Nitrogen Utilization by Western U.S. Cotton

By Jeffrey C. Silvertooth, Kevin F. Bronson, E. Randall Norton, and Robert Mikkelsen

An adequate supply of N is essential for successful cotton production. Sufficient N initially supports rapid development of leaves and roots. Later in the season, most of the N is found in the seeds. Understanding cotton development aids in efficient nutrient management.

Cotton growers have long recognized the vital role N plays in fiber production. They have learned to manage the N supply to provide adequate N for boll filling, but minimize any excess soil N present prior to harvest.

An inadequate N supply during the vegetative period will slow or stop leaf development. Healthy leaves provide the photosynthetic capacity needed to support the growing bolls.

Excess amounts of N can be associated with boll shedding, but the primary detriment is when surplus N encourages excessive vegetative growth. When this occurs, the poor boll set is caused by vegetative shading and increased insect attractiveness, not the excess N. Too much N also causes delays in maturity and difficulty in defoliation.

For optimal N management, it is important to understand the relationship between the morphological and physiological changes as a crop grows. Individual plant species can vary tremendously in physiological behavior over their life cycle and their nutrient requirements will change during various stages of growth.

Nitrogen Uptake and Assimilation Supplying cotton with adequate N first involves transferring the dissolved nutrient from the soil solution across root membranes and then into plant cells. Next, assimilation involves a series of biochemical reactions that convert the N into a form that can be incorporated into plant structures and/or biologically active forms.

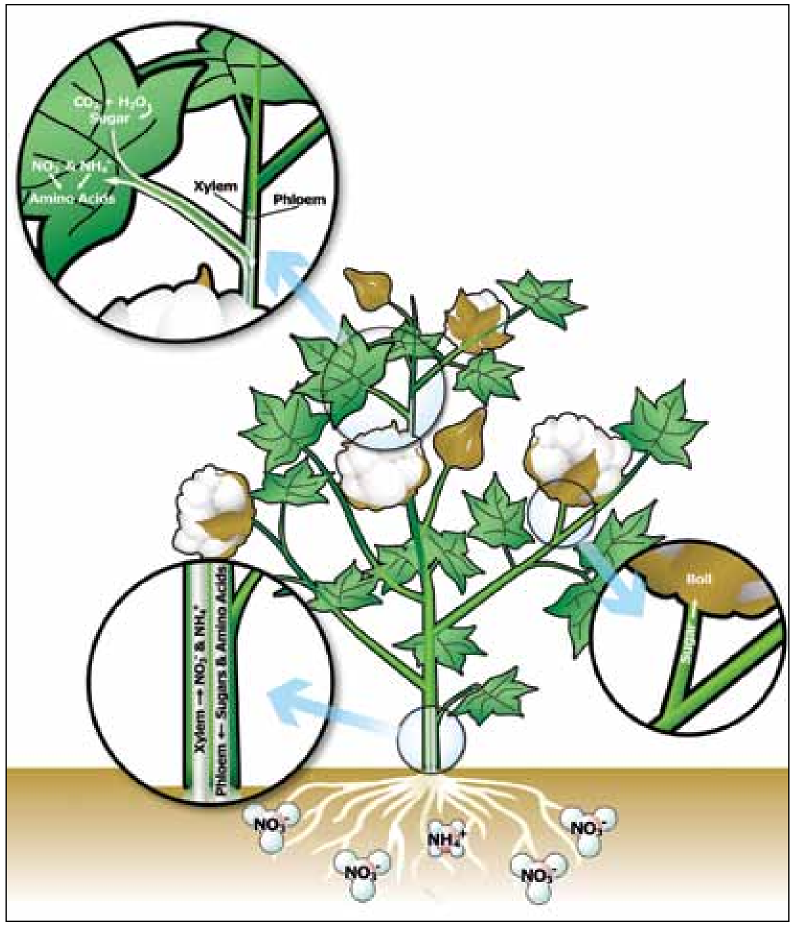

Figure 1. Prior to bloom, most of the N is used in the rapidly growing vegetation and root system. Later in the season, the developing bolls are the largest sink for N, as leaf and root growth declines.

