Soil Fertility

Proper fertilization of cotton is of paramount importance to meet the nutritional needs of the crop. However, this can be difficult to determine because many variables can affect development and production. Anything that causes plant stress will affect nutrient uptake. Some factors include soil texture, drainage, field preparation, weather, variety, time of planting, plant populations, emergence and stand, previous crop and carry-over fertility and/or chemicals. A current soil test is still the best tool for taking the guesswork out of fertilization. Knowing what you have is critical in calculating what you need to apply in order to deliver a balanced nutrient program to achieve desired yield and quality goals (Table 1). Over fertilization is costly to the producer and to the environment. It is also undesirable to the crop, which may result in maturity delays and increased attractiveness for insect pests and diseases.

Table 1. Typical nutrient contents (lbs) required to produce one bale of lint (NCC, 1996).

Element/Nutrient	**Above Ground Plant (leaves, stems, & fruit)**	**Seed Cotton**	**Lint**
Oxygen	2100	700	250
Carbon	1650	550	190
Hydrogen	360	120	35
Nitrogen	62	35 to 40	1
Potash (K_2O)	61	15	3
Phosphate (P_2O_5)	22	13 to 20	0.3
Calcium	27 to 62	1	0.2
Magnesium	11 to 27	5	0.3
Sulphur	8 to 16	1 to 2	trace
Other Nutrients	‹3	trace	trace

Tools such as plant tissue analysis, soil testing, and other laboratory techniques are necessary to diagnose a problem once it occurs. Practical guidelines such as "Be Your Own Cotton Doctor" from the Potash & Phosphate Institute, 2005, USA can be of great benefit to field practitioners. Most state's Cooperative Extension programs offer producers regional guidelines.

Soil nutrients are taken up in direct proportion to growth and temperature. Total nutrient uptake for nitrogen, phosphorus and potassium tracks cumulative heat units. During the spring growing months, when heat units are low, cotton grows slowly and takes up only limited amounts of nutrients. It is during the peak growing months when nutrients need to be most readily available to the crop (Fig.1). Fertilizer applications should be scheduled in a timely fashion so that nutrient availability is synchronized with plant demands (Fig. 2).

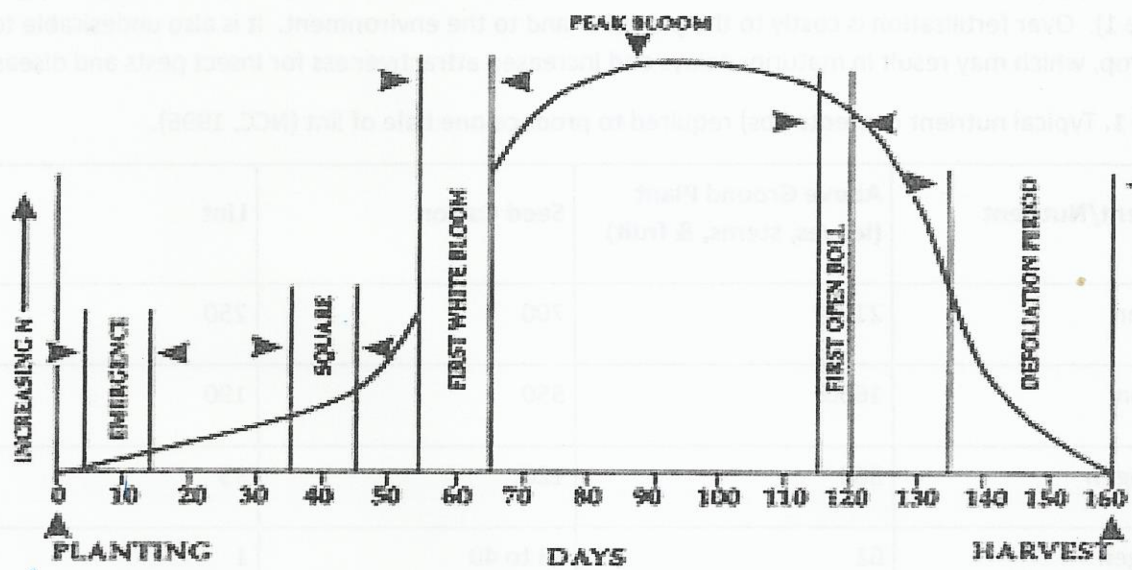

Figure 1. The growth and development of the cotton plant follows a typical sigmoid curve. This curve is representative of nutrient and water demands during the season (NCC, 1996).

