malformed young leaves and abnormal terminal growth. Calcium is not readily leached from the soil, although levels may be quite low in sandy surface soils. Since liming materials contain large amounts of Ca, deficiencies rarely occur in crops other than peanuts, potatoes and vegetables subject to blossom end rot.

Magnesium in the Plant

About 15-20% of the plant Mg is contained in chlorophyll, without which the plant could not capture energy from the sun for growth and development. Magnesium also appears to activate a number of enzymes and plays a role in protein synthesis and phosphorus reactions. Oil seed crops have much higher seed Mg than cereal seed, with Mg and S apparently influencing oil formation within the seed.

In cereal crops, Mg deficiency symptoms include interveinal chlorosis on the lower leaves. Leaf edges may also show a thin hint of red or purple. On broad-leaved crops, the lower leaves of Mg-deficient plants may initially show interveinal chlorosis and become purplish-red with green veins.

Behavior of Calcium and Magnesium In The Soil

Calcium and magnesium behave very much the same in the soil due to similar chemical properties. Both are divalent cations, and their ionic size is about the same. The mobility of both calcium and magnesium is relatively low, especially compared to anions or even other cations such as sodium or potassium. Therefore, loss of these two cations through leaching is relatively low, especially when applied in the form of lime. Where soils are deficient in Ca and lime is not an alternative because of pH or insolubility, a more soluble source such as gypsum (calcium sulfate) should be used.

Sulfur in the Plant

Sulfur is a constituent of several plant biochemicals which regulate plant growth. This element is essential in the synthesis of chlorophyll and in photosynthesis reaction. Along with Mg, S plays a role in the formation of oils within the seed.

Sulfur deficiency symptoms include pale green to yellow leaves along with small, spindly plants and short, slender stalks. The veins of the leaf generally remain green. Symptoms of N and S deficiencies are very similar, but N deficiency symptoms occur near the bottom of the plant while S deficiency symptoms are found near the top or throughout the whole plant. Visual symptoms can be misleading! Use plant tissue analysis when in doubt.

Behavior Of Sulfur In The Soil

Sulfur occurs primarily in the sulfate (SO_4^{-2}) form in the soil. Elemental sulfur (S) may be used as a source of this nutrient, but it must first undergo a biological oxidation process that is dependent upon the Thiobacillus bacteria to produce sulfate. This process is produces large amounts of acid, and occasionally elemental sulfur is used to decrease soil pH. Fertilizer materials containing sulfate do not acidify the soil, although pH may decline slightly for a short period (salt effect).

Sulfate, being an anion (SO_4^{-2}), is not strongly retained and can readily be leached form most soils. Until recently, deficiencies of sulfur were relatively uncommon due to the fact that the atmosphere contained significant amounts of this element due to the use of coal and oil fired processes. Also, commercial fertilizers using ordinary superphosphate contained significant amounts of sulfur. The increased use of high analysis fertilizers such as urea and triple superphosphate with low amounts of S, deficiencies have become somewhat more common.

Sources of Ca, Mg and S

There are numerous sources of calcium, magnesium and sulfur. The following table lists the most common fertilizer sources. In addition, materials such as bone meal, wood ash, manures and sludge can contain adequate significant amounts of these elements. For additional information see the SoilFacts entitled “Nutrient Content of Fertilizers and Organic Materials” (AG-439-18, North Carolina Cooperative Extension Service).

Common inorganic sources of calcium, magnesium and sulfur.

Material	Chemical Formula	Ca	Mg	S
			percent	
Calcium chloride	$CaCl_2$	36	0	0
Burned Lime, or Calcium oxide	CaO	70	0	0
Calcitic Limestone	$CaCO_3$	32	3	0.1
Dolomitic Limestone	$CaCO_3,MgCO_3$	21-30	6-12	0.3
Gypsum	$CaSO_4$	22	0.4	17
Hydrated Lime	$Ca(OH)_2$	50	0	0
Magnesium ammonium phosphate	$MgNH_4PO_4{\cdot}6H_2O$	0	15	0
Magnesium oxide	MgO	0	45	0
Magnesium sulfate	$MgSO_4{\cdot}7H_2O$	2	10	14
Potassium magnesium sulfate	$K_2SO_4.2MgSO_4$	0	11	22
Ammonium sulfate	$(NH_4)_2SO_4$	0.3	0	24
Ammonium thiosulfate	$(NH_4)_2S_2O_3$	0	26	0
Elemental S	S	0		0
Flowable			52-70	
Wettable, Flowers			90-100	
Potassium sulfate	K_2SO_4	0.7	1.0	18
Sulfuric acid	H_2SO_4	0	0	20-33

Chapter 6 Micronutrients

Introduction

Micronutrients are defined as those elements required in small quantities for higher plant growth and reproduction. The exact quantity needed varies with plant species and the specific element. Seven elements are generally considered as plant micronutrients, these include boron (B), Copper (Cu), chlorine (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn). To better understand the relative amount of these elements needed by plants, we can look at the plant removal rate of a crop like corn. A 150 bu/acre corn crop will typically remove 135 pounds of nitrogen, 53 pounds of phosphate (P_2O_5) and 40 pounds of potash (K_2O) per acre. In comparison to these "macronutrients", the removal rates for the micronutrients boron (B), copper (Cu) , iron (Fe), manganese (Mn) and molybdenum (Mo) and zinc (Zn) are 0.06, 0.06, 0.10, 0.09, 0.03 and 0.15 pounds per acre respectively. While the amounts are indeed small, without them plants would not survive.

Manganese (Mn)

Manganese in nature is found as oxides, carbonates, and silicates. The main ores are pyrolusite, rhodochrosite, manganite, hausmannite, braunite, and rhodonite. Manganese is one of the most commonly found micronutrients in nature. Normal concentrations found in soils world wide has been reported as 4,000 ppm total Mn. Total manganese in soil is not used to predict plant response. However, soil extractable Mn is a reliable predictor of plant response.

Manganese availability is mostly affected by soil pH , organic matter and soil moisture. With pH having the greatest effect. Manganese is most available below pH 5.5 . Manganese toxicity in acidic soils can easily be alleviated by liming the soil above pH 6.5. Manganese has an antagonistic interaction with Fe. As Mn concentrations in plant tissues increase, Fe concentrations generally decrease. The reverse is true also. The ratio of Fe to Mn in most growing medium is maintained between 1.5 and 2.5 to maintain plant health. If the ratio is above 2.5, symptoms of Fe toxicity can occur; if it is below 1.5, the plant can suffer from Mn toxicity. Other antagonistic elements include P, B and Ca.

Response to Mn fertilizer varies with the source and application method. In general, broadcast applications are the least effective because they provide the greatest opportunity for other elements to react with Mn. Banded and foliar applications are more effective.

Plants

Manganese is important in activating many plant enzymes in the metabolism of organic acids, phosphorus, and nitrogen. Manganese activates the reduction of nitrate to ammonia and is involved in photosynthesis. It is a constituent of some enzymes involved in respiration and protein synthesis.

Manganese deficiencies are most common on sandy, acidic mineral soils that are low in native Mn, soils with pH above 6.5 , thin, peaty soils overlying calcareous subsoils, alluvial soils and marsh soils derived from calcareous materials, poorly drained calcareous soils high in organic matter, and calcareous soils freshly broken up from old grassland. Manganese deficiency symptoms typically include interveinal chlorosis with dark-green veins. Under severe deficiency, leaves develop brown speckling and bronzing in addition to interveinal chlorosis. Wheat and barley often exhibit colorless spots. In corn, deficient leaves are light green with parallel yellowish stripes. Crops most sensitive to Mn deficiency include: beans, lettuce, onions, peas, potato, sorghum. soybean, spinach, sudangrass and wheat.

For currently growing crops in NC a foliar application is the most effective means of correcting a Mn deficiency. A totally water soluble source of Mn is required for this treatment. Depending on the severity and stage of growth, two application may be required. For preplant conditions, if NC soil test results call for Mn an acid forming starter fertilizer containing Mn should correct the problem. Broadcast applications of Mn are not recommended when the pH is greater than 6.2. When soil tests indicate that over liming is the principal cause of Mn deficiencies, application of acid-forming fertilizers or deep tillage should be considered for lowering the soil pH. Foliar and/or acid banded applications are remedial and may be required for each sensitive crop until the soil pH is below 6.2. The following table contains the NC Cu recommendations. For foliar application apply the recommended Mn in about 20 gallons of water. For nursery crops or aerial application apply a 1 % solution.

Manganese application rates in NC based on application method.

Soil Group	Banded	Broadcast	Foliar Spray
		pounds of elemental Mn/Acre	
Mineral	3	10	0.5
Mineral-organic	3	10	0.5
Organic	3	10	0.5

Manganese toxicity generally occurs in well-drained soils with a pH below 5.5. Toxicities have also been reported under flooded conditions at higher pH levels. Manganese concentrations in plant tissue associated with toxicity generally occur over 200 ppm. Toxic concentrations vary with plant species and environmental conditions. In soybeans, Mn deficiency has occurred when tissue concentrations drop below 20 ppm Mn, and toxicity levels have been reported above 250 ppm. Manganese toxicity symptoms in plants are characterized by marginal chlorosis and necrosis of leaves, leaf puckering, stunted growth and depressed yields. Soils containing toxic concentrations of Mn can be remediated with lime or organic matter.

Fertilizer Sources

Source	% Mn
Manganous oxide	1 - 3
Manganese methoxyphenylpropane	41 - 68
Manganese Frits	10 - 12
Manganese Chloride	17
Manganese Oxide	62 - 70
Manganese Sulfate	24
Basic Slag	1 - 3

Zinc (Zn)

Most of the Zn produced world wide comes from ores containing Zn-sulfide minerals. Although there are more than 80 Zn minerals known, only a few are commercially important. Those of commercial interest and use include sphalerite and wurtzite and their weathered products smithsonite and hemimorphite. Zinc concentration in the different minerals vary and is influenced by the concentration in the magma, premetamorphic rock , and the ability of the crystal lattice to incorporate Zn.

To a large extent, the Zn content of soil depends on the nature of the parent material, organic matter, texture and pH. The most quoted range for total Zn in soils is 10 to 300 ppm. Mean soil concentrations of Zn in the US are around 54 ppm. When using soil tests for predictive plant responses extractable Zn should be used. The distribution of extractable Zn in soil profile has greater variation with soil depth that does total Zn. In most well drained soils, extractable Zn usually decreases with increasing soil depth. Extractable Zn has been positively correlated with total Zn, organic matter, clay content and cation exchange capacity and inversely correlated with free $CaCO_3$, soil pH and base saturation.

Zinc availability is greatly affected by soil pH. As soil pH increases, Zn availability decreases. The reverse is also true. In one study, extractable Zn declined sharply as the soil was limed from pH 4.3 to 5.0. In another experiment liming the soil to pH 6.1 restricted the Zn supply to forage crop severely.

Zinc availability to plants is lower in organic soils, and in mineral soils with significant amounts of organic matter. In North Carolina, the availability of Zn on soil test reports is adjusted based on soil class as it relates to organic matter content.

Plants

Zinc is important in plant nutrition and functions in enzymes , stability of cytoplasmic ribosomes, oxidation processes, transformation of carbohydrates and synthesis of auxin indole acetic acid. Worldwide Zn is the most commonly deficient micronutrient.

Zinc deficiency is caused primarily by three factors: 1) low content of Zn in soils; 2) unavailability of Zn present in soil to the plant; and 3) management practices that depress Zn availability or uptake. Zinc concentrations are low in highly leached, acid sandy soils such as those found in many coastal regions.

Because plants vary in their requirement for Zn, even among cultivars, it is difficult to establish a single critical value. However, plants with Zn contents below 20 ppm in dry tissue can be suspected of Zn deficiency. Normal ranges are usually 25 to 150 ppm in dry tissue. Micronutrient deficiencies are often induced because of interactions with other nutrients. Zinc uptake is often depressed in the presence of excess P. When large quantities of P are applied on marginal Zn soils a Zn deficiency can occur.

During the growing season if a Zn deficiencies occurs due to high pH and P levels, a foliar application will be required. Foliar Zn can be applied using 0.5 lbs Zn/ac in at least 20 gallons of water. Alternatively, use a 1 % solution. If low zinc levels are known prior to planting, banded Zn at 3 lb Zn/ac or broadcast applications of 6 lb Zn/ac can be made to correct the deficiency.

Extractable Zn concentrations that produced toxicity in acid southeastern soils ranged from 450 to 1,400 ppm for corn and 180 to 700 ppm for cowpeas. Extractable Zn concentrations (Mehlich-3) in Goldsboro, fine-loamy soil that have been identified with toxicity problems with peanuts have been reported as 8.5 ppm (Zn-I = 212) at pH 4.5 and over 17 ppm (Zn-I = 425) at pH 6 .Tissue Zn concentrations for plants showing Zn toxicities have been reported as 200 ppm for cotton, 200 to 238 ppm for peanuts, 526 for tomato, and 1700 ppm for oats on a dry tissue basis. In general once plant tissue levels exceed 400 ppm Zn on a dry weight basis, toxicity can be expected.

