7. FERTILIZATION

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A good cotton fertilization program begins with routine soil testing. Soil test results are the most accurate and economical way to determine the fertilizer and lime needs of cotton. Although small amounts of nutrients are removed from the field at harvest, cotton requires a high availability of nutrients, particularly late in the season. A good liming program usually supplies adequate calcium (Ca) and magnesium (Mg); many soils can meet the demand for phosphorus (P) and most micronutrients without annual fertilizer applications. Soil test results can indicate when additions of these nutrients are required.

Cotton is very sensitive to deficiencies of nitrogen (N), potassium (K), sulfur (S), and boron (B). These nutrients can be removed by leaching rains, especially in sandy soils. Of these elements, potassium is least subject to leaching, and its availability can be determined from routine soil-testing. Sulfur levels and recommendations are also included in NCDA&CS soil test reports. Recommended rates of nitrogen, sulfur, and boron are based on long-term field trials over a wide range of conditions. Annual applications of these nutrients are usually recommended for most soils. On soils subject to leaching, two or more applications may be required to improve fertilizer efficiency and ensure adequate availability throughout the growing season. Typical nutrient deficiency symptoms can be seen at the website deficiencies.soil.ncsu.edu, although actual problem diagnoses should be based on soil and plant laboratory analyses.

Fall or early winter is the best time to collect soil samples (September to November if you are sampling for nematodes at the same time). This schedule allows ample time to obtain the soil test report results and to plan your fertilization and liming program before planting. In the coastal plain, sample every two to three years. In the piedmont, sampling every three to four years is adequate. Consult your county Cooperative Extension center, NCDA&CS agronomist, or a certified crop advisor (CCA) for details on sampling procedures.

SOIL ACIDITY AND LIMING

Of the crops grown in North Carolina, cotton is among the most sensitive to soil acidity. Marked growth and yield increases have repeatedly occurred when fields are properly limed. When the soil pH drops below 5.5, aluminum and manganese dissolve from soil clays and can severely decrease root elongation and reduce plant growth. Such a condition causes additional stress on cotton because stunted roots don’t reach as much water or nutrients. Look for “J-shaped” taproots and collect separate subsoil samples to confirm this situation. Acidity also interferes with the availability and uptake of phosphorus, potassium, calcium, and magnesium. Poor nutrient uptake results in fewer and smaller bolls with poor lint quality.

Cotton tolerates a pH range from 5.8 to 6.5 for mineral soils; NCDA&CS uses a target pH of 6.2 for these soils. In organic and mineral-organic soils, a target pH of 5.0 and 5.5 is suggested, respectively. Although soil testing is used by many growers today, low soil pH is still a major yield-limiting factor for cotton production in North Carolina. In FY 2020, where soil testing occurred for cotton production on mineral soils, pH was below 5.5 in 10 percent of samples. Twenty-three percent of the NCDA&CS soil test results were below a pH of 5.8, and about 58 percent of all mineral samples submitted required lime. Cotton grown on organic or mineral-organic soils with target pH less than 6.0 may also need lime. Excess soil acidity continues to be one of our largest yield-limiting factors (Figure 7-1).

The amount of lime required for optimum cotton production varies with soil texture, pH, organic matter content, soil minerals, and fertilizer and lime application history, including animal waste. The lime rate can be determined only through periodic soil testing to document both soil pH and residual soil acidity ("Ac" on the NCDA&CS soil test). The recommended amount of lime should be applied at least three months before planting to allow time for the lime to dissolve and react with the acidic components of the soil. However, lime applied just before planting is much more effective than no lime applied at all. If possible, mix lime thoroughly with the soil to speed the reaction. For more information on soil acidity and liming, see SoilFacts publication AG-439-50, *Soil Acidity and Liming for Agricultural Soils* (content.ces.ncsu.edu/soil-acidity-and-liming-for-agricultural-soils). This publication also describes how to evaluate alternative lime sources such as wood ash and industrial slags.

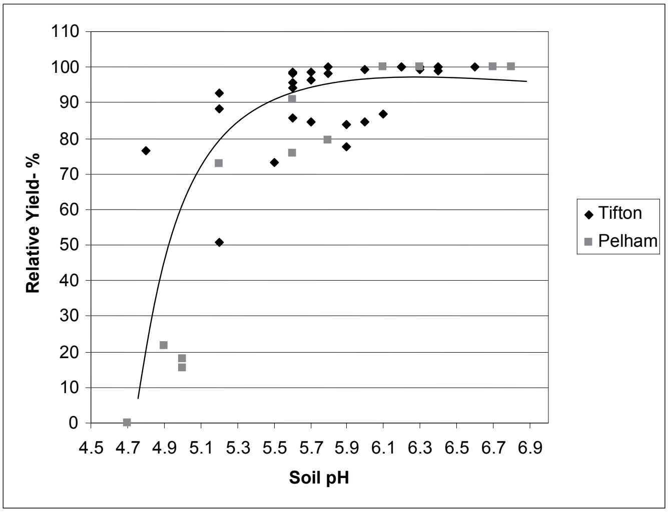

Figure 7-1. Relative yield of cotton as affected by soil pH in the top 0–15 cm soil. *Data are taken from field experiments in Georgia (Gascho and Parker, 2001, Agronomy Journal 93:1305-1315).*