Nitrate (NO_3^-) is the dominant form of N acquired by cotton. Following uptake into the root, NO_3^- is transported in the xylem to the photosynthetically active green leaves **(Figure 1)**. The xylem is the principle pathway for long-range transport of N from roots to the leaves and bolls. It is notable that some N transport will occur in the phloem and it is bidirectional. In cotton, over 95% of the xylem N is in the NO_3^- form. This physiological tendency of loading NO_3^- into the xylem and petioles facilitates the petiole NO_3^- test as an assessment of plant N fertility status, commonly used as an N fertilization guide. The NO_3^- is loaded into the mesophyll cells of leaves where it is reduced first to amino-N compounds and then combined into proteins.

Multiple studies have shown similar patterns where cotton has an initial period of rapid N accumulation in the vegetation, beginning at approximately the formation of the first pinhead squares **(Figure 2)**. Rapid N uptake continues to the time of peak bloom, when accumulation reaches its maximum daily N uptake (flux of 4 to 5 lb N/A/day). Following peak bloom, N uptake continues at a diminished rate and N translocation from vegetative to reproductive plant parts becomes a dominant process **(Figure 3)**. Studies have consistently shown that the seeds are the primary sink for N in the bolls (> 50% of the total N) for both Upland (*G. hirsutum* L.) and American Pima (*G. barbadense* L.) cotton (Unruh and Silvertooth, 1996; Bronson, 2008; Fritschi et al., 2004). Boll walls (burrs) have low N concentrations at maturity and N removal in the fiber is negligible.

Monitoring Crop Growth Cotton development is typically described as a function of heat units (HU) or degree days (DD) to track growth stages. This allows crop development to be standardized among different years and locations. Heat units more accurately track cotton develoment than merely counting days after planting, since crops respond to environmental conditions and not calendar days. This approach of using phenological timelines or baselines works best for irrigated conditions where crop vigor and environmental growth

Abbreviations and notes: N = nitrogen; K = potassium; ppm = parts per million.

conditions are more consistent than in non-irrigated situations.

Estimating the N Requirement A common approach for managing N is the use of a "yield goal" to match estimated crop N requirements to projected plant demand. From soil test information and the analysis of the irrigation water, the amount of available N can be calculated and then subtracted from the total amount required for the crop. This is a useful guideline for N fertilization, but the amount of N required per bale of lint is not constant and it increases as yields increase.

It is estimated that the total crop N demand ranges from 40 lb N/bale (18 kg N/bale) in Texas and California (Yabaji et al., 2009; Fritschi et al., 2004) to 75 lb N/bale (34 kg N/bale) in Arizona (Unruh and Silvertooth, 1996). As much as 70% of the total N uptake ends up in the mature cotton seed (Bronson, 2008). To achieve the greatest efficiency for N uptake and utilization, fertilization practices are synchronized to meet periods of crop demand. When available, fertigation provides an excellent way to supply additional N at rates and times that best match the crop requirements.

Water There are several important implications regarding water availability and N fertility in cotton. First, N nutrition is negatively affected by water stress. Uptake of N is diminished under water stress conditions because of a reduction in energy necessary for active uptake due to reductions in photosynthesis. The transpirational stream will be diminished under drought stress due to stomatal closure, limiting the upward flow of N to the leaves. Additionally, water stress and reductions in photosynthesis will limit the amount of chemical energy necessary for the conversion of NO_3^- to amino acids. Therefore, maintaining adequate moisture in the rootzone will improve N efficiency. Less than optimal management of either N or water will have a negative impact on the other input.

Implications for Fertilizer N Management Studies in California (Hutchmacher et al., 2004) and in Texas (Bronson et al., 2009) have indicated that it is advisable to measure the soil NO_3^- content in the rootzone (2 to 3 ft.) prior to cotton planting. Unlike the humid southeastern USA, NO_3^- leaching losses are generally low and soil profile NO_3^- concentrations can be substantial.

Calculating the N fertilizer recommendation for cotton in the western U.S. usually involves a yield goal and mass balance approach. A producer would start with a yield goal and analysis of soil NO_3^-. Nitrogen credits from the soil and irrigation water will be subtracted from the N fertilizer recommendation. In addition to the "per bale" N requirement already mentioned, the final information needed is the recovery efficiency of N fertilizer added. This can range from 20% in some furrow-irrigated cotton fields to over 70% when N is supplied through drip irrigation (Bronson et al., 2008). When N is carefully managed, fertilizer recovery by furrow-irrigated cotton can also exceed 70% (Navarro et al., 1997).