Fertilizer Sources

Source	**% Zn**
Zinc Carbonate	52
Zinc Frits	varies
Zinc Phosphates	51
Zinc Chelate	
Na_2Zn EDTA	9 - 14
NaZn NTA	13
NaZn HEDTA	9
Zinc Ammonium Phosphate	34
Zinc Sulfate	22 - 36
Zinc Oxide	78 - 80
Zinc Lignosulfonate	5 - 12
Zinc Polyflavonoid	7 - 10

Copper (Cu)

Soils

Copper is found in nature in the form of sulfates, sulfides, sulfosalts, carbonates and other compounds. Chalcopyrite (34% Cu) is the most abundant Cu mineral. In general, soils derived from coarse-grained materials (sands and sandstone) or from acid igneous rocks contain lower concentrations of Cu than those developed from fine-grained sedimentary rocks (shales and clays) or basic igneous rocks. Average concentrations of total Cu in world soils has been reported around 30 ppm (range 2 to 250 ppm). Agricultural soils normally range from 1 to 50 ppm of total Cu. Severely weathered, leached and acid soils have relative low Cu levels compared to other soils. Extractable or "available" Cu are much lower. Copper is strongly fixed by soil organic matter, Fe, Al, Mn and clay minerals. It is one of the least mobile trace elements in most soils. Copper movement can occur under high application rates on humus-poor, acidic peat soils.

Copper in soil can occur in several forms. From the standpoint of plant nutrition, dissolved and exchangeable Cu are of most importance. Copper availability is reduced at pH 7 and higher and is most available at levels below pH 5. In general, liming can lower Cu uptake in plants. Copper availability to plants can also be negatively influenced by N, P , Zn, Mn and Mo.

Plants

Copper is required in small concentrations (5 to 20 ppm) in plant tissue for normal growth of plants. While tissue concentrations of <4 ppm are generally considered deficient, >20 ppm can be toxic to plants. Copper plays an important role in plant enzymes and enzyme systems. Copper deficiencies can effect photosynthesis, respiration, carbohydrate distribution, N metabolism, cell wall metabolism, water relations, seed production and disease resistance.

Copper deficiencies are most likely to occur on peat and muck soils, alkaline and calcareous soils, poorly drained mineral soils, deep sandy soils low in native copper, and mineral soils high in organic matter. Copper deficiency in plants frequently occurred in areas where acid histosols are brought into agricultural production. Crops most sensitive to Cu deficiencies include wheat, alfalfa, oats, barley, millet, sunflowers, carrots, onions, lettuce and spinach.

Copper deficiency is characterized by chlorosis, necrosis, leaf distortion and terminal die-back with symptoms occurring first in the young shoot tissue. Once absorbed, Cu is poorly transported in plants.

Copper deficiencies can be corrected with direct soil application or foliar sprays. Foliar sprays generally are best for corrective action during the growing season, while soil applications can prevent the deficiency for future seasons as well. In North Carolina, if foliar Cu is desired apply 0.25 lbs Cu/acre in at least 20 gallons of water. On small grains 2 lbs of Cu/acre can be applied with the liquid N. For nursery crops use a 1.0 % solution. Higher rates of Cu may result in foliar burn since the materials like copper sulfate are highly caustic when mixed with water. Copper sulfate mixed with an equal amount of CaO (burnt lime) can be used to prevent foliar burning.

For soil application of Cu apply the rate suggested by NC soil test recommendations. The rates suggested are designed to correct the deficiency and build the soil level for future years. For maximum benefit, Cu should be broadcast and incorporated into the plow layer.

Copper toxicity causes reduced plant growth and vigor, leaf chlorosis, reduced branching, thickening and discoloration of roots. Chlorotic leaf symptoms often resemble Fe deficiency. Copper toxicity has been reported at total soil Cu concentrations of 150 to 300 ppm. Extractable (DTPA or HCl) Cu levels of 20 ppm (Cu-I = 1000) or more have been found to be toxic in some plants. Some researchers reported that Cu may become phytotoxic when 20 to 30 ppm extractable Cu (HNO_3) is present for each 1 % soil organic carbon. Other reported that the threshold of soil-Cu toxicity is about 25 ppm (NH_4-exchangeable Cu) for sandy soils and 100 ppm for clay soils. Soil pH also influences toxicity. Research has shown 50 ppm of Cu (NH_4-exchangeable Cu) to be toxic at pH 5 and 100 ppm at pH 6 to 7.

Fertilizer Sources

Source	% Cu	Water Soluble	Application method
Copper sulfate	22.5	yes	foliar, soil
Copper Ammonium Phosphate	30.0	slight	foliar, soil
Copper Chelates	variable	yes	foliar, soil

Iron (Fe)

Iron is probably the most abundant element in the world. Iron is found as ferric and ferrous oxides, iron silicates, iron sulfides (pyrite) and iron carbonates (ferric and ferrous carbonate). Iron is present in many primary minerals such as hornblende, biotite, and chlorite. The solubility of Fe in soils is largely controlled by the solubility of hydrous Fe-oxides.

Total inorganic Fe in solution varies with soil pH and reaches a minimum in the range of pH 6.5 to 8.0. In general, soil levels range from 200 ppm to 10%. The Fe content of US soils range from 0.23 to 11.2 %. Iron in acid soils readily complex with P reducing the availability of both .

Plants

Iron is important in the activation of several enzyme systems in plants including: fumaric hydrogenase, catalase, oxidase, and cytochrome. A shortage of Fe also impairs chlorophyll production. Iron is thought to be associated with the synthesis of chloroplastic protein. Iron has also been shown to be capable of replacing Mo as the metal cofactor necessary for the functioning of nitrate reductase in soybeans.

Iron is moderately mobile in the plant. Foliar applied Fe is distributed from the leaf where it is applied to young expanding areas of meristematic activity. Iron is translocated by phloem and xylem to the meristem tissue. The amount of Fe in the leaves of a normal plant will generally average a few hundred parts per million.

Iron deficiency world wide is very common . It occurs frequently on calcareous soil and on fruit trees, but often is found on acid soils also. A deficiency of Fe first appears in the young leaves of plants thus reducing new growth. Young leaves develop an interveinal chlorosis . In severe cases, leaves can turn completely white. A deficiency of Fe often occurs even in acid soils, frequently limiting the growth of plants that prefer acid soils such as azaleas and rhododendrons. In most plant species deficiencies occur when the Fe content of leaves is below 10- 80 ppm.

If it is known that a real shortage of Fe exists in the soil and is causing deficiency symptoms, the addition of iron fertilizer or other readily available iron sources can correct the shortage. However, if the iron is rendered unavailable to the plant, as may occur with over liming, fertilizer additions to the soil will not be as successful. Application of Fe as a foliar spray in these cases may be an option. Apply 1/2 to 1 % aqueous solution of ferrous sulfate to recently mature leaves. Unless weather conditions intervene, an increase in green color should occur within two weeks if Fe deficiency caused the chlorosis. If the soil is above pH 6.0, application of 3 - 4 lbs of elemental S or 20 to 25 lbs of iron sulfate per 100 square feet can help alleviate the problem.

Fertilizer Sources

Source	**% Fe**
Iron Sulfates	19 - 23
Iron Oxides	69 - 73
Iron Ammonium Sulfate	14
Iron Ammonium Phosphate	22
Iron Chelates	5 - 14
Basic Slag	10 - 14

Boron (B)

Soil

Boron occurs naturally as calcium and sodium borates derived from minerals. The average concentration of B in the earth’s crust is about 10 ppm. Sedimentary rocks generally have higher levels of B than igneous rocks. Some sedimentary rocks of marine origin can have 500 ppm B or more. Concentration of B in soils is related to the concentration in the parent materials and the degree of weathering. In general soil concentrations range from 2 to 100 ppm. Low B content can be expected in soils derived from acid igneous soils, fresh water sedimentary deposits, and in coarse-textured soils low in organic matter. Boron concentrations in soils are generally higher near the soil surface where organic matter concentrations are higher. There are four main forms of B in soils: water soluble, adsorbed, organically bound, and fixed in clay and mineral lattices. In coarse textured soils low in clay and low in organic matter B is highly mobile and subject to leaching losses. Under these conditions B concentrations are often low in the soil surface. Boron availability in soil may also be influenced by soil pH. In general, B becomes more available to plants with decreasing pH.

Plants

Boron is required for plant growth. It is instrumental in forming the conductive tissue that transports nutrients, in the formation of pollen tubes, in bloom formation, in the translocation of N and sugars form the leaves to the fruit, in the formation of amino acids and proteins and in the utilization of absorbed phosphorus and water. In general, grasses require less B than broadleaf plants and legumes seem to have the highest B needs. Tolerant species seem to accumulate B at a slower rate than sensitive species. Boron is relatively immobile in plants once it is utilized in actively growing tissue. Therefore, it is necessary to have a continuous supply of B throughout a plants active growth cycle. Slow growing and mature plants have lower B requirements than young actively growing plants. Deficiency symptoms often appear on the young tissue first. When B is deficient, plant growth and development are strongly affected. Boron deficiencies symptoms vary widely with the stage of growth and the severity of the deficiency . Symptoms can include stunting, bushy foliage and excessive shedding of fruit.

Boron may be applied foliarly to correct deficiencies or as a standard fertilizer method. A common foliar application rate is 0.25 lbs B/acre in at least 20 gallons of water. Another option is to use a 1 % B solution.

As with other required trace elements, an adequate supply for one plant species may be toxic for another. Toxicities have been reported in many plant species when the tissue concentration exceed 100 ppm B on a dry weight bases. Toxic concentration of B have also been reported in irrigation water. In general, irrigation waters may be toxic at the following concentrations: sensitive crops 0.30-1.0 µg/ml; semi-tolerant crops 1 - 2 µg/ml; and tolerant crops 2 - 4 µg/ml. Irrigation water with B concentrations higher than 4 µg/ml are unfit for plants. Toxicity symptoms are similar in most crops, first showing up as yellowing then browning of leaf tips and margins and ending in tissue death.

Fertilizer Sources

Source	%B	Water Soluble
Borax	11.3	yes
Sodium Pentaborate	18.0	yes
Sodium Tetraborate		
Fertilizer Borate 46	14.0	yes
Fertilizer Borate 65	20.0	yes
Boric Acid	17.0	yes
Solubor	20.0	yes

Chlorine (Cl)

Soils

Chlorine is the most abundant of the halogens. It occurs as chloride ion in sea water, salt beds and sea wells. Chlorine is found in most soils and plants. In plants it occurs mostly in the form of water soluble chlorides. Unlike other nutrient elements present in native rocks, Cl does not seem to be fixed by soil colloidal materials and is highly mobile in soils. The amount of Cl commonly found in soils in the form of soluble chlorides will vary, and estimates range from 100 to 1,000 lb Cl/acre.

Plants

Plant deficiencies in Cl are fairly rare. It is estimated that plants generally require about 1 lb Cl for each 4000 lbs dry matter they produce. Plants suffering from Cl deficiency exhibit wilting of leaf tips, a progressive chlorosis of leaves , followed by bronzing, and finally leaf necrosis. In severe cases, plants fail to form fruit.

Molybdenum (Mo)

Molybdenum is found in several minerals including molybdenite, powellite, ferrimolybdite, wulfenite, ilsemanite, and jordisite. Molybdenite, ferrimolybdite, and jordisite are the most commonly mined minerals for Mo. Molybdenum concentrations commonly reported in different rock types include: igneous, 0.9 - 7 ppm; shale, 5 - 90 ppm; limestone, sandstone and dolomite, <3 - 30 ppm. Black shales are high in Mo, with values up to 300 ppm Mo.

Molybdenum concentrations in soils vary with the parent material , degree of weathering, and organic matter content. In general, a range of <3 to 15 ppm has been reported in the United States for surface soils. Median concentrations of total Mo tend to be higher in the western US (6 ppm) than in the east (0.5 ppm). The total Mo content of soil is generally not a good indicator of plant response.

Molybdenum availability unlike most of the other trace elements increases with soil pH. Under alkaline conditions, Mo can leach through the soil profile with rain or irrigation water. Under acidic soil conditions, Mo is less available and less mobile. Under these conditions Mo tends to accumulate in the plow layer and is often associated with organic matter accumulations and Fe oxide content.

Other soil nutrients that often influence Mo availability include P, which increases Mo availability, and S which decreases Mo availability. Researchers have also reported antagonistic relationships between Mo and Mn, Fe, Zn and Cu.

Plants

Molybdenum plays a role in plant enzyme systems. The two most important enzymes requiring Mo are nitrate reductase and nitrogenase. Nitrate reductase is involved in reducing NO_3 to NO_2 , which is the first step toward incorporation of N into proteins. Nitrogenase is involved in the reduction of atmospheric N_2 to NH_3 which is the process that allows leguminous plants to make their own N.

Molybdenum deficiencies often occur in acid and strongly acidic soils. They can also occur in coarse textured soils and soil low in organic matter. Among the plant micronutrients, Mo is needed in the smallest amount. Because of this, the range between deficiency and sufficiency is very narrow. Legumes generally have higher Mo requirements than grasses. Highly sensitive species to Mo deficiency include: spinach, lettuce, tomato, cauliflower and broccoli. In normal plants, Mo usually ranges from 0.8 to 5.0 ppm in the tissue. Deficient plants generally have < 0.5 ppm. The most common symptom of Mo deficiency is leaf chlorosis and resembles N deficiency. The chlorosis is often followed by marginal curling, wilting and necrosis. Symptoms usually appear on older tissue first, then show up on young tissue until the terminal point is killed.