NITROGEN FERTILIZATION

Nitrogen management strongly affects plant growth and lint yield of cotton. Apply too little nitrogen, and yields drop sharply. On the other hand, apply too much nitrogen, or apply it at the wrong time, and plants will be rank, slow to fruit, more attractive to insect pests, late to mature, more difficult to cover with crop-protection chemicals, quick to develop boll rot, more troublesome and expensive to defoliate and control regrowth, and more likely to have grade reductions from bark.

Nitrogen Rate

The recommended rate of nitrogen ranges from 30 to 80 pounds per acre for rain-fed crops (20 to 25 percent higher for irrigated crops). The best rate for a particular field depends on soil texture, organic matter levels, the previous crop, expected rainfall patterns or irrigation, and grower experience in that field. Without knowledge of the field and the specific management practices used, it is difficult to give specific recommendations, but some guidelines are available.

Uptake studies across the Cotton Belt suggest that cotton needs about 60 pounds of nitrogen per acre per bale of lint produced. Why are the suggested rates of 50 to 70 pounds per acre on soil-test reports so much lower? Numerous on-farm nitrogen rate studies throughout North Carolina show that unfertilized soils can supply 40 to 100 pounds of available nitrogen from organic matter, subsoil storage, and rainfall. Soil nitrogen reserves are generally highest on organic or mineral-organic soils and lowest on deep, well-drained sands. A good crop of soybeans or peanuts will usually supply an additional 20 to 30 pounds of nitrogen per acre. When soil nitrogen reserves are included, the recommended rates are consistent with a total available nitrogen range of 110 to 170 pounds per acre following peanuts or soybeans, or from 90 to 140 pounds per acre following other crops.

Realistic yield expectations (RYE) are estimates of the yield potential (averaging the best three out of five years) of a soil series under a high level of management. In conjunction with a nitrogen factor (for cotton, this factor ranges from 0.03 to 0.12 pounds of nitrogen per pound of lint yield), RYE values can be used to estimate total nitrogen needs for a specific field. For example, a Norfolk soil has a RYE value of 875 pounds of lint per acre and a nitrogen factor of 0.09; thus, the calculated nitrogen rate is as follows:

875 pounds of lint per acre × 0.09 pounds N per pound of lint = 79 pounds N per acre

The nitrogen factor varies with residual nitrogen, available water-holding capacity of the soil, and management. In general, as any of these factors increase, the efficiency of nitrogen use increases while the associated nitrogen factor for the site decreases. Thus, organic and mineral-organic soils, with high residual nitrogen and available water-holding capacity, require low nitrogen factors ranging from 0.03 to 0.06, while deep sands, with low residual nitrogen and low available water-holding capacity, require nitrogen factors ranging from 0.07 to 0.12. Loamy soils require intermediate nitrogen factors ranging from 0.06 to 0.10. More information on RYE is available at realisticyields.ces.ncsu.edu or from your county Cooperative Extension center.

Deficiency

Nitrogen deficiency symptoms first appear on the lower leaves since it is mobile in the plant. The leaves become a pale yellowish-green, fading with age, first to hues of yellow, then variously tinted shades of red, and finally brown as they dry up and are prematurely shed. Deficient plants are stunted and generally unthrifty in appearance, and fruit-set is poor.

If deficiency develops, nitrogen can be applied to the soil until the second or third week of bloom or by mid-July. Soil applications beyond that point become questionable. Foliar applications can increase yields at this stage of crop growth when plants are deficient (see the "Foliar Fertilization" and "Monitoring Plant Nutritional Status" sections). If extended rainfall leaches nitrogen out of the rooting zone after the final application but before the second week of bloom, nitrogen should be replaced. Replacement N rates generally should not exceed 30 pounds per acre.