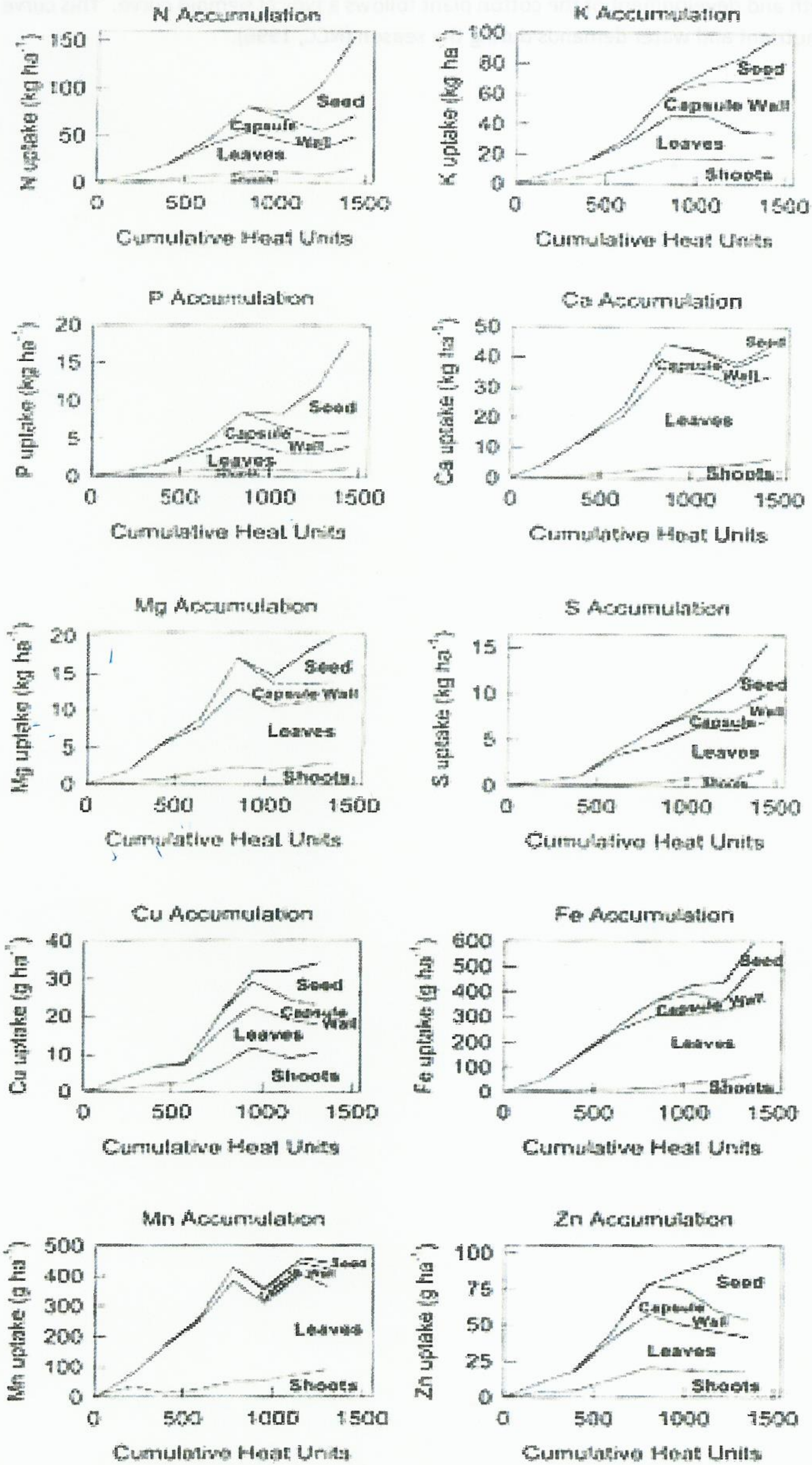
N Accumulation
N uptake (kg ha-1)
Seed
Capsule
Wall
Leaves
Shoots
Cumulative Heat Units
K Accumulation
K uptake (kg ha-1)
Seed
Capsule Wall
Leaves
Shoots
Cumulative Heat Units
P Accumulation
P uptake (kg ha-1)
Seed
Capsule
Wall
Leaves
Shoots
Cumulative Heat Units
Ca Accumulation
Ca uptake (kg ha-1)
Seed
Capsule
Wall
Leaves
Shoots
Cumulative Heat Units
Mg Accumulation
Mg uptake (kg ha-1)
Seed
Capsule Wall
Leaves
Shoots
Cumulative Heat Units
S Accumulation
S uptake (kg ha-1)
Seed
Wall
Capsule
Leaves
Shoots
Cumulative Heat Units
Cu Accumulation
Cu uptake (g ha-1)
Seed
Capsule
Wall
Leaves
Shoots
Cumulative Heat Units
Fe Accumulation
Fe uptake (g ha-1)
Seed
Capsule
Wall
Leaves
Shoots
Cumulative Heat Units
Mn Accumulation
Mn uptake (g ha-1)
Seed
Wall
Leaves
Shoots
Cumulative Heat Units
Zn Accumulation
Zn uptake (g ha-1)
Seed
Capsule
Wall
Leaves
Shoots
Cumulative Heat Units

