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CONSIDERATIONS FOR MORE EFFICIENT NITROGEN MANAGEMENT: SAN JOAQUIN VALLEY OF CALIFORNIA

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Abstract

Objectives in a five-year field study were to identify crop growth and yield responses to applied nitrogen (N) and provide information to improve fertilizer N management using soil residual N estimates. Responses of Acala cotton (*Gossypium hirsutum L.)* to a range of applied nitrogen treatments were investigated in a multi-site experiment in California's San Joaquin Valley. Objectives Baseline fertilizer application rates for the lowest applied nitrogen treatments were based on residual soil nitrate-N (NO_3-N) levels determined on soil samples from the upper 2 ft of soil collected prior to spring N fertilization and within about one to two weeks post-planting each year. Results have shown positive cotton lint yield responses to increases in applied N across the 50 to 200 lb N/ac range in only 41 percent (16 out of 39) of the test sites. Soil NO_3-N monitoring to a depth of 8 feet in the spring (after planting) and fall (post-harvest) indicate most changes in soil NO_3 occur within the upper 4 feet of soil. However, some sites (those most prone to leaching losses of soluble nutrients, water) also exhibited net increases in soil NO_3-N in the 4 to 8 foot zone when comparing planting time versus post-harvest data. The lack of yield responses and soil NO_3-N accumulations at some sites indicate that more efforts should be put into identifying the amount of plant N requirements that can be met from residual soil N, rather than solely from fertilizer N applications.

Introduction

Fertilization of cotton, as with most crops, is conducted primarily with yield and quality objectives in mind. For CA cotton production, objectives often are directed toward optimizing lint yield while maintaining excellent fiber quality. Available information from crop N use estimates, estimated soil test N, and within-season applications (additional foliar or soil-applied N) are all part of the system used to promote good yield performance through maintenance of adequate plant nutrient status to support economic yields. Field experiments evaluating nitrogen management options and responses of CA crops have been numerous over the years, and there is experimental evidence from many of these studies indicating that crop fertilization can be managed so that agronomic, economic, and environmental efficiencies can be significantly improved simultaneously (Hutmacher et al (2001); Boquet and Breitenbeck (2000); Hutmacher et al (1994)).

There are several incentives for considering adjustment of the nitrogen management practices of cotton and other CA crops. With cotton, mid- and late-season N management has an impact on the crop's progress toward, cutout, readiness for defoliation and ease of harvesting. High N levels during bloom and early boll filling can also promote vegetative development at the expense of fruit retention under some conditions (Boquet and Breitenbeck (2000); Mullins and Burmester (1990)). High N levels in cotton can delay harvest, can have a negative impact on the costs of defoliation and efficacy in leaf removal, and can increase problems with some late-season pests (silverleaf whitefly, aphids) that can influence lint quality (Cisneros and Godfrey (1998)). Recent increases in energy costs, which constitute a large part of N fertilizer production costs, are also being passed on as increases in N fertilizer cost.

An additional area of concern is the fate of N applied in excess of plant requirements. If crops grown in the rotation sequence don't have deep enough roots to intercept applied and residual nitrogen, its eventual movement through the soil profile can result in nitrate contamination of groundwater. The potential for NO_3 contamination is a health concern for drinking water supplies in many parts of California as well as in other regions, and can also impact other municipal and agricultural uses for groundwater.

Materials and Methods

Experiments were conducted on 5 to 6 grower fields per year in Fresno, Madera, Merced, Kings, Tulare and Kern Counties plus two sites located on the University of CA West Side and Shafter Research and Extension Centers in the San Joaquin Valley. Some field sites were utilized for multiple years (about 1/3 of the field sites over the five-year period), while the remaining sites were newly chosen each season due to grower decisions on crop rotations. Four field replications in a randomized complete block were used at all experiment locations. Four basic nitrogen (N) fertilization treatments were established each year at each site. The application rate was equal to the desired N treatment level in kg N/ha, minus the calculated soil residual N value in kgNO_3-N/ha determined in the upper 2 feet of the soil profile. Residual N levels were calculated using soil samples collected within about one to two weeks after planting, prior to any N fertilizer applications. If the initial amount of soil residual NO_3-N was greater than 50 lbs NO_3-N/ac, the residual value was used as the baseline for the 50 lb N treatment. All other treatments were added in 50 lb increments after deducting the N present in the baseline. Soil PO_4-P and exchangeable-K were also tested on soil samples, and fertilizer applications were made as necessary to make sure that soil phosphorus and potassium levels were non-limiting to yield in this nitrogen experiment. In 1996, four treatments of 50, 100, 150 and 200 kg N/ha were applied in late May (prior to the first post-planting irrigation), and in three supplemental treatments (50, 100 or 150 lb N/ac initially applied), a second N application of 50 lb N/ac was applied in June just prior to the second irrigation. In 1997 through 2000, the experiments were simplified to four basic treatments (50, 100 150 and 200 lb N/ac) due to the lack of crop growth and yield responses to split-application treatments.

