PLANT NUTRITION AND SOIL FERTILITY

M. Wayne Ebelhar
Mississippi State University
Delta Research and Extension Center
Stoneville, MS

"To understand ***Soil Fertility*** is to understand
a big key to ***Mankind's Survival*** on this planet"

"The good Lord helps those
that help themselves"

Man brings three great helps to nature:

1. More nitrogen, phosphorus, potassium, lime, and other nutrients needed to assure an adequate supply for optimum yields.
2. Water control through irrigation and/or drainage or soil practices that improve water use.
3. Good tillage and production practices to seek the best possible growing environment

FACT

Plants use water and nutrients from the soil and oxygen from the air to manufacture carbohydrates, fats, and protein. The more they can manufacture, the more food or fiber that plant can yield

Introduction

Soils are the medium in which most plants grow. To understand soil fertility is to understand a basic need of crop production. Soil fertility is essential for a productive soil but not all fertile soils are productive. Poor drainage, insects, drought, and several other factors can limit production even when nutrient levels are high. These factors also account for some of the year to year variability that one finds in crops even though fertility remains fairly constant.

Factors that control plant growth are air, heat (or temperature), light, mechanical support, nutrients, and water. Since water and air occupy the pore spaces in the soil, factors that affect water relations also influence soil air. In turn moisture changes affect soil temperature. ***Nutrient availability*** is influenced by soil and water balance as well as soil temperature. ***Root growth*** is also influenced by soil temperature, soil water, and air.

Essential Plant Nutrients

Sixteen chemical elements are known to be essential for plant growth with some others believed to be essential for certain other organisms. They are divided into two main groups, non-mineral and mineral. Non-mineral nutrients include carbon (C), hydrogen (H), and oxygen (O) which come from the atmosphere and water. These are used primarily in photosynthesis and photosynthesis accounts for most of the increase in plant growth. The other 13 essential elements come from the soil and are divided into three groups: primary, secondary, and micronutrients.

Primary Nutrients:	Nitrogen (N), Phosphorus (P), Potassium (K)
Secondary Nutrients:	Calcium (Ca), Magnesium (Mg), Sulfur (S)
Micronutrients:	Boron (B), Chlorine (Cl), Copper (Cu), Iron (Fe) Manganese (Mn), Molybdenum (Mo), Zinc (Zn)

The primary nutrients usually become deficient in the soil first because plants use relatively large amounts compared to the other nutrients.

Nitrogen

Role of Nitrogen (N)

Nitrogen is a part of every living cell and is generally taken up as ammonium ($NH_4^{+)}$) or nitrate (NO_3^-) and sometimes as water-soluble amino acids. Inside the plant, nitrogen is converted to amino acids, the building blocks for proteins. The amino acids are then used in forming protoplasm, the seat of cell division–and thus plant growth. All plant enzymes are protein, so N is necessary for all enzymatic reactions in plants. It is part of the chlorophyll molecule, thus directly involved in photosynthesis and helps the plant produce and use carbohydrates.

Nitrogen Component of Selected Crops

Crop	Yield Level	Pounds of N in Total Crop
Cotton	1000 lb (lint)	120
Corn	150 bu	200
Rice	6000 lb	130
Peanuts*	4000 lb	240
Soybean*	50 bu	280
Wheat	60 bu	120
Coastal Bermuda	10 ton	500

* Legumes get most of their N from the air

Nitrogen increases protein content of plants directly. However, adequate potassium and phosphorus improve the plant's use of high N rates to get more true protein.

Plant Deficiency Symptoms

Nitrogen deficiency causes chlorosis (a yellowing) of the leaves from declining chlorophyll. The yellowing starts on the older leaves and moves to the younger leaves as the deficiency becomes more severe.

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Inadequate N leads to low protein in the seed and the vegetative parts. Nitrogen deficient plants tend to be stunted, grow slowly, and produce few tillers than normal (rice, wheat, and grasses). They usually have few leaves and in crops such as cotton reach maturity (or cut-out) early than plants with adequate N.

Nitrogen Transformations in Soil

Three major N forms in the soil:

1. Organic N -- part of the soil organic matter....unavailable to growing plants.
2. Ammonium N – fixed by clay minerals....very slowly available to most plants.
3. Ammonium and nitrate ions or soluble compounds....the N which plants use.

The soil contains a relatively large portion of unavailable (organic) N and a small portion of available (inorganic) N. Organic N may represent 97-98% of the total N in the soil and inorganic N represents only 2-3% of the total.