Another N fertilizer management tool is monitoring the plant N status during the growing season. Petiole sampling is routinely used in the western U.S. to verify the presence of adequate N. Since NO_3^- is the dominant form of N taken up by the roots and transported to the leaves, petiole analysis provides a guide to determine the available N supply in the soil. Skill is needed to collect and interpret petiole NO_3^- data. For example, the time of day and the position on the plant for collecting petioles can all be important in the interpretation.

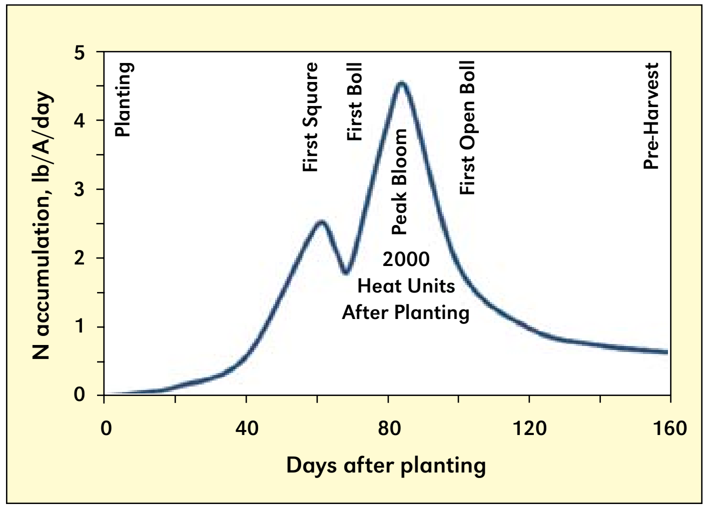

Figure 2. Daily N accumulation rate of upland irrigated cotton during the growing season in Arizona. Silvertooth and Norton, 2011

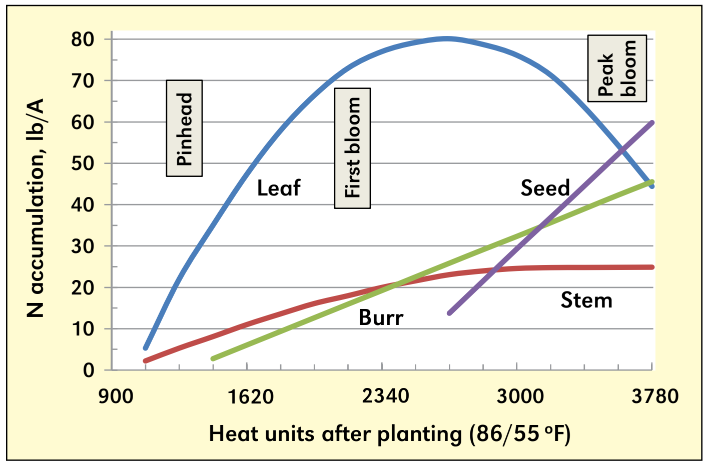

Figure 3. Seasonal pattern of N uptake and accumulation in irrigated cotton in Arizona (Upland "Delta Pine 90"). Unruh and Silvertooth, 1996.

To avoid premature cutout due to N deficiency, the California and the Arizona Extension services recommend keeping petiole NO_3^- concentrations above 2000 ppm during the fruit set period. The effect of N deficiency on fruit set is two-fold. N-deficient cotton plants stop developing new nodes and squares, and enter premature cutout. Furthermore, N deficiency can increase the shed of young bolls.

Foliar applications of N are sometimes used to supplement the soil supply, especially when expected yields are large and the soil supply of N is low. The balance between N demand and supply is determined by the number of bolls, the soil supply, and the plant N supply that can be remobilized to the boll without impairing photosynthesis. Urea or other soluble N sources are commonly sprayed onto foliage at a rate of 5 to 10 lb N/A, sometimes with multiple applications during boll maturation.