Timing of N Fertilization

Timing of N fertilization is critically important for cotton. Unlike crops such as corn and tobacco, cotton takes up only a small portion of the nitrogen before flower buds (squares) begin to set (Figure 7-2). About 45 days after emergence, nutrient uptake increases rapidly until it reaches a prolonged peak about two weeks after first bloom, when the processes of flower production, boll filling, and boll maturation create a heavy demand for nutrients. Too frequently, all of the nitrogen is applied early in the season, or even at planting. While this practice may be the most convenient means of application, it makes little sense in North Carolina due to the unpredictability of leaching rains that can occur prior to nitrogen peak demands, especially on

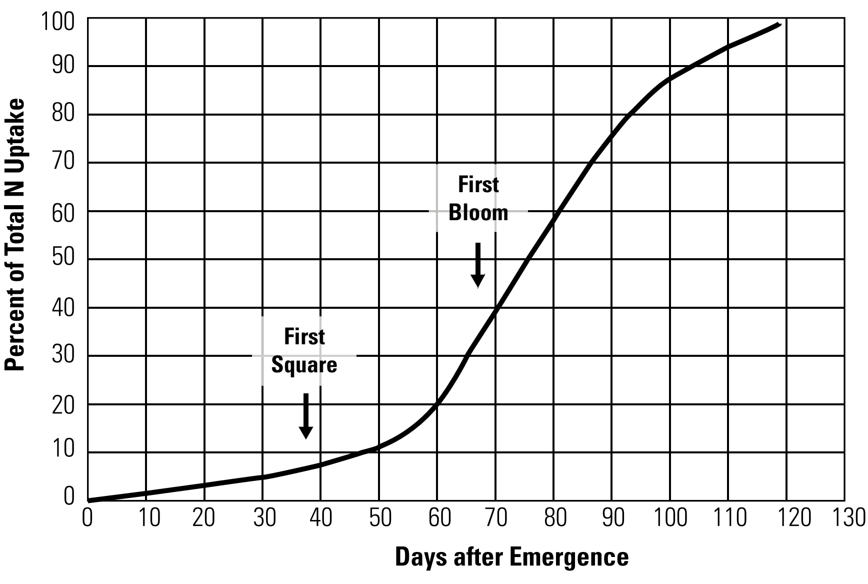

Figure 7-2. Timing of N uptake by cotton. Side-dressing two to three weeks after the first square should provide adequate N to sustain increased needs during the reproductive phase.

sandy soils where much cotton is grown. Leaching losses during this period will need to be accounted for and replaced to attain optimum yield, although these losses are very difficult to accurately assess. Heavy nitrogen applications early in the season also can lead to excessive vegetative growth, smaller and more compact root systems, and reduced early square retention.

Cotton needs only 20 to 25 pounds of nitrogen per acre for early growth up to side-dress time. If the crop is following peanuts or soybeans, no initial nitrogen may be required. If rains were predictable, the best time to side-dress would be just before first bloom. However, as rainfall patterns cannot be predicted, it is safer to side-dress two to three weeks after the first square to ensure that adequate nitrogen is available during the early bloom period. In deep, sandy soils subject to rapid leaching, the side-dress nitrogen can be split, with half applied about four weeks *after emergence* and the remainder three to four weeks later.

Sources

Of the many nitrogen sources available for cotton fertilization, no one source has proven to be superior. Nitrogen solutions, ammonium nitrate, ammonium sulfate, and urea are most frequently used because of their high concentration.

Conversion of ammonium forms to nitrate occurs very rapidly under warm, moist conditions. Fertilizer amendments and slow-release N forms that attempt to reduce N transformations in order to reduce N losses are available, but their efficacy is not well established in cotton production in the Southeast.

The final selection of nitrogen source should be based on price per pound of nitrogen, convenience, and availability of equipment. Nitrogen solutions (UAN-28 to 32 percent N and 24S) are very convenient and exhibit little volatile loss when dribbled beside the row, even without cultivation. Granular urea (46-0-0) is also a suitable nitrogen source, but surface applications should be lightly incorporated in light, sandy soils. High humidity can make this source sticky and difficult to handle. The best results with N solutions, granular urea, or ammonium sulfate are obtained when side-dress applications are placed in the soil either through injection or cultivation, about the time of first square. Avoid root-pruning with careful placement of the N fertilizer in the soil but keep it within reach of developing roots.

Nitrogen, Mepiquat Chloride, and Irrigation

The potential to reduce vegetative growth with the regulator mepiquat chloride has led some growers to increase nitrogen rates with hope of increasing yields. On-farm tests in North Carolina consistently show that cotton yield response to nitrogen is not affected by mepiquat chloride applications. Higher-than-recommended nitrogen rates are not justified simply because mepiquat chloride will be applied. Furthermore, when excessive rates of N are used and soil moisture is good, mepiquat chloride will not adequately control rank growth at labeled rates.

When soils are irrigated, cotton yield potential can sometimes approach three bales. Higher nitrogen rates (90 to 120 pounds of N per acre) may be justified in these situations. When planning high nitrogen rates for irrigated cotton, split the nitrogen applications to provide the bulk as flowering begins. Plan to use mepiquat chloride to help control vegetative growth, but be aware that primary control of rank growth depends on maintaining high square retention and a heavy fruit load.

PHOSPHORUS, POTASSIUM, AND SULFUR

Adequate supplies of phosphorus and potassium are critical for proper plant nutrition. A good soil-testing program will help alert you to potential problems before they occur.

