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Nitrogen Fertility Issues for San Joaquin Valley Cotton

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Nitrogen (N) is an essential plant nutrient that must be available at the correct times and in the proper amounts to produce high cotton yields. Inadequate N can reduce plant growth, number of fruiting sites and reduce yields. Early season cotton N deficiencies are rarely observed in the San Joaquin Valley (SJV), but when they do occur they show up as stunted plants or plants that are pale green in color. N deficiencies can also occur with a very restricted rooting system that limits the plant's ability to explore a larger volume of soil for N and other nutrients. The reproductive (boll production) growth period (late June through August) is a much more likely timing for nitrogen deficiency to occur. During early part of this period, there are significant demands for nitrogen with the large expansion of vegetative growth. Later, as flowers and then bolls develop in significant numbers, most plant nitrogen is being directed to these reproductive structures, and vegetative growth and root growth become less successful in "competing" for available nitrogen. In fact, since some of the major N-containing compounds in plants can be mobilized and translocated early on to new vegetative growth, and later on to supporting boll growth, N deficiencies tend to be most apparent as yellowing of older leaves, progressing to yellowing of younger leaves and reddish coloration of leaves, stems and petioles as more severe deficiencies develop.

N fertilization of cotton at the farm level is directed toward optimizing lint yield, while preserving high fiber quality; but achievement of high yields and quality are not the only incentives for improving N management. N management decisions on all crops may affect movement of N in soils and water. Although there are large differences in growth habit due to type of cotton (Pima versus Upland) and with varieties, cotton is generally indeterminate in growth characteristics. Cotton's relative N nutrition, among other factors, affects the plant's balance between vegetative vigor and adequate reproductive growth. High cotton yields depend on adequate N fertilization, but excessive N can negatively impact the crop's balance between reproductive and vegetative growth, often reducing fruit retention and promoting rank growth. N fertilization beyond those rates that produce consistent yield improvements also represent an unnecessary cost. Moreover, application of excessive N fertilizer can have negative impacts on crop production and input costs by increasing cotton's susceptibility to phloem-feeding insects (Cisneros and Godfrey, 2001), and increasing the need for growth regulators for vegetative growth control (Hutmacher et al, 2004). In the late-season, high N availability can cause fruit maturity delays, make defoliation more difficult and costly, and increase chances of regrowth after harvest aid applications. Tight profit margins now and in the future dictate that all unnecessary crop inputs be reduced or eliminated where possible.

If crops grown in rotation have inadequate rooting depth and densities to intercept applied and residual N, soluble forms such as nitrate can move below the vadose zone with water from rainfall and irrigation and contaminate groundwater (Burrow et al., 1998; Franco and Cady, 1997). Groundwater in many areas can flow laterally into surface water systems, with potential environmental impacts on those ecosystems. Many California cotton fields are grown in a rotation sequence that includes crops such as alfalfa, processing tomatoes, corn or silage crops, small grains, garlic and a variety of vegetable crops. Some of these crops can contribute N (ie. alfalfa) to the soil profile through N-fixation, or have typical N fertilizer applications that in prior experiences can exceed plant uptake, resulting in unused N (reduced N recovery rates) and potential for losses from the soil-plant system. In this type of situation, cotton production practices alone are clearly not the only source of potential leaching losses and environmental impacts, but must be considered as part of the overall system that requires analysis and improvements.