The following methods have been shown to be effective in correcting Mo deficiency in horticultural and field crops: lime application; lime application plus Mo; foliar sprays with Mo, soil application of Mo; seed treatment with Mo; mixing Mo with potting compost; and treatment of seedbed with Mo. Foliar application can be made by applying 0.1 to 0.25 lbs Mo/acre in at least 20 gallons of water. Through foliage coverage is essential to achieve maximum benefit of foliar applications.

Molybdenum toxicity in plants is very rare. Laboratory studies with sand cultures found Mo was less toxic than Ni, Co, Cu, and Zn in decreasing order. Concerns with Mo in the field are more related to animal health rather than plant toxicity. When animals ingest forages containing high levels of Mo (10 to 20 ppm), they can develop a condition called molybdenosis, which is often fatal. Actually, molybdenosis , also known as "teart" or "peat scours", is Mo-induced Cu deficiency, and can rapidly be corrected with injections of Cu. most animals require less than 1 ppm in their diets.

Fertilizer Sources

Source	**% Mo**
Ammonium Molybdate	up to 54
Sodium Molybdate	38 - 46
Molybdenum Frit	30
Molybdenum Trioxide	60
Molybdenum Sulfide	60

Chapter 7 Fertilizer Considerations

Fertilizer Calculations

1. Calculate the amount of ammonium nitrate required to apply 80 lbs/acre of N.
   - Ammonium nitrate is 34% N or 0.34 lb N/lb Ammoium Nitrate

   Pounds per acre of Ammonium Nitrate = _________

2. Calculate the amount of 30% UAN required to apply 80 lbs/acre of N.
   - 30% by weight
   - 10.9 lb/gal
   - lb/gal x 0.3 lb N/lb 30%UAN = 3.27 lb N/gal

   Gallons per acre of 30% UAN = _________

Determining Fertilizer Grade

Given a recommendation to apply 30 lb/ac N, 40 lb/ac P_2O_5 , and 80 lb/ac K_2O, determine the appropriate grade of bagged fertilizer to apply such that you are no more than 10 pounds off the recommended rate.

- Determine the Priority Nutrient (Usually N, so 30 lb)
- Divide each nutrient requirement by priority nutrient requirement

30/30 = 1

40/30 = 1.33

80/30=2.67

So a 1 : 1.33 : 2.67 ratio is needed

If the following grades are available, which one comes closest to the required ratio.

10-10-10

3:9:9

6-6-18

First try 6-6-18 (1-1-3).

Determine fertilizer rate for priority nutrient

30 lb N per acr /0.06 lb N per lb 6-6-18 = 500 lb 6-6-18 per acre

Calculate other nutrients

500 lb 6-6-18 per acre x 0.06 lb P2O5 per lb 6-6-18 = 30 lbs P_2O_5 per acre

500 lb 6-6-18 per acre x 0.18 lb K2O per lb 6-6-18= 90 lb K_2O per acre

Within 10 pounds of recommendations? (30-40-80)

Chapter 8 Soil Testing

Philosophies of Soil Testing

A soil test does not end when the results are determined in the laboratory. Those results must be related to the expected level of plant response and the appropriate rate of fertilizers required to eliminate nutrient deficiency. It is this final stage of soil testing where many disagreements can be found between different practitioners. There are three common approaches used in determining actual fertilizer recommendations once the results and interpretations are made. These include the basic cation saturation ratio, the nutrient maintenance, and sufficiency level concepts.

Basic Cation Saturation Ratio

This philosophy assumes there is an ideal ratio of exchangeable bases in the soil that will optimize plant nutrient utilization and thus crop yields. The commonly used percentages are 65 percent calcium, 10 percent magnesium, and 5 percent potassium. This is equivalent to a Ca/Mg ratio of 6.5, a Ca/K ratio of 13, and a Mg/K ratio of 2. If these ratios are not found, then one or the other of the nutrients would be considered deficient. These percentages also yield a base saturation of 80 percent. This philosophy is most prevalent in the midwest on soils with fairly high cation exchange capacities (CEC) and high natural pH's. Under those conditions the assumptions may be fairly reliable. This philosophy does not address phosphorus, sulfur, or micronutrients.

We consider "cation balance" irrelevant in estimating the nutrient needs of most crops. For one thing, soils in the southeast vary tremendously in CEC; therefore a 5 percent potassium saturation on a very sandy soil will likely be too low, and on a high organic soil will be too high. Midwestern consultants have at times tried to apply this philosophy on North Carolina organic soils and have applied hundreds of pounds of potassium with no improvement in crop performance. They have even suggested the use of calcium sulfate to "balance" the calcium with naturally high magnesium levels. Another instance where this philosophy has been misapplied is in the North Carolina piedmont where soils are high in magnesium. In some cases growers have been advised to use calcitic rather than dolomitic lime to "balance" the soil. There is no evidence that this is necessary.

Nutrient Maintenance

This philosophy assumes that a level of nutrient sufficient to replace crop removal should be applied, regardless of soil levels of nutrients. This does not take into account soils where nutrient levels may be very high, even to the extent of being toxic. We consider this to be irresponsible both economically and environmentally on soils testing high in nutrients. If the soil can supply sufficient amounts of nutrient to grow two or more crops, then applying additional replacement nutrients is not defensible.

Sufficiency Level

This philosophy is based on soil test calibrations that show no yield response to an applied nutrient when the soil tests above a certain level. In other words, when the soil test level of nutrient is sufficiently high, no fertilizer nutrients would be applied. This is the philosophy used by many state-run soil test laboratories and is the one used by North Carolina. It is also the most conservative approach, and as such has been attacked at times as being too conservative. However, this philosophy has the greatest potential for producing the most economic yields and is in harmony with the concepts of nutrient management planning.

Soil Test Calibration

Calibration

A calibrated soil test is a soil extraction procedure resulting in a soil test value that can be correlated with a positive crop response to fertilization. The calibration process involves replicated field trials including a wide range of soil, water regimes, and climatic conditions, and is crop specific. The process has no clear end, considering that new cultivars frequently respond differently than old cultivars, the acceptance of more modern management practices (conservation tillage, fertigation, etc.), and new advances in the laboratory.

Ratings

The state-run laboratories in the Southeast subscribe to the sufficiency level concept of fertilization, or “fertilize the crop, not he soil”. Using this concept can result in increased soil test values with time, but it is not a specific goal to bring about this increase. In the highly weathered, low CEC soils of the Southeast, this philosophy minimizes loss of the more mobile nutrients via leaching. These labs all use a rating scale to indicate the likelihood of crop response at certain soil test levels.

Very Low - Less than 50% of the crop yield potential is expected without addition of the indicated nutrient. A large portion of the nutrient requirement must come from fertilization.

Low - 50 to 70% of the crop yield potential is expected without addition of the indicated nutrient. Yield increase to the added nutrient is expected. A portion of the nutrient requirement must come from fertilization.

Medium - 75 to 100% of the crop yield potential is expected without addition of the indicated nutrient. Yield increase to the added nutrient is expected. A small portion of the nutrient requirement must come from fertilization.

High - Yield increase to the added nutrient is not expected. No additional fertilizer is needed.

Very high - Yield increase to the added nutrient is not expected. The soil can supply much more than the entire crop nutrient requirement. Additional fertilizer should not be added to avoid nutritional problems and adverse environmental consequences.

Field Studies

Data from replicated field studies are statistically analyzed to determine if treatments are really causing the observed results. Statistical analysis allows researchers to deal with some variability within the site, and still measure differences with a high probability of being true.

The results of many such replicated tests are used to generate soil test ratings or index values by all state labs. In some cases, ratings are specific to certain crops as shown for peanuts, or they may be generalized across several crops, with only the nutrient recommendations tailored to the specific crop, as in North Carolina.. Some states also consider specific soils or soil groups

Understanding North Carolina Soil Test Reports

In North Carolina, soil testing is provided as a free service in North Carolina by the Agronomic Division of the North Carolina Department of Agriculture (NCDA). Sampling instructions, information sheets and boxes are provided at no charge and can be obtained at local Cooperative Extension Service Centers, from Area Agronomists of the Agronomic Division, and from many businesses selling lime or fertilizer. Samples and completed the information sheets, should be sent to the Agronomic Division, NCDA, 4300 Reedy Creek Road, Raleigh, NC 27607-6465.

The goal of soil testing is to find out enough about the fertility status of the soil to provide a cost-effective and environmentally sound lime and nutrient lime recommendation. Soil testing is not a perfect science, but it provides the most reasonable approach for growers to assess soil pH and plant-available nutrients, to determine the need for lime and fertilizers, and to avoid losses and environmental damage from improper lime and fertilization practices. Soil testing is a multi-step process requiring analysis, calibration, interpretation and resulting in lime and nutrient recommendations.

Unique Aspects Of the NCDA Soil Test

The soil test procedures and reports generated by the NCDA have several features which are unique to North Carolina. Many of these features came about in order to address the special needs of a state with a wide range of crops and soils, with particular attention to the ORG and MIN classes of the “Blacklands”. While these features improve the soil test results for users, they do make it more difficult to compare results result in a soil test re

1. Use of volume basis for analysis and reporting. Most labs report results on the basis pounds of nutrient per million pounds of soil (parts per million), or pounds per acre. These labs assume the weight of soil in the plow layer (or acre furrow slice) weighs 2 million pounds per acre. While this assumptions is reasonably close for many mineral soils, the acre furrow slice of coarse sands weighs much more, and of organic soils weighs much less than 2 million pounds. To avoid such errors, NCDA results and recommendations are based on the actual <u>volume</u> of soil sampled, assuming an acre furrow slice is 7.9 inch (20 cm) deep.
2. Use of the Mehlich 3 extractant with a 5 minute reaction time. Mehlich 3 extracts about twice as much P from soils than the more commonly used Mehlich 1. Amounts of Mn, Zn and Cu are also higher than with Mehlich 1, but the correlation of the two methods is less predictable for these elements.
3. Use of the Mehlich buffer for determining lime requirement. Recommendations are comparable to labs using the Adams-Evans procedure common throughout the Southeast. NCDA also credits lime applied in the last 12 months for mineral soils, or the last 6 months for organic or mineral organic soils.
4. Use of index values to report P, K, Mn, Zn and Cu rather than parts per million or pounds per acre.
5. Estimation of chemically reactive organic matter by dilute NaOH extraction.

Soil Test Components

Results of the soil test can be presented many different ways, depending on the required use and the comparisons which need to be made. The NCDA soil test report presents results in a manner that attempts to ease interpretation by all users while presenting the details needed by experienced users wishing to modify the recommendations for a specific site. This essential compromise results in a report containing many components and a variety of units which are not directly comparable. An understanding of the various components can help explain the relationships between the different values. We will introduce the components of the soil test in a slightly different order than shown on the soil test report form in order to better illustrate these relationships. We will briefly explain each measurement, and then offer some insight on how the results may be used to evaluate soil fertility status.

Humic Matter Percent (HM-%)

Most soil fertility experts that higher amounts of soil organic matter are related to increased productivity because of its contribution to water holding capacity, improved soil structure, and supply of nutrients. Soil organic matter is composed of partially disintegrated and decomposed plant and animal residues, along with other relatively stable organic compounds produced by soil microorganisms as decay occurs. The latter component is called humic matter. Humic matter may comprise 60 to 80% of the total soil organic matter, and accounts for most of the ability of the organic matter to interact with various nutrient elements and organic compounds such as pesticides.

The standard method of measuring soil organic matter requires the use of chromic acid, and produces a hazardous waste. The NCDA HM-% test uses a rapid, dilute alkali (NaOH) extraction to estimate the most "chemically reactive" component of the soil humic matter. There is no direct way to back-calculate the total organic matter content from HM-% because of variation in the sources of organic matter and their state of decomposition[1]. The humic matter values are usually much lower than the actual organic matter content, particularly on soils high in organic matter. For example, some organic soils show less than 10% HM while the percent organic matter may be 50% or more.

The humic matter test is one of the criteria used to classify soils into broad categories for adjusting lime, phosphorous and micronutrient recommendations, and for determining proper use of pesticides. The labels of many pesticides may restrict application to soils containing a minimum HM-% to prevent movement into groundwater. Others recommend an increased rate with increasing HM-%, or may even prohibit use on soils with high HM-%, since the compounds are bound so strongly they become ineffective. The HM-% will generally be highest in poorly drained soils. Values tend to decrease with improved drainage, and with decreasing clay content. The HM-% of well drained sands are often less than 1 to 2 percent. Soils with higher HM-% will have higher CEC (discussed below), hold more plant available water, and usually require less nitrogen and sulfur. On the other hand, these soil are more subject to Cu deficiencies and leaching of phosphorous.

Weight per Volume (W/V)

The soil weight/volume is shown in grams/cubic centimeter (g/cm3) and is also one of the criteria used to determine the soil testing class of the soil. Soils high in sand have may have W/V values above 1.5, while silt and clay loams may be near 1.0. Soils high in organic matter may have W/V values as low as 0.4. Results reported by NCDA are based on the volume of soil sampled, assuming a sampling depth of 7.9 inches (20 centimeters). Very experienced users will occasionally need to convert NCDA values from a volume to a weight basis for comparing results with other labs, or for reporting purposes. The W/V value makes this possible. This process will be described in more detail later.