Figure 2. Seasonal demands for various macronutrient and micronutrients (Mullins and Burmester, 1991, 1992, 1993a, 1993b).

Soil Sampling

Soil sampling is the best way to determine the soil pH and level of residual nutrients. It is often beneficial to establish a base level of residual nutrients in the soil over time. The ability to make sound fertility decisions are enhanced when producers apply best available sampling techniques for nitrogen, phosphorus, potassium and trace elements.

Cotton absorbs highly soluble and less soluble nutrients by different methods. The highly soluble nutrients in the oxidized form of nitrate, sulfate and borate are readily available for plant uptake in the soil solution, but can also be leached from the soil. Mobility in soil solution reduces the value of soil sampling for soluble nutrients (nitrogen, sulfur and boron), but soil sampling is useful at any time of the year for less mobile nutrients (phosphorus, potassium, calcium and magnesium) and soil acidity.

Sampling depths of 6 inches is satisfactory for pH, other nutrients and trace elements. A deep sample is required for more accurate nitrogen recommendations. A sampling depth of 18 to 24 inches is often recommended. Issues related to mobility in the soil solution dictate deep sampling for residual nitrates are done at planting. The sampling procedure is also very important. Nutrients tend to be more concentrated near the surface and in the drill row on established beds in reduced and no-till production. Consistent sample collection in relationship to the bed is essential for accurate assessment of the nutritional status of the field and for long-term nutritional evaluation regardless of tillage systems used.

Producers often schedule soil sampling activities in the fall. This allows them to get the results in time to plan a soil fertility program for each field. If lime is needed, fall applications are recommended since lime can require several months to react fully with the soil. The time and cost invested in a good soil test, followed by incorporating the recommendations is considered one of the most cost-efficient practices a grower can implement.

Soil pH

Cotton grows best in soil with a pH between 5.8 to 8.0. Yield decreases are usually not severe until the soil pH drops below 5.5 to 5.2 on sandy loam and silt loam soils respectively, or above 8.5 for western irrigated soils in the USA. When the soil pH falls beyond this range, soil amendments are recommended. To raise soil pH, lime is recommended and to lower soil pH, gypsum, or forms of sulfur are the most common amendments applied. For best results, incorporate amendments into the soil several months before planting. In most soils, amendments reach maximum effectiveness 5 to 6 months after application.

