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Cotton Nutrition — N, P and K

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Cotton's Stigma "Destroys the Soil"

One of the misconceptions still perpetuated about cotton is that it wears out the soil and depletes it of nutrients. This stigma could not be further from the truth. Cotton developed this stigma because it is one of the least extractors of soil nutrients, and thus it was planted on the least fertile soil — without fertilizer input — up until the 1860's. Cotton "planters" in the first half of the 1800's utilized manure and cottonseed as fertilizer for their corn and grain crops and left the cotton ground unfertilized. Cotton can be grown, although at low yields, without any fertilizer or manure if the seed and gin trash are returned to the soil.

This issue of Cotton Physiology Today will cover nitrogen (N), phosphorus (P) and potassium (K) uptake and utilization. These two topics are the foundation from which to build an efficient fertilization program.

Nutrient Content of Cotton

Cotton consists primarily of hydrogen, oxygen and carbon derived from the atmosphere and soil water. These atoms form the backbone for every molecule and plant part. After ginning, the mineral nutrients (N, P, K and micronutrients) make up only 1% of a bale's weight. The following table gives the content of a 1 bale (480 pounds) cotton crop. For higher yields, multiply by the estimated bales per acre.

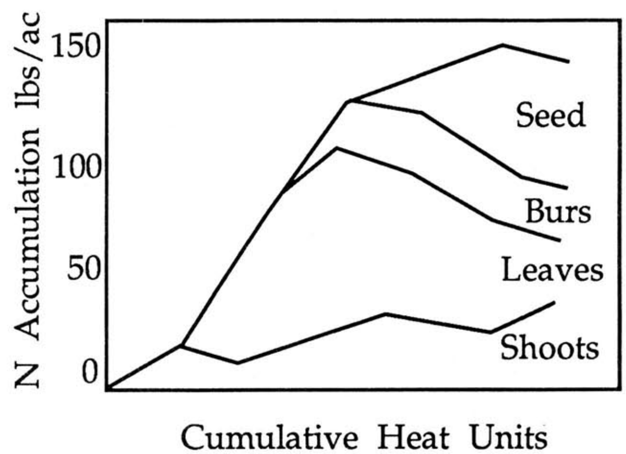
Typical Nutrient Contents

	above ground plant (leaves, stems, fruit)	seed cotton	lint
	— lbs per bale —		
Oxygen	2100	700	250
Carbon	1650	550	190
Hydrogen	360	120	35
Nitrogen	62	35-40	1
Potash (K_2O)	61	15	3
Phosphate (P_2O_5)	22	13-20	0.3
Calcium	27 to 62	1	0.2
Magnesium	11 to 27	5	0.3
Sulphur	8 to 16	1-2	trace

The other nutrients added together contribute, at most, 3 lbs of weight in the leaves, stems and bolls. The "take home message" from this table is that seed cotton extracts limited nutrients from the soil. This low nutrient demand, coupled with the native fertility of most soils, allows cotton to be grown with limited fertilizer input. When high fertilizer rates are required, it usually indicates that some other problem is limiting nutrient availability or uptake. By understanding the "basics" of nutrient uptake and utilization, a fertility program can be designed that avoids these inefficiencies.

Nutrient Uptake

Soil nutrients are taken up in direct proportion to growth and temperature. Total nutrient uptake for N,P and K tracks cumulative heat units precisely. 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 of June and July when nutrients need to be available. The following figure displays the N uptake into various plant parts during the growing season.



(Mullins and Burmester, 1990)

Nitrogen Uptake

The solubility of nutrients in the soil solution is a double-edged sword. On the one hand, only dissolved nutrients can be taken up by plants. On the other, soluble nutrients are vulnerable to loss below the root zone by leaching. This mobility reduces the value of soil sampling for the soluble nutrients — nitrogen, sulphur and boron; but makes soil sampling at any time of the year useful for the immobile nutrients — P and K.

Cotton has evolved separate methods to absorb the highly soluble and the less soluble nutrients. The highly soluble nutrients in the oxidized form of nitrate, sulfate and borate can be leached from the surface soil. To recover these nutrients from deeper depths, cotton has developed a tap root that grows deeper than other annual plants. Additionally, cotton stores N in leaves during periods of greater availability for later use during the peak demand period of boll setting.