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[1] The following equation can be used to convert HM-% to OM% for determining pesticide rates:

$\%OM = (HM\text{-}\% - 0.16) \times 2.7.$ [Weber et al.. 1987. Weed Tech. 41:41-45.]

Soil Testing Class

In order to properly interpret the results, the soils must be grouped according to their readily recognizable properties. Recommendations for lime, phosphate (P_2O_5), copper (Cu), and zinc (Zn) in particular, vary with the amount of soil organic matter present. Agronomists at the laboratory currently classify the soil as Mineral (**MIN**), Mineral/Organic (**M-O**), or Organic (**ORG)** based primarily on HM-% , W/V, and color. Soils in the **MIN** class generally have low HM-%, W/V values of 1.0 or more, and are usually red, yellow or light gray in color. Soils in the **ORG** class have HM-% above 5, W/V values less than 0.8, and are black or brownish black in color. The remaining soils are placed in the **M-O** class, and represent soils with significant soil organic matter.

Cation Exchange Capacity - (CEC)

Most soils in North Carolina have a negative charge resulting from the soil clays and soil humic matter. As a result if this charge, they are able to react with elements of opposite, or positive charge, in a manner similar to the north and south poles of magnets. These positively charged elements, or cations, are held strongly enough to prevent removal by water moving through the soil (leaching), but can be replaced by other positively charged elements. This process is called cation exchange. Soils with a large amount of charge can hold more cations and have a higher CEC. Cation exchange capacity is reported in units of milliequivalents per 100 cubic centimeters (meq/100 cm^3). Soils in North Carolina may range from values of 2 or less in sandy soils to over 40 in soils high in organic matter or certain types of clays.

The CEC value reported by NCDA is the sum of extractable Ca, Mg, K and acidity (**Ac**) expressed in units of meq/100 cm^3. Note that only the **Ac** value is given in this unit on the reporting form. The values for Ca and Mg are reported as percent of CEC, and K is reported as and Index value, as described below. Other cations such as Na, Fe, Mn, Zn and Cu are usually present in relatively small amounts and have little effect on the measured CEC. The CEC increases as soil organic matter and clay content increases. Soils with low CEC can lose substantial amounts of N, K and even Mg when leaching rains occur. The recommended nutrients may need to be split into two or more applications to reduce leaching losses.

Base Saturation Percent - (BS-%)

The elements Ca, Mg and K are called basic cations, because they do not acidify the soil. The percent of the CEC occupied by these three cations is called the base saturation percent. The values for Ca-% and Mg-% are in units of % CEC, and are used directly to make this calculation. The value for K-% is calculated, but not shown on the report. If desired, the K saturation percentage can be calculated by subtracting Ca-% and Mg-% from BS-% :

$$\text{K-\%} = \text{BS-\%} - (\text{Ca-\%} + \text{Mg-\%}).$$

The BS-% is very useful in diagnosing problem areas, and is strongly related to the soil pH for a given soil test group. The BS-% should usually be about 60% or higher for mineral soils and 50% or higher for organic soils. Soils with BS-% over 90% are probably over-limed.

Calcium Saturation Percent (Ca-%)

The Ca-% represents the percentage of the total CEC occupied by Ca. Since Ca is a primary component of agricultural limestone, it is seldom low enough to be deficient to crops if soils are properly limed. A few possible exceptions include peanut, tomato, potato and bell pepper. Where high availability of Ca is required, supplemental Ca may be provided in the form of gypsum ($CaSO_4 \cdot 2H_2O$). Appropriate rates are discussed in the notes included with the soil test report. In general Ca is the predominant cation in soils. Calcium percentage is required to calculate CEC, BS-% and the relationship between calcium and other nutrients.

Magnesium Saturation Percent (Mg-%)

The Mg-% is also expressed as the percent of the total CEC occupied by Mg. Since Mg-% is typically much lower than for Ca, this value is also used to determine the need for including supplemental Mg in lime or fertilizer materials. Since no rating or index is applied to Mg, the easiest way to determine if the value is adequate is to look in the Mg recommendation block. If a value of 0 is recommended, the level is adequate. If inadequate levels are present, a “$” in the block will appear in this block, referring you to the “$” note included with the soil test report. This note suggests using dolomitic lime, which contains a minimum of 120 pounds of Mg per ton, if lime is to be applied. If lime is not recommended for the site, the note recommends applying 20 to 30 pounds of Mg per acre as a water soluble fertilizer source. Soil Mg levels are considered adequate under two conditions. The first conditions requires that extractable Mg (expressed in the same units as CEC, or meq/100 cm^3) is less than 0.5. This value is obtained by multiplying CEC times the Mg-% and dividing by 100:

$$\text{Extractable Mg (meq/100 cm}^3\text{)} = \frac{\text{CEC X Mg-\%}}{100}.$$

When the Mg level falls below 0.5 meq/cm^3, the value may still be considered adequate if extractable Mg is greater than 0.25 meq/100 cm^3 is present, and Mg-% has a value of at least 10.

Ac

Extractable acidity is expressed as meq/100 cm^3 and is the portion of the CEC that is occupied by acidic cations (Al , H, and to a lesser extent, Mn and Fe). This value represents the reserves of soil acidity which must be neutralized by lime to achieve optimum crop growth. While lower values are usually desirable, this varies greatly with the soil class and the CEC. Soils with high organic matter or clay content will have higher Ac values than sandy soils. The Ac value decreases as soil pH increases. In general, the Ac value should be less than 40% of the CEC for mineral soils, and less than 50% of the CEC for organic soils. The primary use of the Ac value is in the calculation of CEC and, along with pH, the lime requirement[2].

pH

Soil pH is a measure of the active acidity (H^+) at a point in time. It is essential for determining the lime requirement. Values may vary significantly from season to season, and are influenced by lime, fertilizer additions, cultural practices and climatic conditions. The pH value is strongly related to BS-% within a soil testing class, and can be used as an indicator or index of certain chemical reactions occurring in the soil. At very low pH, solubility of Al, Mn and Zn increase, and can become toxic to sensitive plants. At high pH values, the solubility of Mn, and to a lesser extent Zn and Cu, can become so low that plants are unable to obtain adequate supplies from the soil. The acceptable pH range varies for each soil class. In calculating lime requirement, a target pH for each soil class is used. The target pH represents the soil pH that is best for most crops growing on soils of that class. The target pH is 6.0 for the mineral soil class (with exception of cotton, alfalfa, bermudagrass hay and most vegetables), 5.5 for the mineral -organic soil class, and 5.0 and for the organic soil class. As organic matter content increases from class to class, the amount of Al and the potential for toxicity decreases, and optimum plant growth can be achieved at lower pH.

Nutrients Reported as Index Values

Soil test results for P, K, Mn, Zn, and Cu results are converted to index values to ease interpretation of results. This format means that specific critical values do not have to be determined (as with Mg above). The index system is used to gauge the likelihood of response, with index values above 50 having little likelihood of response, and those below 25 having a high likelihood of response for P and K. The micronutrients are required in such small amounts that index values above 25 are considered adequate , and unlikely to show a response to additions of these elements (Table 1).

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[2] See Soil Fact Sheet AG-439-17, "Soil Acidity and Proper Lime Use". North Carolina Cooperative Extension Service, Raleigh, NC

Table 1. Relationship between soil test index and crop response.

Soil Test Index		Expected Crop Response to Nutrient Application				
Range	Rating	P[*,**]	K[**]	Mn	Zn	Cu
0-25	Low	High	High	High	High	High
26-50	Med	Low	Low	None	None	None
51-100	High	None	None	None	None	None
100+	V. High	None	None	None	None	None

[*] For soils in the ORG class, the range for P Ratings are: Low 0-16, Medium, 16-30, and High, 30+.

[**] Phosphate and potash recommendations above the 50 index are designed to replenish nutrients removed by crops and for building purposes.

Phosphorous Index (P-I)

Fertilizer recommendations for P decrease on a continuous scale as the soil test index increases. Fertilizer suggestions are given as pounds of P_2O_5 per acre (or per 1000 square feet for some crop codes), the same way fertilizer analyses are given. Phosphorous moves very little in all but deep sands and some organic soils. This means that P can be built up from year to year with little expected loss. Soils with P-I values greater than 100 contain sufficient P to supply crop growth for several years without additional P inputs. Further additions to soils in this range may contribute to surface water pollution, and should have carefully considered. In some cases, a starter fertilizer containing P may be needed to overcome early season stress, or as a cultural strategy to improve resistance to weed insects or diseases. Current laboratory techniques allow reporting of P-I values in the range of 0 to 166. Values greater that 166 are reported indicated as 166+.

Potassium Index (K-I)

The K-I is used in calculating CEC, BS-% and the K recommendation. Values of K-I may exceed 166, since a different analytical technique is involved. Potassium is relatively mobile in soils with low CEC (most soils with sandy surfaces), and can be removed from the rooting zone by leaching rains. On such soils, it may not be possible to build and maintain K-I values above 50 from year to year.

Manganese Index (Mn-I) and Manganese Availability Index (Mn-AI)

The Mn-I block contains two or three values. The bottom value, with no parenthesis, is the Mn-I value as determined by the lab. The top value is the Mn-AI of the first crop. The middle value is the Mn-AI of the second crop, if requested.

As pH increases plant availability of Mn decreases. In addition, some crops are much more sensitive to Mn deficiency. NCDA uses the Mn-I and soil pH, as well as a crop sensitivity rating to calculate an the Mn-AI. The Mn-AI is then, the appropriate value to use to interpret the need for supplemental Mn. If the

MnAI is below 25, a rate of Mn will be given for the first crop and a $ sign for the second crop. The $ sign indicates that Mn may be limiting for the second crop if it was not applied for the first crop. It also refers the user to the "$" note for more information. Recommended rates of Mn are shown in Table 2.

Table 2. Suggested micronutrient rates for North Carolina crops.

	Banded		Broadcast			Foliar Spray		
Class	**Mn**	**Zn**	**Mn**	**Zn**	**Cu**	**Mn**	**Zn**	**Cu***
	pounds of element per acre							
MIN	3	3	10	6	2	0.5	0.5	0.25
M-O	3	3	10	6	4	0.5	0.5	0.25
ORG	3	3	10	6	6	0.5	0.5	0.25

* Primarily for dormant small grain.

Zinc Index (Zn-I) and Zinc Availability Index (Zn-AI)

Two numbers appear in the column for Zn soil test results. . The lower number is the unadjusted soil test Zn index (Zn-I). Availability of Zn is strongly affected by the organic matter content of the soil. The upper number, the Zn-AI, is calculated by multiplying the Zn-I by a factor for each soil class. The factor used to calculate ZnAI is 1.0 for the MIN class, 1.25 for the M-O class, and 1.66 for the ORG class. Zinc will not be recommended unless the ZnAI is less than 25 (Table 1). Recommended rates of Zn are shown in Table 2.

Copper Index (Cu-I)

The Cu index (Cu-I) is the soil test level of Cu. A rate of Cu will be given for crops that are known to need Cu when the Cu-I is less than 25 (Table 1). Recommended rates of Cu are shown in Table 2. A $ sign will appear if calibration data are unavailable or unclear as to the likelihood of a response. In most cases, this indicates that responses are rare for this crop, but may be occur if more sensitive crops are grown. A grower may choose to treat part of the field with Cu (see Table 2 for suggested rates) and evaluate the treated and untreated parts of the field with plant analysis or yield measurements. For best results, Cu should be broadcast and mixed into the soil plow layer. Banded applications are not recommended.

Sulfate Sulfur Index (S-I)

Sulfur (S) results can be misleading. Sulfur leaches readily from sandy soils but accumulates at the top of the clay layers below the surface. The topsoil may test low while the subsoil supplies ample amounts. If plant roots can reach the clay layer (usually within 14 to 16 inches), if the soil is high in clay, or the soil is classed as M-O or ORG, sulfur is unlikely to be deficient. On most soils, a subsoil sample should also be submitted for analysis. The suggested application rate for sulfur is 20 to 25 pounds per acre. Sulfur deficiency is unlikely on the clayey or silty textured soils of the piedmont and mountains.

Soluble Salt Index (SS-I)

The soluble salt index is a measure of the amount of fertilizer elements that are soluble in the soil. A moderate level of soluble salts is desirable for good plant growth but excessive soluble salts can injure plants. Soluble salts in the soil come from fertilizers, manures, or irrigation water. Soils near the coast may have high soluble salts because of salty sea water. The degree of plant injury from excessive soluble salts depends on the soil type, the soil moisture content, and crop sensitivity. The relationship between soil type and the SS-I is shown in Figure 1. Interpretation of soluble salt indexes is interpreted on and individual basis. For greenhouse samples, general guidelines are shown in Table 3.

Table 3. Guidelines for soluble salt interpretation for greenhouses.*

Salt Rating	Interpretation
Low	Soil needs additional fertilizer. No problem with soluble salts.
Medium	Can be fertilized at the lower end of the range; no fertilizer needed at the top end of the range.
High	Satisfactory salt level at the lower end of the range; seed germination and seedling injury may occur at the upper end. Apply no fertilizer.
Very High	Add no more fertilizer. Do not allow soil to become dry. Soils should be leached if salts are near the upper end of the range. Use irrigation water with low salt content.