Mineralization is the process where organic forms are converted to inorganic forms and results from microbiological activity. Microorganisms decompose the organic residues for their energy supply and their essential nutrients. When the organisms use all the nutrients they need they release the excess into the soil for plant growth.

Immobilization is the process where inorganic N is converted to organic forms which is the reverse of mineralization and happens when fresh organic materials such as crop residues are incorporated back into the soil.

Both mineralization and immobilization occur simultaneously in soils. Whether the soil shifts toward one or the other depends largely on the C/N ratio of decomposing organic residues. Materials with high C/N ratios (>30:1) favor immobilization while lower C/N ratio (< 20:1) materials favor mineralization.

When immobilization of soil N exceeds mineralization, there may be little N available for growing crops unless N fertilizers have been applied.

Nitrification is the process where ammonium-N in soils is converted to nitrate-N by certain nitrifying bacteria. This process is important for three key reason:

1. Nitrate is readily available for use by crops
2. Nitrates are highly mobile in soil and move freely with soil water
3. Nitrates are lost through *denitrification* - a process whereby nitrates are reduced to nitrous oxide or elemental N and lost to the atmosphere as a gas

Losses of Nitrogen

1. Crop removal - the amount depends on the crop
2. Ammonium reactions - volatilization or direct loss
3. Nitrification followed by leaching through the soil profile
4. Denitrification - loss to the atmosphere as gas
5. Erosion and surface run-off

Common Sources of Nitrogen

1. Anhydrous ammonia (82% N) - stored under pressure
2. Aqua ammonia and nitrogen solutions (21-49% N)
3. Ammonium nitrate (33-34% N)
4. Urea (45-46% N)

Phosphorus

Role of Phosphorus (P)

Phosphorus is essential for plant growth and no other nutrient can substitute for it. Plants absorb most of their P as the primary orthophosphate ion ($H_2PO_4^-$). Smaller amounts of the secondary orthophosphate (HPO_4^{2-}) can be taken up. Soil pH greatly influences the ratio of these two ions taken up.

Phosphorus plays an essential role in photosynthesis, respiration, energy storage and transfer, cell division, cell enlargement and several other processes in the plant. It promotes early root formation and growth and improves the quality of many fruit, vegetable, and grain crops and is vital for seed formation. Phosphorus helps roots and seedlings develop more rapidly and contributes to disease resistance in some plants. Phosphorus also helps to hasten maturity.

Phosphorus Component of Selected Crops

Crop	Yield Level	Pounds of P_2O_5 in Total Crop
Cotton	1000 lb (lint)	45
Corn	150 bu	85
Rice	6000 lb	50
Peanuts	4000 lb	40
Soybean	50 bu	55
Wheat	60 bu	55
Coastal Bermuda	10 ton	140

Plant Deficiency Symptoms

The first signs of P stress is an over-all stunted plant and leaves may be distorted. With severe deficiency, dead areas may develop on the leaves, fruit, and stems. Older leaves are usually affected more than the younger ones. A purple or reddish color is often seen on corn and other crops especially during cool temperatures.

Visual symptoms are not as clear as with N or K and is hard to detect in many field crops. A some stages, P deficiency may cause the crop to look darker green. When possible, confirm what the eye sees with soil and tissue analysis.

Phosphorus in Soil

Elemental phosphorus is very chemically reactive and is thus not found in the pure state in nature. It is found only in chemical combinations with other elements. Soil P comes largely from weathering of apatite, a mineral containing P and Ca along with other elements such as flourine and chlorine. As the apatite breaks down and releases P, several P compounds are formed, including the two orthophosphates taken up by plants.

Some of the P will form compounds with Ca, Fe, and Al whether it comes from the apatite, fertilizer, manure, or organic matter. Most of these compounds are not available to plants because they are insoluble.

Other sources of P in the soil include organic matter, microorganisms, humus, decaying bodies of insects and other forms of life. The plow layer contains 800 to 1600 lbs of P per acre in combination with other elements– most of it in forms not available to plants.

Movement of Phosphorus in the Soil

Phosphorus moves very little in the soil and generally stays where it is placed by mineral weathering or by fertilization. Nearly all P moves by *diffusion* - a slow and short-ranged process that depends on soil moisture.