Soil-test phosphorus levels in much of the cotton-producing region are adequate without additional fertilization. For fiscal year (FY) 2020, high and very high soil-test phosphorus levels comprised 38 percent and 51 percent, respectively, collectively representing 89 percent of the total samples submitted for mineral soils; there is a *very low probability of a response to P addition* in these fields. Consequently, phosphorus deficiencies are considered rare and usually associated with low pH. When deficient, plants appear darker green than normal, grow at a slower rate, and may appear stunted. As treatments to correct phosphorus deficiency seldom prove effective, placement in the root zone before planting is essential. Plants deficient in phosphorus produce fewer and slower-maturing bolls (see "Starter Fertilizers" section).

Given that cotton is a drought-tolerant crop, much of its production occurs on sandy-textured soils with relatively low ability to retain potassium from season to season. Thus, as compared to phosphorus, potassium deficiency is much more likely to occur in North Carolina. Of the soil samples submitted for cotton recommendations in 2020, 28 percent of all tested samples showed results in the medium, low, or very low categories collectively, and received recommendations of at least 50 pounds per acre of potash. Although surface soils may not retain potassium well, subsoil with significant clay accumulation is known to be important for extra moisture reserves for this deep, taprooted crop. This subsoil can also hold significant potassium that has leached from the topsoil.

Even with adequate K fertilization or soil-test potassium levels, deficiency can occur due to dry soil conditions as K uptake is diffusion-driven. Symptoms of potassium deficiency can be very pronounced and first appear on the older leaves as a yellowish-white mottling since potassium is mobile in the plant. The mottling changes to a light yellowish-green, and yellow spots appear between veins. The centers of these spots die, and numerous brown specks appear at the leaf top, around the margin, and between the veins. The tip and the margin of the leaf break down first and curl downward. As this physiological breakdown progresses, the whole leaf becomes reddish-brown, dies, and is shed prematurely. This premature shedding of leaves contributes to dwarfed and immature bolls.

Growers who manage soils with high leaching potential should seriously consider split-applications of potash, applying half at planting and the other half at the time of lay-by nitrogen, if possible. When warranted, prompt replacement is important, especially early in the season. Approximately 25 to 30 pounds per acre of potash should correct most leaching losses. Where deficiencies from leaching are likely, side-dress applications of potassium have frequently solved the problem. Applications of foliar potassium (such as potassium nitrate) at mid-bloom on potassium-deficient cotton can increase yields. Routine application of foliar K is not recommended as it has been shown to reduce yields in some cases where adequate K was already available. The best way to determine whether K deficiency exists is with a plant tissue sample (see "Plant Monitoring and Foliar Fertilization" section).

In recent years, potassium deficiency symptoms have appeared in the upper part of the plant. In some cases, soil potassium levels appear to be sufficient, but the plants are unable to obtain adequate potassium. In these cases, foliar potassium fertilization has improved yield and quality. At the present time, these symptoms have been associated with four factors:

1. The use of very high-yielding, determinate-type cultivars that set a heavy fruit load over a very short time.
2. Soils that "fix" potassium in unavailable forms.
3. An unidentified disease.
4. Mild-to-moderate drought stress following a heavy fruit-set. Symptoms are most common in parts of California and the mid-South.

A few cases of upper-plant deficiency symptoms have occurred in on-farm tests and experimental plots in North Carolina where (1) subsoil potassium levels were extremely low and short- to mid-season cultivars were planted; or (2) soils contained significant amounts of 2:1 clay minerals such as vermiculite or montmorillonite. Soil surveys from most North Carolina coastal plain counties have soils with taxonomic class names that begin with "Clayey, mixed" (including Bayboro, Bethera, Bladen, Cape Fear, Craven, Dogue, Gritney, Leaf, Lenoir, Roanoke, and Wahee). These soils have "mixed mineralogy." Even though soil-test levels at the surface may be adequate, deficiency symptoms may still develop, and plants will likely respond to foliar applications of potassium. Annual applications to build soil potassium throughout the root zone will eventually correct these problems.

A two-bale cotton crop will take up 20 to 30 pounds of sulfur. Some sulfur is supplied by the decomposition of crop residues and organic matter, and some is supplied by rainfall. In recent years, sulfur deficiencies have become more common in row crops with the decline in industrial air emissions of sulfur dioxide and the increased use of higher analysis materials and bulk blends containing less incidental sulfur. Sulfate-sulfur, the major form of sulfur taken up by plants, is mobile in most soils. Deficiencies are most likely to occur in highly leached, deep, sandy soils with low organic matter content; depth to subsoil clay in these soils is usually greater than 18 inches from the surface. Significant sulfur accumulations are usually found in the subsoil. If sufficient sulfur is present in subsoil and root growth is not restricted, older plants can acquire enough for normal development, although additional sulfur may still be needed for early growth. Low pH in the subsoil can decrease availability of accumulated sulfur, particularly in red clays. For more information on sulfur, see SoilFacts publication AG-439-63, *Sulfur Fertilization of North Carolina Crops* (content.ces.ncsu.edu/sulfur-fertilization-of-north-carolina-crops).