Acala Cotton Responses to Applied Nitrogen. In the late 1990's and early 2000's, University of California researchers conducted a large multi-site study of Acala cotton cultivars in the San Joaquin Valley to evaluate crop yield responses to applied nitrogen fertilizer amounts that ranged from about 50 lbs/acre to about 200 lbs/acre, with fertilizer applications adjusted downward by adjusting for residual soil nitrate-N in the upper 2 feet of the soil profile (Hutmacher et al, 2004). The study sites represented a wide range of soil types, crop rotations and were spread across six San Joaquin Valley counties, and yield levels generally ranged from about 1100 to 1700 lbs lint/acre, in some cases lower than yields now typical for many current SJV cotton growers. Fertilizers were applied as split applications at early to mid-squaring and again at early bloom. The focus at the time was to evaluate newer Acala varieties that tended to be more determinate in fruiting habit (when compared with older varieties) and for target yields averaging three bales of lint/acre or more. The study produced some unanticipated results. N fertilizer applications as low as 56 kg ha^{-1} (50 lbs/acre) led to no significant yield reductions in just over half of the 39 large-scale trial sites over a five year period. In fact, of the trials in which a significant yield response to fertilizer N was noted, maximum yields required 168 to 224 kg ha^{-1} (150 to 200 lbs/acre, respectively) in just over half of the sites in these studies. When residual soil nitrate changes in the upper 2 feet of soil during the season and applied N were both considered, yield N response data from these studies affirmed the N requirements per bale of about 50 to 60 lbs N per 500 lb bale of lint from earlier California or Arizona studies (Silvertooth and Norton, 1998; Hutmacher et al., 2004; Bassett and Mackenzie, 1970. Table 1 shows some recommendations coming out of this study regarding fertilizer N application amounts to consider at three ranges of residual soil nitrate-N levels measured at planting timing (upper 2 feet of soil).

Table 1. Fertilizer recommendations for Acala cotton for different levels of measured soil residual nitrate-N in the upper 2 feet of soil, based on San Joaquin Valley studies (Univ. CA, Hutmacher et al)

Soil Residual Nitrate Levels- Upper 2 feet soil **-** *Spring pre-plant or soon after planting*	**Recommendations for N fertilizer applications per year in lbs/acre** *(values shown are for target yields of 3 to 4 bales/acre)*	**Additional Considerations** *(ie. What situations would cause you to lower or raise applied fertilizer N amounts?)*
< 55 lbs N as NO_3-N	125 to 175 lbs *(possibility of late water-run if yield potential is high)*	Apply less N if low yields predicted due to late planting, field history
55 to 100 lbs N	100 to 125 lbs *(possibility of late water-run if yield potential high)*	Use plant mapping, petiole nitrate to assess yield, N status - apply if > yields and lower than expected petiole NO_3 status
> 100 lbs N	75 lbs or less	Use mapping, petiole nitrate to assess yield potential, likely response

The key finding in these studies was that in many situations a significant portion of the N needs of the crop could be provided by in-field soil N sources (including residual soil nitrate-N, irrigation water

N, carryover in organic residues or manures), thereby reducing the need for N fertilizer applications. Some limited studies done since with Pima varieties suggest N requirements and yield responses may be fairly similar to those found with Acala varieties in these earlier 1990's-2000's studies, but the evaluations with Pima have been far fewer in number and we do not know if the results would be similar under higher yield levels and with more indeterminate cultivars.

Petiole Nitrate Field Evaluations and Crop N Uptake and Removal Estimates. As part of our field research efforts, we have been doing petiole nitrate evaluations and some limited above-ground plant nutrient uptake studies in both Upland and Pima types of cotton as part of several irrigation research projects over a number of years at the West Side Research and Extension Center (WSREC) of the University of California. The nitrogen component of these studies was only a subset of the work on the overall projects, so much of this work has not yet been published, but we will be working on those publications. Current recommendations for borderline deficient and upper level sufficient petiole nitrate-N values developed using petioles from recent, fully-expanded upper canopy leaves are shown in Table 2. Note the following: (1) the large differences between values shown for Pima versus Acala cultivars, in agreement with some previously published information of the University of California; and (2) some of the ranges shown as "borderline" or "sufficient" are fairly large. The range of values shown was largely due to differences seen with drip-irrigated versus furrow-irrigated plants, with the lower values representing plants under drip irrigation.

Table 2. Recommended values for nitrate-N levels for upper-canopy petioles as a function of growth stage and cotton type (Upland versus Pima cotton) – University of CA, Hutmacher et al.