Factors Affecting Phosphate Availability

1. Type of clay....kaolinitic clays "fix" more than others
2. Amount of clay....higher clay means more "fixed"
3. Time of application....close to the time the plant need its
4. Aeration....necessary for nutrient absorption
5. Compaction....reduces aeration and pore space in root zone
6. Moisture....optimum levels make more P available
7. Phosphate status of soil...long-term buildup is better
8. Temperature....right for plant growth, good P availability
9. Other nutrients....applying other nutrients may stimulate uptake
10. Soil pH....sound liming essential on acid soils

Losses of Phosphorus

1. Crop removal - the amount depends on the crop
2. Fixation by clays - not removed from the soil
3. Erosion and surface run-off - carried with clay

Common Sources of Phosphorus

1. Normal (ordinary) superphosphate (20% P_2O_5)
2. Concentrated superphosphate (46% P_2O_5)
3. Ammonium phosphates (MAP: 11-12% N & 28-55% P_2O_5) (DAP: 18% N & 46% P_2O_5)
4. Nitrophosphates (mostly European countries)
5. Ammoniated superphosphates

Phosphate Fertilizer Terminology

1. Water soluble P - extracted from fertilizer with water
2. Citrate soluble P - extracted with neutral ammonium citrate
3. Citrate insoluble P - portion remaining after 1 and 2 extraction
4. Available P - sum of water soluble and citrate soluble P
5. Total P - sum of available P and citrate insoluble P

Potassium

Role of Potassium (K)

Potassium is absorbed by plants in the ionic form K^+ and is essential for plant growth even though it forms no organic compounds in the plant. Its primary function seems to be tied to plant metabolism. When K is deficient photosynthesis declines and respiration increases thus reducing the plant's carbohydrate supply. Potassium is essential to protein synthesis and those controls N and P utilization. Potassium helps the plant to use water more efficiently by promoting turgidity to maintain internal pressure in the plant. Potassium is important in fruit formation and in translocation of heavy metals. Potassium is also responsible for enzyme activation and controls their reaction rates. It has also been found to improve winter hardiness in crops and increase disease resistance.

Potassium Component of Selected Crops

Crop	Yield Level	Pounds of K_2O in Total Crop
Cotton	1000 lb (lint)	85
Corn	150 bu	200
Rice	6000 lb	145
Peanuts	4000 lb	185
Soybean	50 bu	120
Wheat	60 bu	80
Coastal Bermuda	10 ton	420

Plant Deficiency Symptoms

Potassium deficiency symptoms show up in many ways with the most common sign as a scorching or firing along leaf margins. In most plants, firing appears first on older leaves but newer leaves will show symptoms on some crops under certain conditions. Potassium deficient plants grow slowly and have poorly developed root systems. Stalks are weak and commonly lodge. Seed and fruit are small and shriveled and plant have little disease resistance. Plants under stress from low K supplies are susceptible to unfavorable weather conditions.

Potassium in Soil

Although most soils contain thousands of pounds of K, only a small percent is available to plants over the growing season -- probably less than 2%. Soil K exists in three forms:

1. Unavailable K – found in minerals (rocks) which are slowly released as the soil minerals weather....too slow to be available to growing plants.
2. Slowly available K – "fixed" or trapped between of certain soil clays as they shrink and swell during dry and wet soil conditions. The K^+ ions can be trapped between the clay layers and are only slowly released.
3. Available soil K – readily available K found in the soil solution plus the K held in exchangeable form by soil organic matter and clays.

Movement of Potassium in the Soil

Potassium moves very little in the soil and generally stays where it is placed by fertilization. Nearly all K like P moves by *diffusion* - a slow and short-ranged process that depends on soil moisture.

Fertilizer Potassium in the Soil

Two kinds of soil K have been recognized that are readily available to he growing crop. They are:

1. Solution or soluble K – found in the soil water
2. Exchangeable K – loosely held in an exchangeable form by soil clays and organic matter

Factors That Influence K Fertilizer Placement

1. Crop
2. Available labor and equipment
3. Soil fertility level
4. Soil type
5. Fertilizer rate and time of application
6. Use of crop protection chemicals in combinations with fertilizer

Combining row with broadcast is often the best way to apply fertilizer. It gives a fast early start and a nutrient reservoir throughout the growing season.