Sulfur and nitrogen reactions in the plant are interrelated, and deficiency symptoms for the two nutrients are sometimes confused. Deficiency symptoms of both nutrients appear as general leaf yellowing. However, nitrogen is mobile within the plant, and its deficiency symptoms first appear on the lower, older leaves. Sulfur is relatively immobile, and deficiency symptoms first appear on younger, upper leaves. In cotton, persistent yellowing of new leaves and reddening of the petioles are typical sulfur-deficiency symptoms. In severe cases, the whole plant may become yellow. When attempting to correct the deficiency, it is important to diagnose the problem correctly as nitrogen and sulfur deficiencies may be present at the same time. Plant analysis is recommended because visual symptoms are difficult to interpret. If sulfur is lacking, the addition of nitrogen will not correct the problem. Soil application of sulfur appears more effective than foliar treatments for correcting deficiencies. Early detection is critical because treatments after flowering begins have not increased yields in most cases.

When sulfur is low (S-I ≤25) on NCDA&CS soil-test reports, 20 to 25 pounds per acre is recommended for mineral soils and 15 to 20 pounds per acre for organic soils. For cotton planted on more sandy, low-organic-matter soils, annual applications of 10 to 20 pounds of sulfur per acre may be beneficial. Sulfur will probably not be needed if cotton follows peanuts that received gypsum (land plaster). A variety of fertilizer materials contain sulfur (see Table 7-1). Ammonium sulfate, potassium sulfate, magnesium sulfate, sulfate of potash-magnesium, or granular and pelletized gypsum can be included in dry blends as a sulfur source, or applied in a separate application. Elemental sulfur can also be used, but the sulfur must first be oxidized by soil organisms to the sulfate form; sulfate sources are likely better choices. Because of this need for oxidation, elemental sulfur should be finely ground and applied early in the season to allow time for conversion to sulfate. There is increasing interest in adding 3 to 5 pounds of sulfur per acre in starter fertilizers. This practice can ensure adequate early-season sulfur, but additional sulfur should be included in side-dress materials, especially on leachable, sandy soils. Sulfur-containing nitrogen solutions (24-S) are popular among growers. Since these solutions contain low S concentrations, inadequate sulfur may be applied if using 24-S solutions, depending on the rate of nitrogen applied. Supplemental applications may be warranted.

Table 7-1. Sources of Sulfur in Fertilizer Materials

	Nutrient Content	
Materials	**Percent Sulfur**	**Percent Other**
Ammonium sulfate	24	21 (N)
Potassium sulfate	18	50 (K_2O)
Magnesium sulfate	14	10 (Mg)
Sulfate of potash-magnesium	22	22 (K_2O) + 11 (Mg)
Gypsum (land plaster)	17 to 20	22 (Ca)
Sulfur-containing nitrogen solutions	3 to 5	24 (N)
Elemental sulfur	88 to 100	—

LIMING TO SUPPLY CALCIUM AND MAGNESIUM

Lime increases soil pH and is the primary source of calcium and magnesium for cotton. Dolomitic lime supplies both calcium and magnesium, while calcitic lime supplies only calcium. Cotton has relatively high calcium and magnesium requirements. A two-bale crop will take up 60 pounds of calcium and 23 pounds of magnesium, with 4 pounds of calcium and 7 pounds of magnesium actually removed in seed and lint. The cheapest source of magnesium is dolomitic lime, which contains 120 pounds per ton of lime. Calcitic lime can be used successfully on soils where there is little-to-no leaching potential and adequate magnesium exists based on soil testing guidelines. On low-organic-matter, sandy soils, dolomitic lime is suggested.

Calcium deficiencies are seldom seen because acidity (low pH) and aluminum toxicity usually limit growth first. The magnesium content of soil is usually less than that of calcium because less magnesium is added in lime application and it is more leachable than calcium. Magnesium deficiencies are most likely to occur on highly leached, sandy soils low in organic matter. Heavy applications of land plaster or potassium can also result in magnesium deficiencies. In cotton, magnesium deficiency appears first on the lower leaves as an intense yellowing between the major veins. In severe cases, and sometimes in cool soils, a purplish-red color develops around the leaf margins and between veins, while the veins maintain their dark-green color. Leaves will also shed prematurely. Late in the season, this color may be confused with the orange and red colors caused by the normal aging of leaves. If magnesium is deficient and lime is not recommended, a source such as magnesium sulfate (10 percent Mg) or sulfate of potash magnesium (0-0-22, 11 percent Mg) can be applied at a rate to supply 20 to 30 pounds of magnesium per acre.

MICRONUTRIENTS

Boron (B), copper (Cu), chlorine (Cl), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) are all necessary for plant growth, although the quantities needed are small. Specifically, boron, manganese, copper, and zinc are of most concern in North Carolina cotton production.