Macronutrients

Macronutrients can be broken into two more groups: primary and secondary nutrients. The primary nutrients are nitrogen, phosphorus, and potassium. These major nutrients usually are lacking from the soil first because plants use large amounts for their growth and survival. The secondary nutrients are calcium, magnesium, and sulfur. There are usually enough of these nutrients in the soil so fertilization is not always needed.

Nitrogen (N)

For economic yields, cotton must have the right amount of N in all phases of growth and fruit development (Fritschi *et al.*, 2004). Excessive N delays maturity, causes rank growth, can intensify insect infestations, encourages diseases and increases the risk of boll rot and reduced lint quality. On the opposite side of the spectrum, allowing N deficiency to continue will result in small stalks, pale green leaves, small bolls, fruit shed, and low yields.

Very little N is used by the cotton plant in the seedling stage. The heaviest demand for N is during the fruiting stages of squaring and boll formation, but the amount of N required for optimum yields will vary with the situation. High yielding cotton can contain as much as 180 pounds N per acre in the root system and above ground plant parts. Plant available N is subject to loss during the season due to conditions such as leaching, volatilization and denitrification. Field scouting for visible problems and petiole nitrate analysis should be used frequently to monitor nutritional status.

Nitrogen is mobile in both the soil and the plant. In cotton, N is translocated from older to newly developing plant parts. Thus, nutrient deficiencies first appear on older leaves as yellowing, or in severe cases, reddening of the leaf blade. Plants deficient in N tend to be spindly, mature too early and result in reduced boll retention and yield. Research also reveals that a shortage of sulfur can result in inefficient use of available N by cotton. Thus, balanced plant nutrition is a sound best management practice for high yield, high quality cotton production (Mullins, 1998).

An excess or an improperly timed application of N can result in late season vegetative growth and defoliation problems. Too much N can cause delayed maturity, damage fiber quality, increase the likelihood of regrowth after defoliation and reduce yields. Larger leaves, plant lodging, higher pest damage and delayed fiber maturity and boll opening are often observed with excessively high N rates.

Plan a fertility program based on past field production levels and realistic expectations. Only small amounts of N are needed in the seedling stage, and split applications are often recommended. If higher than expected yield potentials are apparent into the flowering stage, and soil and plant monitoring indicate a need, there is still time to supplement the plants with extra N prior to cutout (Fig. 3) (Silvertooth *et al.*, 2001; Robertson et al., 2002). The correct amount of seasonal N will produce a timely N deficiency and fruiting cutout, which helps mature the crop for defoliation and harvest.

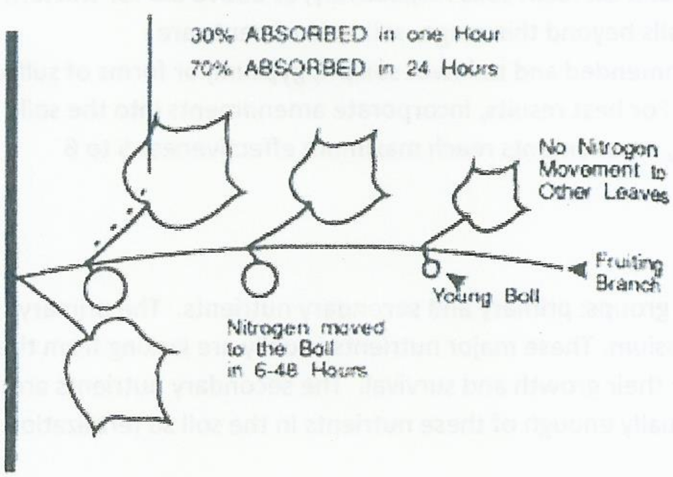

Figure 3. Uptake and movement of foliarly applied nitrogen (Miley and Oosterhuis, 1989).