Losses of Potassium

1. Crop removal - the amount depends on the crop
2. Fixation by clays - unavailable or slowly available form
3. Erosion and surface run-off - carried with clay
4. Leaching - in very sandy or organic soils

Common Sources of Potassium

1. KCL (muriate of potash) - mined from a number of minerals
2. Potassium sulfate
3. Potassium nitrate
4. Sulfate of Potash-Magnesia

Calcium

Plant Function (CA)

Calcium stimulates root and leaf development. It forms compounds which are part of cell walls and strengthens plant structure. Calcium helps reduce nitrates in the plant....to activate several enzyme systems....to neutralize organic acids in the plants. Calcium influences yields indirectly by reducing soil acidity which lowers the solubility and toxicity of Mn, Cu, and Al. It also helps yields indirectly by improving root growth conditions and stimulating microbial activity, molybdenum availability, and uptake of other nutrients.

Deficiency Symptoms

Poor root growth and in severe cases the growing point dies. Ca-deficient roots often turn black and rot. Calcium deficiencies cause gelatinous leaf tips and growing points because it is not being translocated. Calcium deficiencies seldom show up in the field because secondary deficiency effects such as high acidity usually limit growth first.

Calcium in the Soil

Calcium, like K, exists as a cation (Ca^{2+}) and is governed by cation exchange phenomena just like other cations. It is present in the soil solution and is held on exchange sites (negatively charged surfaces of soil clay and organic matter). Calcium is part of the structure of several soil minerals and such minerals as dolomite, calcite, apatite, and calcium feldspars are a major source of calcium. Total amounts in the soil range from <0.1% to as much as 25%.

Sources of Calcium

Calcitic and dolomitic limestones, gypsum, basic slag, marl, and hydrated lime. Adding large amounts of Ca can cause nutrient imbalances.

Magnesium

Plant Function (MG)

Magnesium is a mineral constituent of chlorophyll so it is actively involved in photosynthesis. Most of the Mg in the plant is found in the chlorophyll but seeds are also relatively high. Magnesium also aids in phosphorus metabolism, plant respiration and the activation of several enzymes systems.

Deficiency Symptoms

Deficiency symptoms first appear on lower leaves and shows as a yellowish, bronze or reddish color while leaf veins remain green. Imbalances between Ca and Mg in the soil may accentuate Mg deficiency. When the Ca/Mg ratio becomes too high, plants may take up less Mg. Magnesium deficiencies can also occur when high lime rates (calcitic lime) have been used on low Mg soils. It can also come from high K rates or high ammonium-N rates when the soil is low in Mg.

Magnesium in the Soil

Magnesium, like K, exists as a cation (Mg^{2+}) and is governed by cation exchange phenomena just like other cations. It is present in the soil solution and is held on exchange sites. Magnesium, other than added in fertilizer or liming materials, comes from the weathering of rocks containing such minerals as biotite, hornblende, dolomite, and chlorite. Magnesium is more soluble than Ca and is subject to leaching losses.

Sources of Magnesium

Dolomitic limestones is the best source and offers both Ca and Mg. Other sources include magnesium sulfate, magnesium oxide, basic slag, and potassium-magnesium sulfate.

Sulfur

Plant Function (S)

Sulfur is essential in forming plant protein because it is a structural part of certain amino acids. It helps develop enzymes and vitamins, promotes nodule formation on legumes, and aids in seed production. Sulfur is necessary for chlorophyll formation although it is not a constituent. It is generally distributed throughout the tissues of plants.

Deficiency Symptoms

Sulfur-deficient plants show a pale green color, usually appearing first on the younger leaves but the whole plant can exhibit the pale green color. Nitrate and carbohydrate usually accumulate in S-deficient plants. Leaves tend to shrivel as the deficiency progresses. Leaves die only in extreme cases although seedlings can die. The plant stems tend to grow thin and woody. Sulfur deficiencies show up most often on sandy soils, low in organic matter, in areas of moderate to heavy rainfall.

Sulfur in the Soil

Inorganic S occurs in the sulfate form (SO_4^{2-}) while considerable S is tied up in the organic matter. Organic matter is the major source of S in most soils. The sulfate anion is not attracted to soil clay and is not held in the cation exchange phenomena. It remains in the soil solution and thus can be leached. Soil S is replenished primarily by sulfur dioxide gas from the atmosphere brought down in precipitation, and by S-containing fertilizers. In recent years, S deficiencies are occurring because the atmosphere is being cleaned of the SO_2 gases and high analysis fertilizers are low in S.

Sources of Sulfur

Elemental S, ammonium sulfate, aluminum sulfate, and gypsum.

Micronutrients

MICRONUTRIENTS ARE ESSENTIAL FOR PLANT GROWTH!!

....THEY ARE NOT MIRACLE WORKERS....