For additional information see Plant Pathology Note No. 2, "High Soluble Salts Injury to Field and Forage Crops" and Note No. 10, "High Soluble Salts Injury to Vegetable Crops". Plant Pathology Dept., NCSU, Raleigh.

NO_3N and NH_4-N

Soil nitrate nitrogen (NO_3N) and ammonium nitrogen (NH_4-N) are seldom determined because soil N status can change rapidly. The primary use of the NO_3N test is greenhouse soils or growing media. Nitrogen is recommended for each crop based on the expected need with no credit given for residual N from a previous crop.

Sodium (Na)

Sodium is not routinely determined but is included on reports for problem samples. The units are the same as those for CEC (meq/100 cm^3). Low values are of little concern, but when present in excess, Na can degrade soil structure, slow infiltration rates, and interfere with uptake of Ca, Mg and K. When present in very high amounts, salt damage to plants is likely. Additional information to aid interpretation will be included with the report on when this element is requested.

Changing Index Values to Other Equivalent Units

When comparing test results among laboratories, it may be beneficial to convert all the laboratory values to the same units. The conversion factors are given in Table 4.

Table 4. Factors for converting the North Carolina soil test index to other equivalent values. Conversions shown are based on a volume of soil to a depth of 20 cm (7.9 inches).

Nutrient	mg/dm3	kg/ha	lb/acre	meq/100 cm3	meq/dm3
P-I	1.20	2.40	2.138	N/A	N/A
K-I	1.955	3.91	3.484	0.005	0.05
Ca-% x CEC	200.0	400.0	3.56	1.00	10.00
Mg-% x CEC	121.6	143.2	2.17	1.00	10.00
Na	230.0	460.0	409.86	1.00	10.00
Mn-I	0.16	0.32	0.285	N/A	N/A
Zn-I	0.04	0.08	0.071	N/A	N/A
Cu-I	0.02	0.04	0.036	N/A	N/A
S-I	0.40	0.80	0.713	N/A	N/A

NOTE: mg/dm^3 = ppm; mg/dm^3 x 2 = kg/ha; kg/ha x 0.891 = lb/acre

As an example, let's say we want to convert the soil test P values to lb/acre for comparison purposes. The soil test shows a P-I of 30, Mg-% of 7 and a CEC of 5. To convert to lb/acre:

P-I x 2.138 = P (lbs/acre), or

30 x 2.138 = 64.14 lbs/acre,. and

Mg-% x CEC x 2.166 = Mg, lb/acre or

7 x 5 x 2.17 = 75.95 lb/acre.

Note that these conversions are calculated on a sample volume basis. Direct comparison with labs using a weight basis further requires that the results be divided by the W/V (unless the W/V is assumed to be 1.00).

Chapter 9 Plant Analysis

Purpose and Use

A plant analysis has three main applications:

- To confirm a suspected nutrient element deficiency when visual symptoms are present
- To monitor the plant nutrient element status in order to determine whether each tested nutrient is in sufficient concentration for optimum yield.
- To serve as the basis along with a soil test for making fertilizer recommendations for fruit and nut crops.

The diagnostic role of plant analysis is well established. Confirm a suspected deficiency by plant analysis before applying a corrective treatment. Numerous cases can be given where incorrect diagnosis in the field has led to crop failures, as well as costly and ineffective corrective treatments. Take care when sampling plants which are being stressed nutritionally. Plants that have been subjected to long periods of stress tend to develop unusual nutrient contents. Therefore, obtain samples as soon as symptoms appear. Do not include dead tissue or tissue that is showing severe symptoms in the sample

The monitoring role of a plant analysis or a series of plant analyses is not used extensively; however, it offers the opportunity to maintain high quality production with a minimum of nutrient deficiency problems. To provide a means of noting changes in nutrient content, sample each year or on a regular basis and compare analytical results from one sample to the next. Study carefully upward or downward trends along with previous production inputs to warn of a potential nutrient deficiency or imbalance. Therefore, corrective treatments can be applied before significant losses in yield or quality occur.

Plant analysis has proved to be a very effective means of predicting fertilizer needs for orchard crops. It does not completely replace a soil test. Soil and plant analyses serve different purposes and when properly used they supplement and support each other. In the case of annual crops, soil analysis prior to planting makes it possible to determine whether limestone, phosphorus, potassium, magnesium or zinc applications will be -needed. Plant analysis of the growing crop will indicate if the applied materials were effective and whether the preplant prediction by soil analysis was correct.

Soil analysis is very useful in appraising soil acidity where crops have failed and the need for limestone applications in established orchards. Plant analysis is particularly useful in determining the nutritional status of permanent deep-rooted crops such as apple, peach or pecan trees or because soil samples of the plants' entire feeding zone are very difficult to obtain.

In fruit crops, perhaps more than in any other crop, nutrient imbalances may manifest themselves in quality characteristics of the fruit of otherwise normal appearing trees. Incipient nutrient imbalances or low nutrient levels that may seriously reduce crop yield and quality may exist even in the absence of noticeable growth reduction. Therefore, when considering the adequacy of nutrition for fruit and nut trees, it is important that nutrient levels are sufficient to prevent reduced growth or leaf symptoms, abnormal fruit color, abnormal texture or storage quality or abnormal nut filling.

Visual observations, knowledge of the site, a soil test and the plant analysis results provide an effective means of evaluating the nutrient status of the soil-plant environment. However, a plant analysis result may not solve every problem or uncover all unseen nutrient element deficiencies excesses. When a nutrient deficiency is confirmed by a plant analysis or an unseen deficiency is uncovered, a corrective treatment may not always be applicable to the sampled crop. Treatments may be specified for future growing seasons or additional tissue and soil samples may be needed to fully evaluate the suspected deficiency.

A plant analysis may indicate that a nutrient deficiency or excess does not exist. Therefore, the cause for poor plant growth or visual symptoms needs to be sought elsewhere. Such directing can be invaluable and is not to be underestimated. In order to use the plant analysis technique effectively, take care when collecting, preparing and sending plant tissue to the laboratory.

Sampling

Proper sampling requires that a definite plant part be taken such as a particular leaf, group of leaves or portion of the plant..

The general rule of thumb is to sample the uppermost recently mature leaves. Young emerging leaves, older mature leaves and seed are not usually suitable plant tissues for analysis since they do not ordinarily reflect the general nutrient status of the whole plant. When sampling mixed stands, particularly forages and pastures, separate plant species. Similarly, the sample should be of only leaves or petioles or whole tops and not mixtures The recommended time to sample usually occurs just prior to the beginning of the reproductive stage for many plants. However, sampling earlier or even later than specified may be recommended for specific plants or circumstances. Sample plants which are showing a suspected nutrient deficiency symptom at the time or shortly after the visual symptoms appear.

When whole plants are sampled, remove the roots and wash the upper portion to remove soil particles. Do not sample or include in a sample plants under a nutrient stress for an extended period of time, dead plant tissue or plants or tissue mechanically injured, diseased or insect damaged. Do not sample plants which have been stressed extensively by cold, heat, moisture deficiency or by excess moisture. Examine both the below ground as well as the above ground portion of the plant. The presence of nematodes or roots damaged by other insects or diseases should preclude the need to sample.

Have recent soil tests results available when submitting a plant tissue sample for analysis or submit a soil sample along with the tissue sample. The submission form should be completed in its entirety as it serves as the only means of communication between the you and the one who is to interpret the analysis.

Washing to Remove Contaminants

Avoid dusty or soil-covered leaves and plants whenever possible. Under normal conditions rainfall is frequent enough to keep leaf surfaces fairly free from dust and soil particles. However, when leaves are dusty, brush or wipe with a damp cloth to remove the contaminants. If this is not effective or when leaves are covered with spray materials, wash in a mild detergent solution (0.30 percent) and rinse in running water to remove most attached substances. Do not prolong the washing procedure or allow the plant material to "stand" in either the washing or rinsing baths. Wash and rinse briskly. Wash leaves which have been sprayed with nutrient solutions while they are still fresh. If iron is of primary interest, wash leaves regardless of their outward appearance. Wash whole plants sampled shortly after emergence to remove soil particles which are frequently attached to the new tissue.

Partially air dry plant tissue samples before shipment to the laboratory. When samples are placed in the mailing envelope, allow the sample to set in a warm place for one-half day with the end of the envelope open. This will generally remove excess moisture. It is not necessary to maintain the tissue sample in the fresh state unless the tissue will require washing in the laboratory. Never place fresh plant tissue in polyethylene bags or tightly sealed containers unless it is kept under refrigeration. When samples are shipped in polyethylene bags by routine mail, they have generally started to decompose by the time they are received for processing. Such samples are not analyzed, because erroneously high nutrient concentrations are measured.

Follow these steps when collecting and submitting plant tissue samples:

1. Obtain necessary forms from the local county Extension Center or regional NCDA agronomist.
2. Study the instructions before proceeding.
3. Following the sampling instructions, collect the prescribed plant part and the proper number.
4. Air dry the collected tissue if necessary and then place it in a large mailing envelope.
5. Complete the submission form in its entirety and include it with the sample as described in the instructions.
6. If recent soil test data is not available, collect a soil sample and place in a separate container. Make note of submitted soil sample on plant analysis submission form.
7. Mail plant analysis kit and soil sample to Laboratory

Interpreting A Plant Analysis Result

Difficulties have been encountered in the use and interpretation of plant analyses, although the quantitative association between absorbed nutrients and growth has been studied by many. Reliable interpretive data are lacking for a number of crops, particularly for plants during the initial stages of growth, and concentrations near or at toxicity levels. Initially, single concentration values were sought, but research showed that ranges in concentration would better describe the nutrient status of the plant.

Several problem areas have been identified in interpreting plant analyses. With extreme deficiencies, element concentrations may be greater than those found in plants free of the deficiency. The range in concentration between deficiency (with visual symptoms) and the critical concentration (with no visual symptoms) can be small. For some elements and plants the techniques needed to detect these small changes in concentration have yet to be adequately defined. The effects of time of sampling, variety or hybrid and environmental factors , such as soil moisture, temperature, light quality and intensity, may significantly affect the relationship between nutrient concentration and response. Thus, it is essential that the time of sampling, stage of growth and character of growth prior to sampling be known and considered when interpreting a plant analysis result.

Many of these problems can be overcome by proper sampling, and the use of sufficiency ranges, as described below.

Practical Interpretation System

An interpretation of a plant analysis is based on comparing the elemental concentration found against a sufficiency range. The concentration of each element analyzed is reported as less than, greater than or within the sufficiency range. If soil test data and cultural practice information are supplied, an explanation for element concentrations outside the sufficiency range is given. Corrective treatments when required are also normally given.

The cause(s) for a nutrient concentration to fall outside the sufficiency range are many and varied. Low or high soil test levels, low or high soil pH, improper fertilization, soil compaction, nematodes and climatic factors are common causes. For most crops and cropping situations, the nutrient concentration found in leaf or plant tissue more closely follows the soil test level and/or soil pH rather than amount of fertilizer applied. The one major exception is nitrogen. The use of a balanced lime and fertilizer program over a period of years will do more to maintain the proper nutrient balance in plants than any one specific lime or fertilizer treatment. As a general rule, a soil testing MEDIUM to HIGH in the essential plant nutrients will produce plants with elemental concentrations which will normally test within the sufficiency range.

There are some common occurring soil-plant growth conditions which are usually closely related. Soil test P and plant P. and soil test K and plant K are usually significantly and positively correlated, irrespective of other soil factors. Phosphorus uptake can also be affected by cool soil temperatures, water-logged soil conditions and extremely low soil pH.

Soil test Ca and plant Ca are usually positively related, but soil pH, fertilizer treatments and climatic factors can have some affect on this relationship. As the soil pH increases, the correlation between soil test Ca and plant Ca decreases. Heavy applications of N and K fertilizer will tend to decrease the uptake of Ca.

Plant Mg can be affected by several factors. A decreasing soil pH and an increasing K soil test level can markedly reduce the uptake of Mg irrespective of the Mg soil test level. The uptake of Mg decreases sharply when the soil pH drops below 5.4. This is why a Mg deficiency can be partially corrected by just increasing the soil pH by liming. When the soil test level (in lbs./A) of K to Mg exceeds 4:1 or when the soil test level (in lbs./A) of Ca:Mg exceeds 8:1, Mg uptake by some plants may be depressed. This is of primary importance with forages where greater ratios could lead to increased incidence of grass tetany. Therefore, with some crops, take extra precautions to ensure that the proper balance of Mg to both K and Ca is maintained. As with Ca, the correlation between soil test Mg and plant Mg decreases as the soil-water pH increases.

The effect of soil pH on the availability of most of the micronutrients is well known. In general, as the soil pH increases, the availability and, therefore, the uptake of Cu. Fe, Mn, and Zn decreases. Also, as the organic matter content of the soil increases, the soil pH effect is intensified. The primary exception is Mo where availability tends to increase with increasing soil pH.

Boron deficiencies are due primarily to lack of adequate B in the soil. The corrective treatment is to apply B fertilizer according to current recommendations. Excesses would only result from over fertilization with B.

Copper deficiencies occur primarily on high organic matter soils and possibly on sandy soils which contain low amounts of indigenous Cu and which have pH values approaching 7.0. Excessive Cu plant levels could occur where large quantities of some animal manures, particularly poultry litter, have been applied over a prolonged period.