Boron

Boron is needed throughout the life of a cotton plant, but adequate supplies are especially crucial during flowering and boll development. Boron occurs in soil as an uncharged molecule (boric acid) and leaches readily. Boron is associated primarily with organic matter and is released as the organic matter decomposes. A temporary boron deficiency can occur due to dry weather because organic matter decomposition slows and slow root growth limits boron uptake. Thus, cotton grown on well-drained, sandy, low-organic-matter soils is more prone to boron deficiency, especially in years of heavy rainfall or drought. Deficiency can sometimes be induced by a soil pH greater than 6.5 or a heavy lime application in the recent past. The most pronounced boron deficiency symptoms include:

- Abnormal shedding of squares and young bolls
- Ruptures at the base of squares or blooms

- Dark-green rings on leaf petioles accompanied by discoloration of the pith under the rings
- Death of the terminal bud and shortened internodes near the top of the plant, resulting in a dwarfed and multi-branched plant
- Mature bolls that are small, deformed and do not fluff normally

In many cases, the first real indication of a problem may be excessive growth. Close observation will usually reveal abnormal fruit shed as the reason for this problem. If plants are not carefully monitored, the problem may not be noticed until harvest.

The actual uptake requirement of boron by a two-bale cotton crop is about 0.2 pounds per acre. Because boron is essential to successful production and its availability is difficult to assess, annual application of boron to cotton is strongly recommended. Boron can be applied to the soil or foliage. Although boron is not included in NCDA&CS soil testing due to high leachability, the suggested rate of soil application is 1 pound of actual boron per acre broadcast before or during seedbed preparation, or 0.2 to 0.4 pounds of actual boron per acre if a borated fertilizer is banded. Manufactured fertilizers containing boron or granular borate in dry blends can be purchased. Preplant applications are most effective for soils with limited leaching potential.

For foliar applications, supply sufficient boron to account for uptake inefficiencies and to offset leaching losses. The recommendation is to use 0.5 pounds per acre of actual boron applied at early bloom or 0.25 pounds per acre at early bloom and another 0.25 pounds per acre about two weeks later. Foliar applications allow placement of boron on the crop during peak demand. Some of the applied material will be taken into the plant and the remainder washed into the soil. Once inside the leaf, boron moves very little. This lack of movement means that new, untreated vegetation can be deficient in boron unless it is supplied by the root system. The recommended rates of boron for foliar application will provide for the immediate needs of the plant. Additionally, some residual amounts will increase soil levels. This residual supplies the root system as long as the boron remains in the root zone. On deep, sandy soils, split foliar applications ensure availability during the critical bloom and boll-filling periods. Soluble boron sources are generally compatible with mepiquat chloride and most insecticides if enough water is used to dissolve the compound.

Copper, Manganese, and Zinc

Deficiencies of copper, manganese, and zinc are seldom seen in cotton. Determine applications of these elements based on soil test reports. The NCDA&CS Agronomic Division soil-testing laboratory recommends these micronutrients when a soil-test index value of 25 or less occurs (www.ncagr.gov/agronomi/pdffiles/st$note.pdf). Special attention is needed when soil pH is 6.5 or higher due to lower availability of micronutrients in soils. Based on field experience, manganese is most likely to be deficient, especially at high pH in coastal plain soils. Consult your county Cooperative Extension center, NCDA&CS agronomist, or certified crop advisor (CCA) for guidance in these situations.

FOLIAR FERTILIZATION

Recent studies have proven that foliar-applied nutrients such as urea nitrogen, potassium, and certain micronutrients can be absorbed through the leaf. The amounts of nutrients absorbed will not meet the full daily demands for these nutrients but can supplement soil-supplied nutrients. Under most conditions, the soil supplies adequate levels of nutrients.

Foliar fertilization may increase yields only when deficiencies occur. Deficiencies can result from improper fertilization; leaching of mobile nutrients by heavy rains; drought; or insect and disease stresses that damage root systems. Some researchers have observed that foliar nitrogen application may occasionally "stick a few more bolls" early in a drought as water (and nitrogen) uptake declines. But if the drought continues, these bolls may also shed. Reactions in the leaf essentially shut down when wilting occurs early in the day and foliar applications become ineffective.

Deficiencies also can occur when cotton is heavily fruited, soil moisture is good, and insect control is excellent. Under these conditions, the plant's resources are directed mainly into fruiting rather than root and shoot growth. Nutrient uptake from roots can be less than required to meet peak demands. When deficiencies are detected using plant tissue or petiole analysis, foliar fertilization can improve yields. The real key is to know when deficiencies are present, and the only way to know is to monitor leaf and petiole nutrient levels, also called tissue analysis (see "Monitoring Plant Nutritional Status" section).