Phosphorus (P)

Solubility of P in the soil is the opposite extreme of nitrogen. Phosphorus has low mobility in the soil and leaching is not a problem. Instead, mobility to the roots is the prime limitation to uptake. Because of the low mobility of P, root interception is the prime method of uptake, regardless of soil pH. Cotton roots are aided in the uptake of soil P by mycorrhizal fungi.

Phosphate is tightly bound in the soil, especially at either low or high pH, which reduces its solubility. Cold soils further decrease P uptake due to the slow root growth and reduced solubility of phosphate in cold water. Despite cotton's peak consumption of P during the summer months, deficiencies often occur in seedling cotton when the plant outgrows the stored P in the seed (Duggan *et al.*, 2009).

Field observations are an important part of the total management process in producing high-yielding, high-quality cotton. However, cotton does not always display visible symptoms of P deficiency. Phosphorus performs throughout the growing season starting with promotion of a rapidly developing root system. It also promotes the movement of growth substances within the plant, such as sulfate transport into leaf chloroplasts.

When P deficiency symptoms occur in cotton they are usually not as clearly defined as with most other nutrients. Symptoms may include smaller, very dark green leaves with purplish reddening. Other possible symptoms are overall stunting, poor boll retention and delayed flowering. Regardless of how the in-season symptoms are expressed, the ultimate consequence of P deficiency is yield reduction.

Potassium (K)

All nutrients are needed during the crop's entire growth cycle, but the need for K increases dramatically when bolls are set on the plant. Bolls are major points of utilization for K, and high concentrations of K are required to maintain sufficient water pressure for fiber elongation (Read *et al.*, 2006). Potassium is also involved in enzyme activation and pH balance in the cell, which is important for plant health and disease suppression.

Potassium mobility in soils is intermediate between N and P, but is not easily leached because it has a positive charge (K^+) which causes it to be attracted to negatively charged soil colloids. Roots have to grow near the source of K, but micorrhizae are not required for K uptake. Potassium is stored in leaves for use later by developing bolls, just like nitrogen. The peak need for K is during boll filling. To be available at this time, K must be in solution when late-season roots are less active.

When fruit retention is low, crop demand for K is less. Foliar K has been successfully used in some areas to partially satisfy K demand for high yield conditions, but soil applications is one of the best ways to supply all fertilizer nutrients, including this nutrient.

Potassium deficiency symptoms appear as a yellowish-white mottling of the foliage and changes in leaves to a light-yellowish-green color with yellow spots appearing between the veins. The centers of these spots die and numerous brown specks occur at leaf tips around margins and between veins. The tips and margins break down first and curl downward. As symptoms progress, the whole leaf becomes reddish brown, dries and becomes scorched and blackened in appearance. Premature dropping of leaves is also characteristic and may affect boll development resulting in bolls not maturing or only partially opening and containing poor quality fiber (Cassman *et al.*, 1990)

Secondary Nutrients

Secondary nutrients include calcium (Ca), magnesium (Mg) and sulfur (S). These nutrients are sometimes referred to as "the synthesizers." They play key roles that are essential for plant growth and health. Cotton plants take up Mg and S in about the same quantities as P, a major nutrient. Calcium is required in even greater amounts.

Calcium functions to strengthen cell walls, which prevent collapse, enhancing cell division and plant growth, protein synthesis, carbohydrate movement and balancing cell acidity. Increased susceptibility to seedling diseases and poor stalk strength are possible effects of Ca deficiency. All Ca is taken up from the soil.