Iron availability and uptake is a complex subject because as many soil and plant factors can influence the Fe level in the plant. Deficiency may occur when the soil pH is near neutral and the soil is high in organic matter. Iron deficiency has been observed in centipede grass, azaleas, blueberries and camellias as well as pecan trees, some sorghum and a few soybean varieties and pin oak trees. In pecans, high Zn in the trees is thought to be a contributing factor in inducing Fe deficiency. From soil and plant conditions, the only corrective treatment is to change varieties or try another tree.

Manganese availability is markedly influenced by soil pH, probably more so than any other micronutrient. Manganese toxicities can occur when the soil pH is less than 5.4 and deficiencies when the soil pH is greater than 6.3. For most soils in the Southeast, soil pH exerts the greatest influence on Mn availability to plants.

Molybdenum is an interesting element. Deficiencies are not easily detected by a plant analysis. The Mo requirement of legumes is high since the N fixing bacteria require higher levels of this element than the plant itself. The normal corrective treatment is a seed treatment with Mo. Also, the Mo related deficiency of poor N fixation is affected by soil pH. The response to Mo seed treatments for most legumes is most pronounced at low soil pH (5.2) and decreases as the soil pH increases. Therefore, maintain the proper soil pH to eliminate the potential of a Mo deficiency.

Zinc availability is related to both soil pH and level of soil Zn. Zinc uptake normally decreases as the soil-water pH increases. However, soil test Zn is usually a good indicator of Zn availability. A Zn deficiency can be readily corrected by applying Zn according to current recommendations.

Aluminum is not an essential plant nutrient, but can be a factor affecting plant growth. High Al (if not due to soil or dust contamination) levels in the plant are the result of either a very low soil pH (pH's less than 4.8) or anaerobic soil conditions such as flooded or heavy compacted soils. Aluminum does not readily enter the plant, therefore its presence in the plant in high concentrations indicates an extreme soil condition.

It is evident that the interpretation of a plant analysis and a corrective recommendation based on such an analysis can become a complex task requiring considerable skill on the part of the interpreter and sufficient knowledge of the site conditions. One of the common errors made by those submitting plant tissue for analysis is failure to supply the essential information needed to properly interpret the analysis and prescribe corrective treatments. A properly completed questionnaire (see page 64) is an essential part of the submitted plant tissue because without it, proper evaluation of a plant analysis result is impossible.

Plant Analysis As A Diagnostic Tool

Plant analysis has been considered and primarily used as a diagnostic tool. Farmers and growers are urged to confirm suspected nutrient element deficiencies by a plant analysis before applying a corrective treatment. In order to effectively use a plant analysis in diagnosing growth disorders, employ specific sampling and evaluation techniques.

Collect plant samples from both affected as well as normal plants whenever possible. If plants have been under nutrient stress for a long period, a comparative analysis may be misleading, particularly when the stressed and nearby normal plants are at markedly different stages of growth. Therefore, sample the plants when they are at the initial stages of a developing nutrient deficiency. This is essential when using a plant analysis in a diagnostic situation. Exercise great care to ensure that the proper sampling procedures are used. Plants selected for sampling and exhibiting symptoms of the suspected nutrient deficiency should be similar in appearance and all at a similar stage of development. Avoid dead or severely affected tissues and do not include in the sample. Confine the sampling area to plants in close proximity to each other. Use the same sampling procedures for those plants selected as the normal counterparts. Collect soil samples from both the affected and normal areas.

By comparing the analysis of both soil and plant tissue from the normal and affected areas, differences in test levels and concentration of particular elements can be evaluated. The comparison of analyses may be far more useful in the interpretation than using known interpretative values for this comparison and evaluation. Examine associations between a soil test value and the plant analysis value of similar or related elements. For example, differing soil pH's can result in changing levels of Mg and Mn in plant tissue. Variations in the soil test P and K levels are usually reflected in the P and K levels of the plant tissue. The presence or lack of such commonly occurring associations can be significant clues. With experience, you can become quite efficient in the evaluation of plant analyses when used for diagnostic purposes.

The most common error made when a plant analysis is used as a diagnostic tool is due to the failure to use sufficient care when collecting the plant tissue and soil samples. The effectiveness of a plant analysis to diagnose a particular nutrient problem is hampered by improper sampling and the failure to include both sets of tissues and the necessary soil samples. Therefore, follow the procedures prescribed with great care when collecting these samples. Failure to do so can significantly limit the effectiveness of the evaluation and may lead the interpreter into drawing incorrect conclusions

Nutrient Monitoring

Repeated plant analyses during the growth cycle of a plant or from one season to another can profile changes which are occurring with time as a result of applied fertilizer treatments. These analyses can provide a guide for corrective treatments. For long seasoned crops, analyses made at the critical periods can be effectively used to prescribe immediate corrective treatments. Supplemental treatments can be scheduled based on a series of analyses. For example, when using a series of leaf analyses for greenhouse tomatoes, the need for supplemental fertilizer treatments can be determined in order to maintain a high level of productivity over a long growing season. For the pecan grower, yearly leaf analysis results should be plotted versus time to determine what effect lime and fertilizer treatments are having on leaf composition. Up-or-downward trends can be observed and adjustments in yearly lime and fertilizer treatments made before deficiencies or excesses develop which would reduce yield or quality.

Similar examples can be given for other crops or cropping sequences. Such analyses and the maintenance of leaf analysis result logs are invaluable to any farmer. Since most of the more common nutrient deficiencies experienced by many farmers are the result of long term effects of improper lime and fertilizer practices, developing deficiencies or excesses can be seen before they appear as visual symptoms or reduced yield and quality.

Base supplemental applications of N on a plant analysis, particularly when there is a suspected or anticipated N deficiency. Analyze crops which are particularly sensitive to excess N such as cotton, forage grasses, fruits and vegetables prior to the application of additional N. Keying N treatments to actual need can save the farmer unneeded fertilizer and reduce potential excesses.

Therefore, in order to obtain the maximum value from a plant analysis, establish a regular schedule of plant analyses and keep careful records to provide a usable history of test results.

Chapter 10 Soil pH, Acidity and Liming

Soil pH

An acid is any substance which can give up a proton (H^+) to some other substance. Some common example would be muriatic acid (HCl), a strong acid, and vinegar (acetic acid), a weak acid. A base is any substance which accepts H^+ . When placed in water, an acid ionizes into the acid (H^+) and the associated anions, such as shown by the dissociation of muriatic acid:

$$HCl \leftrightarrow H^+ + Cl^- .$$

The amount of H^+ is the ***active*** acidity present. In a strong acid, the compound fully ionizes, and essentially all the H^+ is released. In a weak acid, ionization only a portion of the total acid present. The undissociated hydrogen in a compound like vinegar may account for 99% of the acid, which represents the ***potential*** acidity, while only 1% is active.

What is pH? It is a measure of the active H^+ concentration in the soil solution, and indicates the relative acidity or basicity. The pH scale ranges from 0 to 14. A neutral state is indicated at pH 7.0, representing the value found in pure water. Values above 7.0 are basic, while values below 7.0 are acid.

The pH scale is logarithmic, meaning each unit has a 10-fold increase or acidity or basicity. Thus, compared to a pH of 7.0, pH 6.0 is ten times more acid, and pH 5.0 is 100 times more acid.

Soil Acidity

The more H^+ held on the soil, the greater the acidity of the soil. Nearly all soils in the southeast are acidic. These soils were acidified over thousands of years by inputs of acids from atmospheric sources (carbonic sulfuric and nitric acid), plant exudates and the decay of plant and animal residues, and removal of basic cations by the natural processes of leaching and crop removal. In agricultural soils, organic and ammoniacal forms of N or S are converted to nitrate or sulfate by microorganisms, releasing acid in the process. About five pounds of lime are needed to neutralize one pound of ammoniacal N.

These acidic inputs and leaching cause minerals to dissolve as soil pH decreases. This in turn releases cations such as Al^{3+}, Mn^{2+} and Fe^{3+} which can react with water to release more H or replace basic cations on the exchange complex. These displaced basic cations are taken up by plants, or are leached away, and the base saturation is lowered.

Soils act as weak acids, with only a small portion of their potential acidity present in the active form. The amount of actual H^+ present in solution is a very small part of the total acidity until pH is less than 3. Exchangeable Al, Mn and Fe metals, along with pH-dependent charges on organic matter and clay edge sites constitute the major sources of potential acidity (also called the reserve or **total** acidity). The reserve acidity, in conjunction with the exchangeable bases help **buffer** or enable the soil to resist rapid changes in pH.

Plants growing in acid soils must be able to contend with high levels of Al and Mn, and low availability of P, Ca, and Mg. Beneficial microorganisms do not compete well under these conditions, and are replaced by fungi. Since most crops are intolerant of these conditions, the soil must be amended to make the rooting environment more hospitable.

Benefits of Liming

The primary reason for liming is to neutralize toxic elements in acid soils, rather than simply to raise soil pH. The acidic cations, especially Al and Mn are phytotoxic at relatively low soil solution concentrations. Thus, pH is primarily an indicator that Al and Mn toxicity is likely. Liming, through addition of hydroxide (OH^-) decreases the solubility of Al^{3+}, Mn^{2+}, and Fe^{3+} (as well as Zn and Cu), causing them to precipitate as sparingly soluble silicate clays, oxides and hydroxides.

Lime also supplies significant amounts of Ca and Mg, depending on the source. Indirect effects of liming include increased availability of P, Mo and B, and more favorable conditions for microbially mediated reactions such as nitrogen fixation and nitrification, and in some cases, improved soil structure. Some diseases are decreased by liming, while others are enhanced. By increasing soil pH, liming also improves the effectiveness of several herbicides.

Plants vary in their tolerance to soil acidity and toxic elements. In general, the pH should not be raised any higher than necessary, since this entails unnecessary expense and increases the danger of overliming. Recommended pH for some common plants are shown below

Since lime applications tend to decrease availability of Zn, Fe, Mn and Cu, excessive applications can cause deficiencies of these elements, with Mn deficiency being the most common in southeastern soils. Heavy applications of lime have also caused decreased uptake of B in some cases.

Table 3-1. Recommended pH for selected NC crops.

Crop	Recommended pH
Intolerant	
Alfalfa, Clover	6.5
Cotton	6.2
Soybean	6.0
Most vegetables	6.5
Moderately Tolerant	
Corn	6.0
Small Grain	6.0
Tobacco	6.0
Peanuts *	6.0
Grasses**	6.5
Tolerant	
Blueberries	5.0
Sericiea Lespedeza	5.0-6.0
Azaleas	5.0-6.0

* Peanuts have a very high Ca requirement.

** When heavy N rates are applied, pH drops rapidly. Higher target pH is recommended to avoid frequent applications

Nutrient Availability and pH

Plant nutrient availability is strongly tied to the activity of H^+, or pH in the soil solution. Decreasing soil pH directly increases the solubility of Mn, Zn, Cu, and Fe. At pH values less than approximately 5.5, toxic levels of Mn, Zn or Al (a non-nutrient element common in soils) may be released. The availability of N, K, Ca, Mg and S tend to decrease with decreasing pH since conditions which acidify the soil such as weathering and plant uptake also result in removal of these nutrients or in decreased microbial activity.

The effects on P and B are primarily indirect as well, since the availability of these nutrients depends on formation of less soluble compounds with Al, Fe, Mn and Ca, which are affected by pH. As a result, P and B availability decrease at both very low and very high pH, with maximum availability in the range of pH 5.5 to 7.0. These reactions bind P much more strongly than B, with the result that available B can be readily leached from soils. These reactions are discussed more fully in the sections dealing with individual nutrients.

The figure below illustrates these general relationships between soil pH and the plant availability of nutrients.