Foliar applications of nitrogen or potassium to correct late-season deficiencies are usually made using either urea (46-0-0) or potassium nitrate (13-0-44) as the source. Other materials are available and being tested, but urea and potassium nitrate have proven to be effective thus far. Applications during the first five weeks of bloom are most effective in correcting nutrient deficiencies. Generally, the solution is made by mixing 10 pounds of the fertilizer material with 10 to 20 gallons of water for each acre to be treated. Both materials will cause the temperature of the water to drop as they dissolve; use of warm water or agitation speeds dissolution. By using hot water or extended agitation, solutions as concentrated as 10 to 20 pounds of material in 5 gallons of water can be made; such solutions are primarily used in aerial applications. Premixed solutions are beginning to appear on the market in some areas. Urea and potassium nitrate both seem compatible with commonly used insecticides. Check the pesticide label for warnings or instructions on mixing with fertilizers as mixing order may be important.

MONITORING PLANT NUTRITIONAL STATUS

Plant tissue analysis provides a "snapshot" in time of the nutrients (N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B) that have accumulated in the uppermost mature leaves. Tissue analysis is a management tool to gauge nutrient sufficiency or adequacy for optimum growth and yields. It evaluates nutrient shortages or excesses and helps determine appropriate corrective action. For example, nutrients that are mobile in the soil, such as nitrogen (N) and sulfur (S), can easily move out of the root zone by leaching due to rain; deficiencies due to such loss can be detected with tissue analysis.

At first bloom, the plant has accumulated only about half of its total nutrient uptake (Figure 7-2). At this stage, the root system is still active. The plant continues to accumulate nutrients for vegetative and fruit growth over several more weeks. From mid-bloom through maturity, root expansion and nutrient uptake slow down, even though the crop requires 10 or more weeks to fully mature. At the later growth stages, since much of the nutrient uptake has already occurred, leaf analysis is less effective in predicting nutrient needs of the crop. Hence, cotton leaf analysis as a tool to assess current nutrient status is best done during the pre-bloom or early bloom period.

Cotton leaf and petiole tissue analyses are available from the Agronomic Division of the NCDA&CS for a fee; check with the Ag Division of NCDA&CS for current rates. Detailed sampling instructions and laboratory data interpretation guidelines are available at www.ncagr.gov/agronomi/pdffiles/11cotton.pdf. Contact your county Cooperative Extension agent or regional agronomist if you would like help experimenting with this management tool.

Sample the most recently mature leaf. This leaf blade is four to five nodes below the terminal leaf (bud) and is generally 10 to 16 days old. Sample as follows:

- Collect about 20 leaves including petioles (stems) for each sample. Do not sample damaged leaves.
- Remove the petiole from the leaf at the time of sampling.
- Place the leaf blade and petiole in a paper bag.
- Correctly identify the growth stage and include on the information sheet for proper interpretation.
- Forego sampling during times of environmental stresses, such as unusual wetness, dryness, or cloudiness. These conditions can alter leaf chemistry and complicate the interpretation of results.

The leaf analysis is more of a predictor of nutrient uptake or accumulation that occurred in growth a few weeks earlier. The petiole analysis is a reliable indicator of currently available soil nutrients during the bloom period, especially for nitrate-nitrogen (nitrate). The petiole is a pipeline to and from the blade, with limited nutrient storage capacity. Petiole analysis is a much more sensitive indicator of N availability than leaf analysis. As shown in Figure 7-3, nitrate concentration decreases following bloom. A leaf sampling program should begin pre-bloom to establish a baseline nutritional status. Fields with “low” petiole nitrate will have a high likelihood of responding to additional nitrogen, either applied to the soil if early during the bloom period or as a foliar application if later in the season.

Unfortunately, anything that affects nutrient uptake by the root system, such as drought or excess soil moisture, also strongly affects petiole nutrient levels. Thus, petiole-monitoring programs are most effective when soil moisture is good to adequate.