Sulphur and boron are not remobilized from older storage tissue to young growing tissue, but are needed in much lower amounts than N. The highly soluble nutrients are swept into the roots with the soil water that is pulled up through the plant and out the leaves. This water flow can pull soluble nutrients via mass flow, from a distance greater than the nearest feeder root, effectively scavenging the entire root zone. Mass flow is greatest when cotton is well watered — but not saturated — during hot, dry weather. Uptake of most nutrients, not just N, is reduced when crop water use is decreased from drought, cold weather or wet, humid weather.

Nitrogen Utilization

Nitrogen is a small atom compared to the other mineral nutrients, and thus readily forms and reforms chemical bonds with carbon, oxygen and hydrogen. Most of the plant's N is tied up in proteins since many key amino acids (building blocks of protein) use N as the reactive site. Cotton leaves store N as protein for later use in seed production. Cottonseed contains 40 to 50% of the plant's N at harvest. To meet this high N requirement of the seed, daily N uptake can reach a peak of 2 to 4 lbs per day during mid boll filling, depending on yield level.

Excess N and Yield

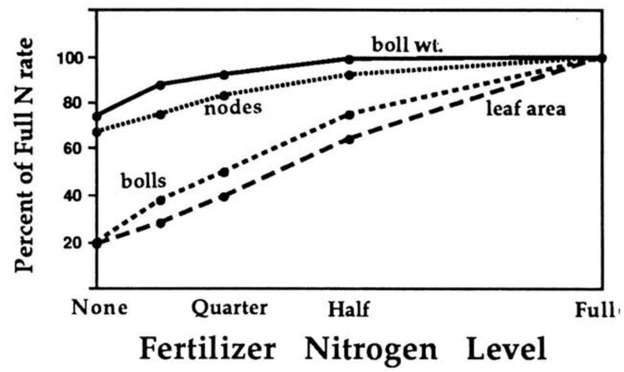
While grains and most vegetables maintain top yields when excess N is applied, cotton is one of the few crops that responds adversely to excess N fertility (others include sugar beets and tobacco). Cotton suffers delayed maturity with high N levels. This late maturation is due to both reduced early boll retention and delayed boll opening, and thus severely decreases yield and quality in short growing seasons. Leaf size is dependent on both N and plant water status. In the humid rainbelt, leaf size can become very large if excess N is applied. Large leaves shade lower fruiting positions contributing to boll shed, boll rot, delayed opening and immature fiber. In the irrigated west where wet falls are rare, excess N fertilizer is less detrimental to yield and quality than in areas where boll rot and wet harvest seasons are common.

N Deficiency

Because N is used in every plant part, a deficiency affects the entire plant. Nitrogen deficiency dramatically reduces total leaf area by curtailing leaf expansion and mainstem node production. This reduced leaf area sets an upper limit on the number of bolls that can be filled. Prematurely N deficient plants will reach this limit early in the season, by cutting out and shedding all the young bolls. The plant sheds small bolls adjusting the fruit load to match its carry capacity (total leaf area). This is advantageous to the plant, because the retained bolls then have sufficient nutrients to mature, as demonstrated in the minimal effect of nitrogen deficiency on boll size.

Under severe N and P deficiencies, feeder root branching is decreased. Roots systems from both N and P deficient plants are less efficient at transporting water from the soil to the plant. In addition to the N deficiency symptoms of reduced squares and blooms, leaves from early season N deficient plants are often light green, while late season deficiencies result in red to yellow leaves.

Effect of N Level on Final Plant Size



(Jackson and Gerik, 1990)

Managing N Fertility

A cadillac system of N fertilization consists of 3 parts: (1) supply approximately 10 to 20% of the season total N fertilizer to the pre-bloom plant, (2) supply the remaining N during the short 60 to 75 day boll development period, and then (3) deplete the soil N for an abrupt N deficiency to mature the crop for harvest. This ideal is difficult to reach, but efficiency of N fertilization can be improved with the following suggestions.