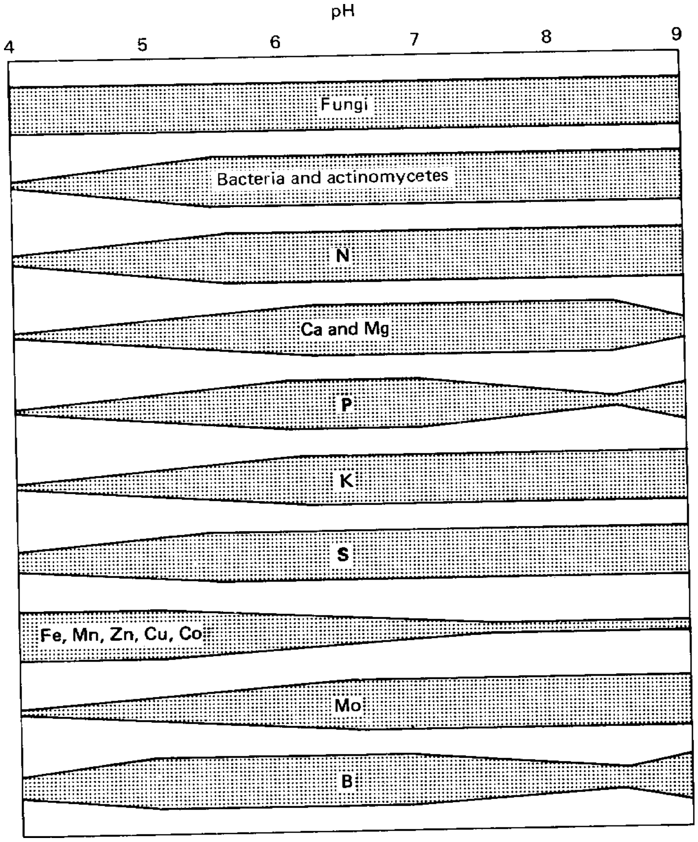

Figure 3-1. Effect of pH Nutrient Availability for Plant Uptake

How Lime Neutralizes Acid Soils

Lime is composed primarily of sparingly soluble calcium and magnesium carbonates. Some liming materials contain Ca oxide or Ca hydroxides which have a somewhat higher solubility. When mixed with water, lime begins to slowly dissolve. In the presence of a acid source, dissolution proceeds more rapidly. Many people incorrectly assume that Ca (or Mg) is the active ingredient in raising soil pH. While Ca helps displace exchangeable acidity from the soil, it is the anionic (carbonate, oxide or hydroxide) component which actually reacts with soil acidity. Carbonates and oxides dissolve in water to form hydroxides. For calcium carbonate, the reactions occurs as ::

$$CaCO_3\ _{(solid)} + H_2O \text{ -----> } Ca^{+2} + HCO_3{}^- + OH^-.$$

For calcium oxide, the reactions is

$$CaO + H_2O \text{ -----> } Ca^{2+} + 2\ OH^-$$

and , the acid in solution is neutralized

$$H^+ + OH^- \text{ -----> } H_2O.$$

The calcium cation remains in the exchangeable form to serve as a plant nutrient. The same would occur with magnesium.

Liming Materials and Chemical Composition

A number of materials are available for liming acid soils (Table 3). The selection of a liming material should be based on its ability to neutralize soil acidity, chemical composition, fineness of grind, ease of handling, and cost.

Limestone is a naturally occurring sedimentary rock rich in the minerals calcite ($CaCO_3$) or dolomite ($Ca,Mg(CO_3)_2$). Most limestone is formed in thick, compacted deposits of calcareous skeletons and shells of sea animals on the ocean bed. Relatively pure deposits of calcite are called calcitic limestone, while materials containing more Mg are called dolomitic limestone. Dolomitic limestone is widely used as Mg source in the southeast. According to the North Carolina Lime Law, dolomitic limestone must contain at least 6 percent Mg. When either calcitic or dolomitic lime is heated, the carbonate is driven off, and calcium (magnesium) oxide is formed. When treated with water, or slaked, calcium oxide forms $Ca(OH)_2$, also called slaked or hydrated lime. These are very reactive and caustic materials, and are difficult to apply at rates used for agricultural liming. These materials are occasionally used when very rapid changes in pH are needed, such as prior to planting a high value crop on limited acreage. Even though these materials are seldom used to lime soils directly, they are used in lime stabilization of sludges and other biosolids, and eventually find their way to the soil.

Table 3. Sources of lime materials, and their calcium carbonate neutralizing equivalency.

Liming Source	Formula	Calcium Carbonate Equivalence (CCE %)
Calcitic Limestone	$CaCO_3$	85-100
Dolomitic Lime	$Ca,Mg(CO_3)_2$	95-108
Hydrated Lime	$Ca(OH)_2$	110-135
Burnt Lime	CaO	150-175
Marl	$CaCO_3$	50-90
Wood Ash		40-80
Basic Slag	$CaSiO_3$, CaO	50-70

As with most sedimentary materials, limestone varies in purity and chemical composition. In order to compare the acid neutralizing value of various liming materials, the Calcium Carbonate Equivalence (CCE) test uses pure calcite ($CaCO_3$) as the standard, with an arbitrarily assigned value of 100 per cent. A CCE value greater than 100 indicates the material can neutralize more acid than the same weight of calcite. Pure dolomitic limestone has a CCE of 108, or 8% higher than pure calcite. Since Mg has a lower mass than Ca, a larger percentage of the material is carbonate, the "active ingredient" in lime. The North Carolina Lime Law does specify a minimum CCE for liming materials, but a printed label must indicate the amount of material required to obtain the equivalent of one ton of limestone with a CCE of 90%.

Fineness of Grind

Since liming materials have a limited solubility, the rate of reaction is largely determined by the amount of surface area exposed to acid soil. As fineness increases, the rate of reaction increases. Particle size is determined by passing the materials through a series of screen or sieves, which catch particles too large to fit through the holes, and allow smaller particles to slip through. Sieve number indicates the number of holes per square inch. Thus a 20 mesh sieve has 20 openings in each direction, or 400 openings per square inch. A 100 mesh sieve has 10,000 openings. As the particle size decreases, the surface area increases, doubling each time the dimensions of the particle are halved. Thus a one inch square particle of limestone has a surface area of 1x1x6=6 square inches. When ground to pass a 100 mesh screen, there would be 100x100x100, or 1,000,000 particles with a surface area of 0.01x0.01x6 square inches, or 1,000,000 x 0.0006=600 square inches.

Particles passing a 60 mesh sieve are small enough to cause desirable changes in soil pH at a reasonable speed. The North Carolina Lime Law specifies that for calcitic lime, 90% must pass through a 20 mesh sieve, and 25% must pass through a 100 mesh sieve. For dolomitic lime, which is slightly less soluble in acid soils, the requirements are 90% for a 20 mesh sieve and 35% for the 100 mesh sieve.

Lime Requirements and Application Rates

Calculation of lime requirements involves analysis of soil pH, and exchangeable acidity, as well as knowing the target pH of the crop. The pH of a soil is a function of the type of exchange complex present, and proportions of the CEC which is occupied by acidic and basic cations. As the base cation saturation of a soil increases, the pH increases in a predictable manner. Likewise, as the acid cation saturation increases, the pH decreases. Since the saturation percentage (a ratio me of exchangeable bases to total CEC) is the determining factor, the relationship between pH and base saturation can hold for soils with different CEC values. For soils with similar cation exchangers, this relationship can be used to predict the increase in base saturation required to raise the soil pH to a desired level. Lime requirement calculations are based directly on this relationship.

It is important to remember that soil pH is only a measure of the relative intensity or ratio of the base cation saturation of the exchange complex. It does not give any indication of the total amount of acidity which must be neutralized, only the relative intensity of the acidity. As a result, the exchangeable acidity must be measured.

In some ways, the soil pH value is like a blood pressure reading. The device used to measure blood pressure directly reads the amount or intensity of force required to move blood through the body. The measurement gives little direct information about the chemical and physical processes which regulate the intensity of the pressure, and provides almost no information on the total supply of blood in circulation. But when combined with other information, a blood pressure measurement can be an excellent indicator of health or illness. Soil pH likewise gives little direct information about the total acidity present in a soil, but when combined with a knowledge of other soil properties and measurement, it can be a very useful indicator of potential problems. Under these conditions it tells you the approximate base (or acidic) saturation. By measuring the extractable acidity at this base saturation level, we can then calculate the amount of acidity which must be neutralized to raise the soil pH to the target level for the crop.

For example, we have a soil with a pH of 5.0 and a base saturation of 40%. At this level, we measure the extractable acidity and find it to be 3 meq/100g. We wish to raise the base saturation to 90% (which we will say is pH 6.0). We can calculate the acidity to be neutralized by first calculating the CEC. Since we know the soil has a base saturation of 40%, the acid saturation must be 60%. Since the extractable acidity is 3 meq/100g, the CEC is:

$$3.00/0.6 = 5.0 \text{ meq}/100 \text{ g}.$$

The increase in base saturation is:

$$90\% - 40\% = 50\%.$$

Fifty percent of 5.0 is 2.5 me.

Most soil testing labs use a pH-buffered solution to determine the exchangeable acidity component. Thus, the terms buffer pH, Acidity and Exchangeable Acidity are commonly seen on soil test reports.

In general, sandier soils have less "buffering" capacity or reserve acidity than finer textured soils; therefore, the amount of limestone needed to increase the pH of a sandy soil will be much less than the amount of limestone needed to increase the pH of a loamy soil even though both soils may have similar pH values prior to liming

Managing Lime Applications

Since liming materials sparingly soluble and are relatively immobile in the soil, surface applications affect only the top 2 or 3 inches, and are an inefficient means of amending the soil. Thorough incorporation in the rooting zone increases the rate of reaction and treats a larger volume of the soil, maximizing the benefits of lime.

All these reactions essentially prevent the movement of lime in soils. Beneficial effects are obtained only where lime and soil are in contact. For this reason, it is imperative to adjust the pH of fields prior to beginning no-till plantings.

Fall liming has many advantages. Lime has more time to react with the soil before the period of most rapid growth begins in the spring. Lime may also react more rapidly due to lower pH in the fall. In addition, soils are generally drier and more accessible in the fall than in the spring.

Overliming

Overliming dramatically reduces availability of micronutrients, and can result in deficiencies which are very difficult to correct. In some cases, the only alternative is to reduce the pH using sulfur or aluminum sulfate. Lime application should be based on soil tests to ensure that excessive lime is not added.

While a good liming program usually provides adequate levels of Ca and Mg for crop production, there are times when lime is not recommended, but additional Ca and/or Mg /are required. Use more soluble sources such as gypsum (calcium sulfate), magnesium sulfate, and potassium-magnesium-sulfate to supply needed nutrients rather than lime.

Chapter 11 Salt Affected Soils

Saline, Saline-Sodic and Sodic Soils

Most salt-affected soils occur in the arid and semiarid climates where rainfall is not sufficient to dissolve and leach salts such as Cl, SO_4, HCO_3, Na, Ca, Mg and K,, below the root zone. They are particularly prevalent in irrigated regions where improper irrigation and drainage methods are used. Sodium is of particular note, since it can be toxic to plants and detrimental to soil structure.

Salt problems in soils usually develop from

- salts already present in the soil
- high groundwater tables (including brackish water intrusion)
- salts added in irrigation water

In low lying coastal areas, salt affected soils have resulted from poor drainage practices, salt water intrusion, poor quality irrigation water, and submergence.

The most common measurements of salt effected soils involve the amount of exchangeable sodium. The ***exchangeable sodium ratio*** (ESR) is defined as :

$$\frac{\text{exchangeable Na}}{\text{exchangeable (Ca + Mg)}} \quad \text{(all unit in meq/100g)}$$

For measurements in solution, the ***sodium adsorption ratio*** (SAR) is commonly used:

$$SAR = \frac{Na+}{\sqrt{\frac{(Ca + Mg)}{2}}}$$ (all units in meq/liter.)

The ESR is related empirically to the SAR by the relationship:

$$ESR=0.015(SAR).$$

Finally, the ***exchangeable sodium percentage***, which had traditionally been used for classifying salt-affected soils is related to ESR by:

$$ESP = \frac{(100)ESR}{1+ ESR}$$

Salt affected soil are classified into three categories, according to the total soluble salts (measured by electrical conductivity), pH and exchangeable sodium percentage, as shown in the following table.

Table 4.1. Summary of salt-affected soil characteristics.

Classification	Conductivity (mmhos/cm)	Soil pH	Exchangeable Sodium Percentage	Soil Physical Conditions
Saline	>4.0	<8.5	<15	Normal
Saline-sodic	>4.0	<8.5	>15	Normal
Sodic	<4.0	>8.5	>15	Poor

Saline soils were once called white alkali soils because of the deposits of salts found on the surface following evaporation. The excess salts, mostly found as Na, Ca, and Mg sulfates or chlorides, can be leached out with little increase in pH.

Sodic soils have much higher pH, and ESP than saline soils. These soils were formerly called black alkali soils, because the high pH dissolved organic matter which was deposited on the surface along with the excess salts (primarily Na.).

Saline/sodic soils are a mixture of high salt content and high ESP. When leached, the pH tends to increase, and the soils become sodic.

Corrective treatments for saline and sodic conditions include both chemical and physical methods which seek to replace excess sodium with Ca and remove it by leaching with high quality irrigation water. In many cases, drainage is required to facilitate leaching. For soils with high pH and containing CaCO3, the addition of sulfuric acid or elemental sulfur may be used to dissolve the lime and free Ca to displace the Na. In most other situations, gypsum is recommended.

Use of salt tolerant crops such as cotton and bermudagrass are strongly recommended during the reclamation of salt affected soils.

Chapter 12 Nutrient Management & Realistic Yields

Development, implementation and periodic maintenance of a plan to apply nutrients at rates necessary to achieve realistic crop yields, improve timing of nutrient applications, increase nutrient use efficiency

The primary goal of Nutrient Management is to prevent accumulation of nutrients on the farm to the point they threaten plant growth or the environment. Nutrients come to the farm as fertilizers, feeds and mineral additives. The cost of fertilizers tends to reduce the rate of accumulation of nutrients applied from this source, although very high levels have accrued for high value crops over time. Animals transform feed nutrients into body mass and manure. Unless the manure nutrients are transported off the farm, they will build up to levels that could negatively affect crops, ground water, and surface water supplies. The concentration of nutrients in manure, especially liquids, is low enough that transport very far off the farm as a fertilizer is seldom practical. A land application system on the farm allows manure nutrients to be used to grow crops. The nutrients, in the form of crops, can then be exported off the farm to prevent buildup.