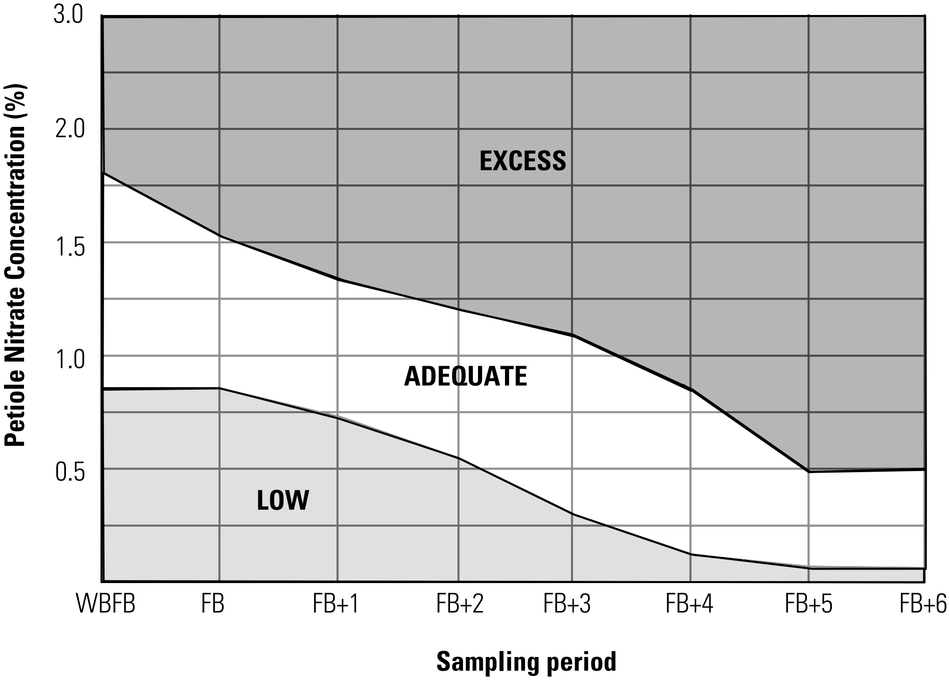

Figure 7-3. Ratings for petiole nitrate concentrations during the bloom period.
(WB = Week Before; FB = First Bloom; the number after FB indicates weeks after first bloom.)

STARTER FERTILIZERS

In a high-management situation, starter fertilizers can enhance early season growth, promote earlier fruiting, and increase yields. Enhanced growth frequently allows for more effective weed control. The extent of these effects varies with soil and climatic conditions, and effects may not be seen every year. Responses are usually greatest on cotton planted early in cool, wet soils with low phosphorus levels, especially in reduced tillage systems, but are not limited to these conditions. Over a period of several years, replicated trials with soils testing high in phosphorus have shown an average increase in cotton lint yield of 60 pounds per acre when using starter phosphorus. On soils testing “very high” in phosphorus (P-index greater than 100), there has been no advantage to including additional phosphorus in the starter band (for instance, the highest yields occurred with only nitrogen in the starter). The most consistent responses have occurred when the starter is placed in a narrow band 2 inches below and 2 inches to the side of the seed. Other techniques, such as surface bands 3 to 4 inches wide applied over the row, have been successful but are much less consistent.

Tests with nitrogen and nitrogen-plus-phosphorus solutions mixed with preemergence herbicides have been the least successful. This finding could be expected because the fertilizer is sprayed in a much wider band, and the N concentration in the row is greatly diluted. Starter fertilizer trials throughout the Southeast have shown that responses are possible in some cases with nitrogen only, with one-to-one mixes of UAN-nitrogen solutions with 10-34-0 or similar ammonium polyphosphate solutions, and with granular fertilizers such as DAP (diammonium phosphate, 18-46-0). A maximum rate of 100 to 120 pounds of starter fertilizer per acre is suggested to maximize response and minimize the chance of seedling injury. A careful setup is essential. Placement too close to the seed can necessitate replanting. In-furrow fertilizers are not recommended for cotton!

In summary, trials throughout the Southeast support the use of starters on soils where potential yields are greater than 700 pounds per acre and where other good management practices are followed. Starters will not help much where timely weed control, insect management, and nitrogen fertilization are not practiced, but they can help a well-managed crop perform better.

ANIMAL WASTES AS A NUTRIENT SOURCE FOR COTTON

In many of the important cotton-producing areas of North Carolina, poultry and swine manures are available for use on cropland. Manure is often a cost-effective substitute or supplement to fertilizer-supplied nutrients. Animal wastes should be analyzed prior to use to determine nutrient amounts and forms in the waste; a current analysis is encouraged. Key points to consider in its use include:

- The largest quantity of nutrients will be nitrogen, phosphorus, potassium, and sulfur, along with some magnesium, calcium, copper, zinc, and manganese. The agricultural lime equivalent can be evaluated if requested.
- With a rate chosen from manure, make sure that excess available nitrogen is not supplied.
- Between 40 and 80 percent of the total nitrogen will be available for uptake by plants in the first year of application. Recent work in Alabama indicates that essentially 100 percent of the nitrogen in poultry litter is available when incorporated just before planting.
- 100 percent of the P and K is available to the plant the first year.
- Incorporate animal wastes as soon as possible after application to decrease volatile losses of nitrogen and to lessen the impact of runoff on nearby water bodies. Since cotton is very sensitive to over-application of N, apply animal wastes at a rate to supply sufficient P preplant, then side-dress with a liquid fertilizer at the appropriate rate to obtain the rest of the N needed by the crop.

For more information on the use of animal wastes as nutrient sources, ask your local Cooperative Extension agent for a copy of the SoilFacts publications AG-439-04, *Swine Manure as a Fertilizer Source*; AG-439-05, *Poultry Manure as a Fertilizer Source*; and AG-439-28, *Dairy Manure as a Fertilizer Source*; or visit content.ces.ncsu.edu.