- Does N leach below the root zone? If it does, split applications may be necessary to enhance availability for the peak growth period.
- How much N does this field receive from non-fertilizer sources such as rotation crops, manure, high nitrate irrigation water? To avoid excess N these inputs must be budgeted against the fertilizer N.
- What is the realistic yield to fertilize for? Plan a fertility program based on historic field production levels not "banker's yield goals". If the season gets off to a bumper start (early and warm: the major cause of bumper yields), we still have time to supplement with extra N.
- What are the risks from excess N? In regions with wet falls and potential for boll rot the yield loss from rank late season growth and poor leaf drop can be sizeable. In these growing regions, running out of N at the end of the season is often our only way to terminate the crop and prepare it for harvest.

Split Application of Nitrogen

In the Mid-South, split applications of nitrogen, half at or before planting and half at early to mid bloom, have been a successful method to produce top yields without delaying maturity. When the second application is made at early square instead of early bloom, the plant runs out of N early reducing the top crop. In the Irrigated West, pre-plant fertilization with a single high rate of N has given top yields on fine textured soils, while coarse textured soils benefit from multiple applications.

Phosphorus Uptake and Utilization

Phosphorus (P) is another example of the double-edged sword of solubility but at the opposite extreme of nitrogen. Phosphorus has such low mobility in the soil that leaching is not a problem, instead mobility to the roots is the prime limitation to uptake. Due to this low mobility of P, regardless of soil pH, root interception is the prime method of uptake. Cotton roots are aided in their interception of soil P by mycorrhizal fungi. These fungi grow in the small feeder roots and surrounding soil, deriving food from the plant and in return increasing uptake of immobile nutrients by enhanced interception. Cotton is highly dependent on mycorrhizae for P uptake. If these fungi are suppressed, seedling cotton is stunted and weak. In dry climates (Irrigated West and Australia), the term "Fallow Field Syndrome" refers to the suppression of these fungi that occurs if fields are left clean and fallow for several years. In the absence of plant hosts (crops and weeds) these fungi are suppressed. Fumigation or long term flooding can also suppress these organisms. Where mycorrhizal disruption has occurred, it would be better to plant a crop that is less mycorrhizal dependent such as grain or corn, prior to planting to cotton.

The uptake of P is very similar to N, paralleling plant growth and with seed having the highest concentration at harvest. Despite this similarity, the mechanisms of uptake are quite different and explain why P fertilization is often applied for early growth and not for boll filling. 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. For these reasons, although peak use occurs during the summer, deficiencies often occur in seedling cotton, when the plant outgrows the stored P in the seed.

The form of P taken up by roots and utilized by plants is the highly oxidized form, phosphate. Phosphate is a major component of cell membranes which surround and separate all of the plant's living tissue, thus plants deficient in P are stunted. Another major use of phosphate is energy transfer. Deficient plants cannot transfer photosynthetic energy out of the chloroplast where it is produced, thus causing starch to build up and disrupt the chloroplast resulting in the loss of green color and increase in red/purple color, typical of P deficient plants.

Phosphorus Management

The strong influence of soil temperature on P uptake restricts most P fertilizer needs to the cool part of the growing season. Winter crops such as small grains generally require a higher level of soil P than the warm season crops such as cotton. When wheat or winter vegetables are grown in rotation with cotton, fertilizer P is often applied to these rotation crops and cotton relies on the residual carryover. Where carryover P is not available, such as continuous cotton, applications are made to provide P during the cold soil periods, often as a starter fertilizer or mixed in the surface soil. Subsoils can become deficient in P due to its poor mobility, which restricts root growth and water uptake from the subsoil.

Along with the demise of the moldboard plow in cotton production has come the need to carefully analyze both the surface and the subsoil separately for immobile nutrient availability.

Potassium Uptake and Utilization

It seems that many of our misconceptions about cotton fertilization derive from backyard tomato gardening — one nutrient for leaves, one for roots and another for fruit. Of all the nutrients, potassium (K) is the only one that comes close to being specific to a plant part. All nutrients are needed during the entire growth of the plant, including K, but the need for this nutrient rises dramatically when bolls are set on the plant. Bolls are major sinks for potassium. Part of the reason for the high concentration of K in the boll lies with the requirement for K in maintaining sufficient water pressure for fiber elongation. Besides K's role in maintenance of water pressure, K is involved in enzyme activation and pH balance in the cell, a critical necessity to healthy plants and disease suppression.