Petiole Nitrate (NO_3-N) – in ppm				
	Upland Cotton		**Pima Cotton**	
Growth Stage	*Borderline to Deficient*	*Sufficient Upper Level*	*Borderline to Deficient*	*Sufficient Upper Level*
Early square	<14,000	>20,000	<10,000	>12-14,000
1^{st} flower	<11-12,000	14-18,000	<6,000-7,000	>8,000-10,000
1^{st} flower + 10 days	<8000-10,000	12,000-14,000	<4,000-5,000	>6,500-8,000
Peak bloom	<3,500-5,500	>7,000-9,000	<2,500-3,500	>4,500-6,000
Early open boll	<1,500-2,000	>3,500-4,500	<1,000-1,500	>2,500-3,000
10-15 days after cutout	<750-1,200	>1,500-2,000	<750-1,000	>1,250-1,500

With new requirements associated with the development of Nitrogen Management Plans, there has been renewed interest in some studies we have done at the University of CA West Side Research and Extension Center describing cotton N uptake and N removal with harvest operations. These have been irrigation and cultivar response studies done over the past 8 years, and shown in Table 3 are some averages and standard deviations for:

(a) harvest-time total plant N uptake (lbs N in above ground plant parts/acre) and
(b) N removal in lint plus seed with harvest (in lbs N/ton of lint plus seed)

The values shown in the table below were determined using small area harvests in field research plots, with plants partitioned in different components, weighed, and then subsampled to determine N content.

Table 3. Harvest time above-ground total N uptake and N removal with seedcotton harvest in Upland, Acala and Pima irrigation studies at Univ. CA West Side REC – Hutmacher et al.

Type of cotton	Total Plant N Uptake in these studies (above-ground) **Mean and std deviation**	Total Plant N Uptake in these studies (above-ground) **Range of values**	N Removal with harvest (in lint plus seed) (lbs N/ton of lint plus seed) **Mean and std deviation**	N Removal with harvest (in lint plus seed) (lbs N/ton of lint plus seed) **Range of values**	Total Number of observations used for averages*
Pima cotton	216 +/- 29	161 to 265	44 +/- 3	36 to 48	14 sites
Acala types of Upland cotton	205 +/- 31	163 to 258	42 +/- 4	38 to 44	8 sites
Non-Acala types of Upland cotton	206 +/-30	172 to 239	41 +/- 3	38 to 45	5 sites

** generally there were three samples replicates per site for these evaluations.*

The average values that we have for N removal with harvest for Pima types of cotton are actually quite similar to those in some more limited studies we have done using Acala and Upland varieties (Table 3). These small data sets represent what we feel is just a start in providing estimated uptake and removal numbers representing CA cotton production conditions, since the data shown represents: (a) a relatively limited number of evaluations all done in small plots at the same soil type / site; (b) a small number of cultivars; and (c) harvest removal values shown include removal with lint plus seed, but do not account for removal associated with gin trash (which could be significant, especially with more indeterminate, harder to defoliate Pima cultivars). Additional studies to address some of these concerns will be conducted If funding can be identified.

Summary Key Messages from Nitrogen Studies:

- Accurate assessment of cotton nitrogen (N) fertilizer needs requires an integrated evaluation of the characteristics of your production system.
- Field history is important. Yield goals should be reasonably assessed and matched with likely N fertilizer needs – aiming for higher yields is a good profitability strategy, but don't over apply fertilizers when very high yields are improbable.
- Soil type, texture, infiltration rate, and physical limitations to the depth and extent of rooting may impact crop growth and your management options.

- Growing seasons differ in yield potential. Early season weather and soil conditions differ between seasons, and can impact yields and cotton N use. Lower than usual early-season heat unit accumulation may limit yields.
- Crop rotation patterns and management practices impact amounts of residual soil N and where it may be located in soil profile. When cotton follows alfalfa, heavily fertilized vegetables or corn, residual N may be high; after small grains or sugar beets, lower residual soil N usually occur.
- Pre-plant soil nitrate-N analyses to a depth of at least 2 feet are useful in estimating readily accessible plant-available N. Adding soil nitrate-N analyses in the 3rd and 4th foot depth can give an even better estimate of available N.
- Irrigation water can contribute added nitrate N – should test water for nitrate-N content.
- Petiole nitrate monitoring during late squaring through peak bloom can aid in assessing supplemental N needs during the season, particularly under conditions where soil test nitrate-N levels are marginal to moderate and fruit set and yield potentials are high.
- Fruit load evaluation , in combination with residual soil nitrate measurements and petiole nitrate-N monitoring, is essential in estimating the need for and likelihood of a favorable response to supplemental N
- Improved N management practices and better assessments of crop N needs should reduce excessive residual soil N levels over time.

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