Magnesium is essential for the production of the green pigment in chlorophyll. The need for both Ca and Mg is best determined by taking routine soil tests and applying lime (calcitic or dolomitic) as needed. As a nutritional disorder becomes more severe, cotton may first experience a shortage of Mg without showing visual deficiency symptoms or hidden hunger. As the deficiency becomes more severe, older leaves on the plant will often show visible deficiency symptoms.
Sulfur is essential for the production of three amino acids, which are the building blocks in the synthesis of proteins. Assessing the need for S is difficult. A soil test is of limited value since sulfate (SO4), the form used by plants, can be readily leached or moved out of the root zone. Sulfur deficiencies sometimes are seen in cotton planted on sandy soils that has formed from parent material low in sulfur with low organic matter levels. Sulfur deficiencies look much like N deficiencies, pale-green leaves on the upper part of the plant. Sulfur deficiency appears on new growth first; whereas N deficiency appears on older leaves first.

Micronutrients

The essential micronutrients are elements that are needed in only small amounts. There are seven of these: Boron (B), Molybdenum (Mo), Zinc (Zn), Iron (Fe), Manganese (Mn), Copper (Cu) and Chlorine (Cl).

Plants can suffer from a deficiency or an excess of any of these nutrients, depending on their soluble concentrations in the root zone. Micronutrient availability is influenced by soil pH. As soil pH increases from 4.0 to 7.0, the solubility of boron, zinc, iron, manganese and copper decreases. In contrast, the solubility and availability of molybdenum increases as the pH increases. As a result, liming to a pH of 6.0 to 6.5 is generally recommended.

Regular soil tests will provide most of the information that is necessary to build an efficient fertilization program. However, a separate B analysis is needed for certain suspect fields when low organic matter, excess lime, sandy texture, severe fruit drop and/or delayed maturity has been observed.

Cotton is considered a B responsive crop. However, B is a more important supplemental micronutrient in the Delta, Mid-South and Eastern regions of the U.S. cotton belt than in the arid West where B can be a problem from excessive levels. Boron plays an essential role in the development and growth of new cells in the growing meristems. Boron is also required for protein synthesis where N and carbohydrates are converted into proteins. It also performs key functions in pollination and reproduction. In the Delta region, B is more critical in the northern areas of production. This is due to a shorter season and lower temperatures during the latter part of the fruiting season (Albers *et al.*, 1993).

A distinguishing feature of B is that it is not mobile within the plant. Therefore, B deficiencies occur in newly developing plant tissue. The terminal bud often dies, resulting in development of many lateral branches. Young leaves of B deficient cotton are yellowish green in color. At low B levels, flower buds become chlorotic and bracts flare open. Many of the fruiting forms become dried out and shed from the plant. Bolls that survive often are deformed, presenting a flat-sided or hook-billed appearance. A dark discoloration will be inside the boll and inside the boll petioles.

Soils can be tested for micronutrients, but generally the expense to conduct the tests is not needed. Instances where a micronutrient deficiency might exist would be: sandy soils low in organic matter; subsoils exposed due to grading or land leveling; cold and wet weather with slow breakdown of organic matter; alkaline soils; and very high levels of other nutrients (high phosphate levels can induce zinc deficiency).

Summary

An efficient fertilizer program can be developed by keeping in mind the time when different nutrients are needed and the fate of those nutrients when applied to the soil. Cotton's N requirement is greatest during boll filling, but carry-over into harvest is detrimental. Phosphorus is needed all season long, but the ability of roots to extract P is reduced in cool spring soils, justifying "at planting" fertilizer applications for increased availability. The heaviest demand for K and B occurs during boll filling. Phosphorus, K, Ca and MG stay where they are placed until that soil zone is disturbed; but N, B and S are vulnerable to leaching losses from the root zone prior to plant uptake.

Soil testing should be conducted every two to three years to establish residual nutrient levels. More frequent sampling can provide seasonal decisions on fertilizer recommendations when large yields are being produced. An understanding of soil nutrient levels combined with attainable yield goals will improve nutrient recommendations. Base application timings to meet crop needs. Calibrate application equipment and avoid fertilizer applications on wet soil to minimize compaction, runoff, leaching and denitrification. Using grass filter strips along ditches and waterways will help reduce soil erosion, runoff and nutrient loss. These practices are not only a part of a good stewardship program, but help reduce costs and improve fertilizer efficiency.