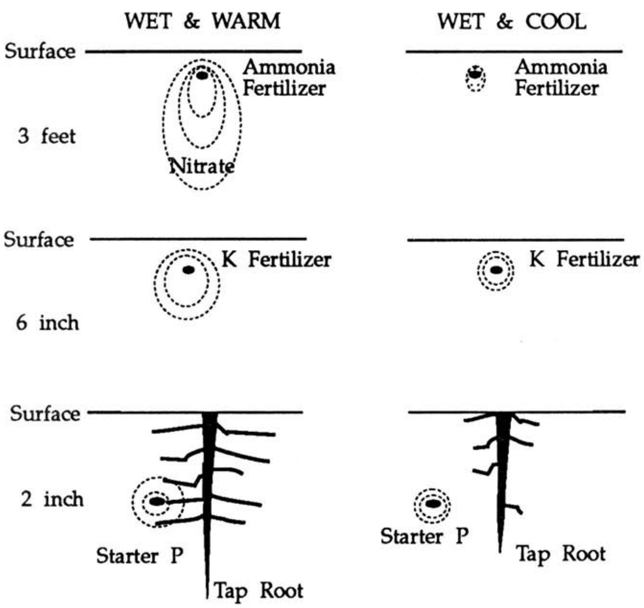
Potassium mobility in soils is intermediate between N and P. Roots have to grow near the source of K, but mycorrhizae are not required for K uptake. Potassium is stored in leaves for reuse later by developing bolls, just like nitrogen; but when a heavy boll load is set, the demand for K often exceeds the soil's and leave's ability to supply K. As a result, the bolls strip the K from the nearby leaves causing the deficiency symptoms of leaf bronzing and leaf death in the top of the plant. Some researchers have hypothesized that the modern high-yielding, fast-fruiting varieties place a greater demand on the soil's ability to supply K than older varieties. Due to modern varieties and high yield management practices we are seeing K deficiencies in more fields than before.

Potassium Management

Because of the high K content of bolls, potassium needs to be most available during boll filling. To be available at this time, K must be in solution where late season roots are active. This presents a difficulty for some fields, because a surface placement of K may not be available if the soil surface is dry and roots inactive. Methods to deep place K have been developed for these conditions. Seasonal K fertilizer requirements depend on the intensity of boll retention, how many over how short a time. Years with low fruit retention place less demand on the soil's ability to supply K than intense boll setting periods. Foliar K has been successfully used in some areas to partially satisfy K demand of high yielding years, but soil applications should be the foundation for K as well as N and P cotton fertilization. Fertilizer K often is applied prior to winter tillage to allow mixing with as deep a soil layer as possible.

Putting it Together in a Fertility Program

Adequate nutrient fertilization should be important to every cotton producer because the amounts used (and thus the cost) are slight compared to the dollars lost from yield limitations. Although, the price of many of the N fertilizers is anticipated to increase substantially in 1991. Additionally cotton is one of the few crops where yield and quality are highly responsive to both too little and too much fertilizer.



The figure to the right shows the relative movement of N, K and P fertilizers under different temperatures.

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. Plant needs for nitrogen are greatest during boll filling, but carryover into harvest is detrimental. Phosphorus is needed all season long but the ability of roots to extract P is reduced in the spring, justifying at planting fertilizer applications for greater availability in the spring. The heaviest demand for potassium occurs during boll filling. Phosphorus and potassium will stay right where they are placed until that soil zone is disturbed, but N is vulnerable to losses from the root zone prior to plant uptake.

About the Authors

Ken Cassman has researched K and N nutrition in cotton, as Agronomy Professor at the Univ. of Cal. He will be leaving this position to assume responsibilities of Head, Div. of Agronomy, Plant Physiology and Agroecology at the Int'l. Rice Research Institute in the Philipines. Wayne Ebelhar is an Agronomist at the Delta Research and Extension Center in Stoneville, Mississippi. Wayne has conducted extensive research into the optimum timing and application of N and K fertilizers.