A Nutrient Management Plan begins as a tool to help you define the nutrient needs of the crops you will grow, and how best to provide the amount sources, placement and timing of those applications to maximize nutrient uptake of the crop, and improve yields. Since fertilizers contain guaranteed nutrient contents, and are for the most part highly available, very precise applications can be made.

For manure, a nutrient management plan (also called a waste utilization plan) this involves determining the number of acres and types of crops to be grown based on the amount of manure produced and the nutrient requirements of your crops. The process requires estimating the amount of manure produced, and the amount of plant available nutrients the manure contains. Based on these factors, environmentally sound cropping systems are matched with your production and waste handling systems to come up with the most economically acceptable alternatives for land application.

Once a plan is written, it still must be implemented. A Nutrient Management Plan requires your careful attention to make it work properly. A properly implemented plan will let you utilize nutrients in a manner that meets crop needs while reducing the effects on surface and ground water supplies. Even for commercial fertilizer sources, this requires careful attention to timing, crop growth and seasonal variations. The inherent variability of manure complicates the process even further. Implementation requires an understanding of the information in a plan, along proper use of analytical tools, monitoring information and equipment calibration to make the plan work for you. must be implemented

Components Of a Nutrient Management Plan

Developing a Nutrient Management Plan requires information on the nature of the source, the amount of nutrients which can be safely land applied, the placement of nutrients on the field, and the timing of nutrient applications. These four components -- **source, amount, placement and timing** -- must be considered together to ensure that the nutrients used on the farm are applied in harmony with crop needs and environmental goals, such as prevent erosion or direct discharge of manure into a water supply. In addition, a Nutrient Management Plan will identify best management practices (BMPs) which will help prevent the movement of nutrients from your fields. Let's briefly review each of these components, then take a more detailed look at how they are used in developing a Nutrient Management Plan.

Source

You should consider all sources of nutrients on your farm when planning nutrient applications. Sources to include are nutrients already in the soil, commercial fertilizers, crop residues, biosolids, septage and manure. Legumes such as soybean, peanut, clover and alfalfa can leave from 25 to over 120 pounds of available N for the following crop. To account for these nutrients, we can use manure and soil analysis. For manure sources, we need to consider how much manure will be produced, the concentration of nutrients the manure contains, and how readily available those nutrients are for plant uptake. Table 1. Shows average total nutrient content of swine lagoon wastes.

Table 1. Average Total Nutrient Composition of Swine Manure

Manure Type	Total N (TKN)	Ammonium NH$_4$- N	Phosphorus P_2O_5	Potassium K_2O
			lb/ton	
		lb/1,000 gallons		
Liquid slurry [2]	31	19	22	17
Anaerobic lagoon sludge	22	6	49	7
		lb/acre-inch		
Anaerobic lagoon liquid	136	111	53	133

[1] Collected within 1 week.

[2] Six-12 months accumulation of manure, urine, and excess water usage; does not include fresh water for flushing or lot runoff.

Nutrient availability varies greatly with source. Commercial fertilizers are highly soluble, and their nutrients are quickly available to plants. Manure and biosolids not only vary in nutrient content, but also in the availability of the nutrients they contain. This is derived in part from rather rapid loss of volatile components such as ammonia, and in part from the slow mineralization and release of organically bound nutrients such as N, P and S. The method of waste handling or treatment has a significant effect on the nitrogen content and form in manure sources, as described below in Table 4.

Amount

The amount of a nutrient to supply to a growing crop should be determined by the **agronomic rate** – the amount of the nutrient needed to optimize yield and economic return while minimizing undesireable effects on the environment. Insufficient applications result in nutrient deficiencies which can reduce crop yield and quality, and decrease utilization of other applied nutrients. Excessive applications can negatively affect both the plant and the environment. The effect of too much fertilization on plant growth depends on the crop and nutrients involved. In most cases too much phosphorus (P) and potassium (K) have little effect on plant growth and yield unless so much is applied that salt injury results. Too much nitrogen (N), however, can reduce yields by making plants more susceptible to diseases and insects, increasing lodging, and stimulating vegetative growth at the expense of fruit or grain production. Excess metals such as copper and zinc can be toxic to the plant. In extreme cases, soil levels of theses metals can be high enough to limit and sometimes prevent the growth of certain crops. An added concern of over application of nutrients is the potential for water pollution. Both nitrogen and phosphorus are known to enhance algal blooms, which can ultimately lead to fish kills.

For sources, such as manure and biosolids, that contain several elements in significant concentrations, the amount to apply should be based on the **priority nutrient** – the nutrient most likely to have negative effects on crop yield or the environment. In most current regulations, nitrogen is specified as the the priority nutrient. Plans based on nitrogen only may result in application of other nutrients far in excess of plant growth requirements. As a result, soil fertilility levels should be monitored to ensure excessive nutrients do not become a problem.

For most crops, aronomic rates are determined by the realistic yield expectation (R.Y.E.) of a site (covered in more detail below) and the amount of N required to produce a unit of that crop (Table 2). For example, corn requires 1.0 to 1.25 pounds of N per bushel. For a site with a realistic yield potential of 120 bushels of corn per acre the agronomic rate of N is 120 to 150 pounds of N per acre, as calculated by:

120 bu/ac x 1.00 lb/bu = 120 lb/ac, and 120 bu/ac x 1.25 lb/bu = 150 lb/ac.

Realistic Yield Expectations

A number of factors can affect the realistic yield expectations (R.Y.E.) of a given site. One of the most obvious is the soil. Soil related factors which can influence yields include:

- Depth to subsoil
- Depth to rock or root confining zone
- Texture of surface soil-water-holding capacity
- Organic matter content
- Permeability- infiltration, runoff

- Drainage - aeration, water availability
- Mineralogy - charge, nutrient pools, workability
- Structure
- Slope - erodibility, drainage
- Local climate - drought, soil temperatures, excessive water etc.

Management factors can overcome many of these site specific properties, but greater inputs in terms of irrigation, nutrients, labor and skill will be required to achieve high yields on poorer soils.

Table 2. Nitrogen Response Factors For Selected NC Crops

Crop	**Suggested Nitrogen Application Rates**
Wheat (grain)	1.7 to 2.4 lb N/bu
Barley (grain)	1.4 to 1.6 lb N/bu
Oats (grain)	1.0 to 1.3 lb N/bu
Rye (grain)	1.7 to 2.4 lb N/bu
Triticale (grain)	1.4 to 1.6 lb N/bu
Corn (grain)	1.0 to 1.25 lb N/bu
Corn (silage)	10.0 to 12.0 lb N/ton
Sorghum (grain)	2.0 to 2.5 lb N/cwt
Soybean	3.8 lb/bu
Cotton	0.06 to 0.12 N/lb llint
Sorghum-sudangrass (hay[1,2])	45.0 to 55.0 lb N/dry ton
Bermudagrass (hay[1,2])	40.0 to 50.0 lb N/dry ton
Tall fescue (hay[1,2])	40.0 to 50.0 lb N/dry ton
Orchardgrass (hay[1,2])	40.0 to 50.0 lb N/dry ton
Annual ryegrass (hay[1,2])	40.0 to 50.0 lb N/dry ton
Small grain (hay[1,2])	50.0 to 60.0 lb N/dry ton
Millet (hay[1,2])	45.0 to 55.0 lb N/dry ton
Pine and hardwood trees[3]	40.0 to 60.0 lb N/acre/year

[1] Annual maintenance guidelines

[2] Reduce nitrogen rate by 25 percent when grazed only.

[3] On trees less than 5 feet tall, nitrogen will stimulate undergrowth competition

.

Methods of Determining R.Y.E.

The best method of determining R.Y.E. is to use producers actual historic yields for each field. Most agencies have agreed to base realistic yield expectations on the average of the three highest yields in a five year period in which the crop was grown in that field. An example of this calculation is shown in the following table. Using this method reduces the risk of seriously underestimating yields from one or two bad years.

Table 3. Calculation of realistic yield expectation by Average and Best 3 of 5 methods.

Year	Last 5	Best 3 of 5
1991	93	93
1993	70	
1994	118	118
1996	149	149
1997	90	
Average	104	120

Soil based yield potentials. Unfortunately, field specific data for a three to five year period is seldom available, especially where a new crop is being grown. In such cases, other alternatives must be used. In 1994, a special nutrient management database was put together by the Natural Resource Conservation Service that provides estimates of the realistic yield expectations for various crops by soil series. Where actual yields are not available, these values give reasonable estimates of yields for various crops under high levels of management. The database is limited in the number of crops available, and in some cases, the yield potentials are inferred from soils with similar properties. Thus, these values are useful for estimating land requirements and approximate yield potentials, but may or may not represent actual yield levels attained under different management regimes. Where two or more soils occur in the same field, the predominant soil type is used, or the field may be further split into smaller management units based on soil type.

Placement

Nutrient placement affects crop uptake, and the likelihood of movement from the site. Application to the soil surface without incorporation typically results in greater potential for nutrient loss through volatilization (escape as a gas), runoff and erosion than where nutrients are incorporated or injected. Uniformity and distance from the root system can also influence crop response to nutrient applications. The method of application can also affect odor emissions associated with manure. Careful placement also means irrigating at rates that prevent runoff.

As previously mentioned, application methods also affect nitrogen availability. When surface applied on some soils, nutrient sources containing urea or ammonium can loose nitrogen, as a gas, through a process called volatilization. The volatilized nitrogen is usually in the form of ammonia and once in the air is subject to deposition via rainfall. Ammonia deposition has been cited as a major contributor of nitrogen in the Chesapeake Bay. Ammonia volatilization varies with the source. In manures of NC, ammonia losses are considered to be between 35 and 75 % for different manures if they are broadcast applied and not incorporated. If incorporated within 48 hours, losses are between 10 and 25%. If irrigated without incorporation, ammonia losses are considered to be between 35 and 75 % for slurry and lagoon effluents. If incorporated, losses are 25 and 40 % for slurry and effluent applications.

Temperature and moisture conditions also strongly affect mineralization rate.

The following table is an example of the **first year availability coefficients** (FYAC) used to determine plant available (PA) nutrients from swine manures in the year they are applied. Additional tables for other sources are included in the Reference section of this manual. These values represent the availability of nutrients to the plant from ammoniacal and mineralized organic forms. Additional nutrients form organic forms may be released in the following years. In general 50% of the organic form of N is released the first year, with 20%, 10%,and 5% of the remaining organic N released in year 2, 3, and 4, respectively.

Table 4. First-Year Availability Coefficients for Swine Manure.
[**NOTE**: These data are based on older data, focused on agronomic response over a wide area of the US, and are subject to change as better data becomes available from NC research.]

	Application Method			
Manure Type	Soil Injection[1]	Incorporation[2]	Broadcast[3]	Irrigation [4]
	$P_2 0_5$ and $K_2 0$ availability coefficients			
All manure types	0.8	0.8	0.7	0.7
	N availability coefficient			
Scraped paved surface	--	0.6	0.4	--
Liquid manure slurry	0.8	0.7	0.4	0.3
Anaerobic lagoon liquid	0.9	0.8	0.5	0.5
Anaerobic lagoon sludge	0.6	0.6	0.4	0.4

[1] Manure injected directly into soil and immediately covered.

[2] Surface-spread manure plowed or disked into soil within two days.

[3] Surface-spread manure uncovered for one month or longer.

[4] Sprinkler-irrigated liquid uncovered for one month or longer.

Timing

All nutrient sources should be applied at times that will maximize crop use and minimize the possibility of loss. In general, nutrients should be applied to an actively growing crop or within 30 days of planting a crop. Ideally, applications will be closely matched to crop nutrient demands. Timing is most important for nutrients applied to soils with a high leaching potential. Applying nitrogen to a sandy soil when there is no crop to remove it will almost certainly result in loss of nitrogen to the shallow ground water. There are potential human health problems when excessive levels of nitrogen reach ground water used for drinking. Proper timing of lagoon effluent requires that pumping frequency be carefully matched with cropping sequences. Low storage capacity will require frequent applications, and year round cropping systems, while larger storage volumes may allow less frequent applications to a single crop such as bermudagrass.

Site Characteristics and Selection

Properly locating the site on FSA, Soil Suurvey and USGS maps is the first critical step in assessing the suitablity for a land application system. Maps are used ot determine current farm acres and crops, if applicable, and the soils on which the land application system must function. A knowledge of the soils helps to assess the potentila for offsite movement through leaching and erosion, as well as clearly identifying shallow or very pooly drained soils ill-suited for land application systems. USGS maps provide the basis for recognizing perennial streams and other hazards such as sink holes karst topography, and rock outcrops. Soil testing may also become an important tool in assessing and monitoring the site for correct pH and accumulation of nutrients.

Best Management Practices (BMPs)

Practices that reduce losses of nutrients and thereby reduce the potential for negative environmental impact are considered BMPs. BMPs may include erosion and sediment control to reduce movement of soil and nutrients into streams from field edges, such as grassed waterways, buffer strips and riparian buffers. Incorporation of nutrients to reduce off-site movement, volatile losses and odors may also be considered best management practices. Using cover crops to scavenge nutrients remaining in the soil could also be an effective best management practice to reduce the loss of nutrients from a land application site.

Nutrient Management and Waste Utilization Plans

A waste utilization plan is a relatively simplified nutrient management plan that deals with proper application of only a single "priority" nutrient. Most legislation is targets nitrogen as the priority in manure, and most other organic sources.