Emerging technologies to rapidly assess in-season cotton N status include the chlorophyll meter and canopy-level spectroradiometers. Studies in West Texas indicate that these sensors can result in modest savings of N fertilizer without reducing lint yields, compared to soil-based N management (Yabaji et al., 2009; Bronson et al., 2011).

Definitions Unique to Cotton Development

Bale: 480 to 500 lb, or 218 to 225 kg of cotton lint.

Boll: The cotton fruit consisting of seeds, fibers, and burrs. Bolls begin to develop following pollination in three phases: enlargement (3 weeks), filling (3 weeks), and maturation. Under typical conditions it requires approximately 50 days after pollination occurs for a boll to "open" prior to harvesting.

Cut out: Growth stage when flower development ceases.

Defoliation: Defoliating chemicals are applied to terminate growth and make machine harvesting easier.

First square: The initial square formed on a fruiting branch.

Flowering: The period when the cotton plant is still blooming. This stage can last for 6 weeks or more.

Heat units (degree days): The accumulated temperature effect when growing conditions are between 55 and 86 °F.

Match head: The second stage of square development, following the pinhead stage.

Peak bloom: Period of maximum bloom production, proceeded by stages of early bloom and cut out.

Pinhead: The first stage where a new square can be identified.

Square: A fruiting bud that forms at the initiation of a fruiting branch.

Summary

While an adequate supply of all plant nutrients is essential for successful cotton production, management of N is especially important. Both pre-season and in-season monitoring of N is needed to maximize N efficiency. A shortage of adequate N during intense demand periods of peak bloom and first boll opening will reduce yields. An excess supply of N during early vegetative stages and in the late season cut-out will be detrimental to yield and quality. BC

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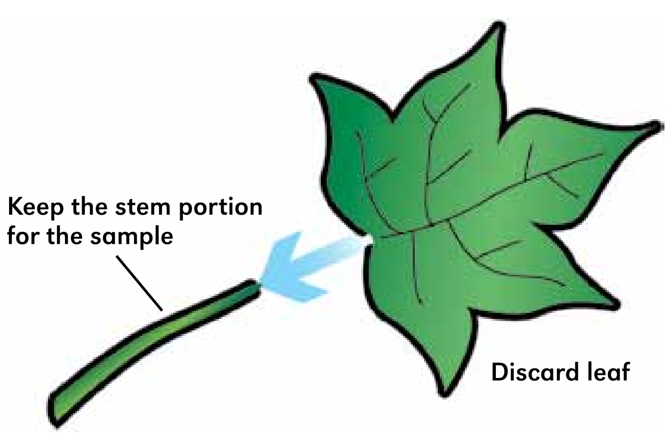

Petiole Testing and Tissue Sampling

Tissue testing is used to analyze the entire leaf blade for all of the essential nutrients that might be of concern. Leaf tissue testing is generally done before first bloom to detect any nutritional shortage. Petiole sampling begins around the first bloom and continues for the next 8 to 10 weeks. Nitrate is the major constituent, but P and K are sometimes monitored too.

Petioles are collected from areas that are representative of management zones in the field. Petioles are removed from the most recently fully matured leaf, usually the 4th and 5th leaf from the top of the plant. The lab needs 25 to 35 petioles for analysis.

Following are selected sufficiency guidelines used for monitoring petiole NO_3-N concentrations in the uppermost fully developed leaf during critical stages of growth. Nitrate concentrations will decline during the growing season and critical concentrations are general benchmarks. Additional concentrations can vary among varieties and between species (e.g. Upland and Pima cotton).

California

	ppm NO_3-N			
Range	First squares	First flowers	First bolls	First open bolls
Should be sufficient	18,000	12,500	7,000	3,500
May be deficient	12,000	7,500	3,000	1,500

Source: Basset and MacKenzie, 1983. Acala variety, SJ2

Arizona

	ppm NO_3-N			
Range[1]	First squares	First flowers	First bolls	First open bolls
Variety				
Pima	>10,000	>8,000	>4,000	>2,000
Delta Pine	>18,000	>14,000	>8,000	>4,000

[1]Contents of petioles from uppermost, fully developed leaves from Upland and Pima cotton grown under irrigated conditions.
Source: Pennington and Tucker, 1984