Seven of the 16 essential plant nutrients are called micronutrients and are as important to plant nutrition as the primary and secondary nutrients, but plants don't use much of them. A lack of any one of them in the soil can limit plant growth, even when every other essential element is present in adequate amounts. Micronutrient fertilization should be treated as any other production input. If a micronutrient deficiency is suspected, you can pinpoint it through soil tests, plant analyses, and/or local field demonstrations. One should develop the habit of observing the growing crop for potential problem areas.

Soil pH affects micronutrient availability sharply. Availability decreases as pH increases with all micronutrients but molybdenum (Mo).

Micronutrient	pH Range for Maximum Availability
Boron	5.0-7.0
Copper	5.0-7.0
Iron	4.0-6.5
Manganese	5.0-6.5
Molybdenum	7.0-8.5
Zinc	5.0-7.0

Field diagnosis should be one of the most effective tools available in production management.

Boron

Plant Function (B)

Boron is essential for germination of pollen grains and growth of pollen tubes. It is essential for seed and cell wall formation. Boron also forms sugar/borate complexes associated with sugar translocation and is important in protein formations.

Boron Deficiency

Boron deficiency generally stunts plant growth with the growing point and younger leaves affected first. In cotton, the deficiency appears as ringed or banded leaf petioles, with dieback of terminal buds, causing rosetting effect at the top of the plant (seldom seen in the field). Ruptured squares and thick, green leaves that stay green until frost are other symptoms.

Copper

Plant Function (CU)

Copper is necessary to form chlorophyll in plants and catalyzes several plant processes. Cooper is necessary in promoting plant processes, though it is not usually a part of the product.

Copper Deficiency

Common symptoms include dieback in citrous and blasting of onions and truck crops. Many vegetable crops show symptoms with leaves that lose turgor and develop a bluish-green shade before becoming chlorotic and curling. Generally, plants fail to flower.

Iron

Plant Function (FE)

Iron is a catalyst to help form chlorophyll and act as an oxygen carrier. It also helps form certain respiratory enzyme systems.

Iron Deficiency

Iron deficiency shows up as pale green leaf color (chlorosis) with sharp distinction between green veins and yellow interveinal tissues. Because Fe is not translocated within the plant, deficiency symptoms first appear on the younger leaves at the top of the plant. Severe deficiencies may turn the entire plant yellow-to-bleached white. Iron deficiency is thought to be caused by an imbalance of metals such as Mo, Cu, or Mn. Other factors which may contribute are excessive P in the soil and a combination of high pH, high lime, wet, cold, soils, and high bicarbonate levels.

Manganese

Plant Function (MN)

Manganese functions primarily as a part of the enzyme systems in plants and activates several important metabolic reactions. Manganese aids in chlorophyll synthesis and also accelerates germination and maturity. It also increases the availability of P and Ca.

Manganese Deficiency

Symptoms appear in younger leaves as yellowing between the veins and sometimes a series of brownish black specks appear. Deficiencies are most often in high organic soils or neutral-to-alkaline pH soils naturally low in Mn.

Molybdenum

Plant Function (MO)

Molybdenum is required to form the enzyme, nitrate reductase which reduces nitrates to ammonium in the plant. It is vital for helping legumes form nodules which are needed for symbiotic N fixation. It is also needed to convert inorganic P to organic forms in the plant.

Molybdenum Deficiency

Molybdenum deficiency symptoms show up as general yellowing and stunting of the plant. It can cause N deficiency in legumes crops because soil bacteria on legumes must have Mo to fix atmospheric N. Heavy phosphate applications increase Mo uptake while heavy S applications can decrease Mo uptake.

Zinc

Plant Function (ZN)

Zinc aids plant growth substances and enzyme systems and is essential for promoting certain metabolic reactions. Zinc is necessary for producing chlorophyll and forming carbohydrate.

Zinc Deficiency

Zinc is not translocated within the plant, so symptoms first appear on the younger leaves and other plant parts. Young buds turn white or light yellow in early growth. Other symptoms include bronzing in rice. Zinc deficiency may occur on high P soils and several plant species show Zn-P interaction. Zinc like other micronutrients can be toxic if applied in large quantities.

Chlorine

Plant Function (CL)

Chlorine is known to be essential for plant growth , but little is understood about the role of chlorine in the plant. It has been reported to interfere with P uptake and seems to enhance maturity of small grains on some soils. Fortunately, it is seldom limiting in soils. Chlorides are not retained in the soil to any extent, so are subject to considerable leaching. Excess Cl can reduce the quality of certain crops, especially tobacco, but has no detrimental effect on cotton.