In all field plot locations, soil samples were collected to a depth of 2 ft at a time within about a week after planting and analyzed for soil NO_3-N and NH_4-N. In addition, for the purposes of evaluating nitrate movement, soil samples were also collected to a depth of 8 feet two times per year in all plots using a power-driven soil core sampling device with a 1.75 inch diameter tube. The two times were within 3 to 4 weeks after planting, and again within 1 to 3 weeks after harvest. Each of three replicate plots within each treatment at each location was sampled in 1 foot increments to a depth of 4 feet, and then in 2 foot increments to an ending depth of 8 feet, resulting in 6 separate samples per sample hole. The soil samples were kept refrigerated (2 to 4 degrees C) until subsamples were collected for specific analyses. Separate subsamples were collected to evaluate gravimetric soil water content and to provide subsamples to collect 2 N KCl extracts as well as air-dried soil samples. A 2 N KCl extract on the soil samples was used to determine soil NO_3-N and NH_4-N (Carlson (1978)). A separate subsample air dried at 35 to 45 degrees C was prepared from a composite of the three to four sample locations for each depth within each plot, and was subsequently also analyzed for NO_3-N, plus PO_4-P, ammonium acetate exchangeable-K and other nutrient, pH or salinity analyses as each site required (Keeney and Nelson (1982)). Bulk density was determined on 1.75 inch diameter soil core samples collected at 6 inch increments from three field replications per research site using only the post-harvest soil samples.

At all locations, seed cotton was mechanically harvested using commercial-type spindle pickers. Seed cotton yields were weighed in the field and 6 lb sub samples taken for determination of moisture content. Lint and seed yields were calculated and adjusted for moisture content.

Results and Discussion

This report will focus mostly on: (1) basic descriptions of soil nitrate-N (NO_3-N) status at the field plot sites in the immediate post-planting period each year; and (2) crop yield responses to applied plus residual nitrogen (N). The soil NO_3-N levels found in the upper 2 feet of soil profile within a week post-planting covered a wide range of levels each year of the study (Table 1). Although not true in all cases, sites with relatively low residual soil NO_3-N in the upper 2 feet of soil profile generally were in cotton following either cotton, fallow or small grains, while high residual soil NO_3-N more typically were in cotton grown following field corn (for silage or grain), processing tomatoes, or forage alfalfa. It is recognized that there are other forms of soil nitrogen that can also be analyzed (total Kjeldahl N, NH_4-N), and in this study these forms of N were also determined for comparison purposes in a more limited number of field tests. NH_4-N data was also variable across soils, test sites and years, and NH_4-N levels were generally quite low relative to soil NO_3-N.

Soil N as NO_3-N was converted into lbs N/acre-foot of soil volume, and soil bulk density measured, allowing calculation of net changes in soil test N as NO_3-N during the growing season (planting to post-harvest). Examples of individual site data as well as across-site averages are shown in Table 2. There are recognized limits in interpreting this type of data, since values change over time with processes such as mineralization and denitrification. However, these changes in soil NO_3-N over time still represent a general index of soil changes in N status resulting from crop uptake and other processes / losses during the growing season. Data in general has indicated that most net depletion of soil NO_3-N was seen in the upper 4 feet of the soil profile.

As levels of applied N increased at most sites, soil NO_3-N levels in the 4 to 8 foot zone of the soil profile generally increased. Average changes in soil NO_3-N between the Spring (planting time) and Fall (post-harvest) soil sample timings for 1997 can be used as an example of general findings (Table 2). Negative numbers indicate a net "loss" or a reduction in soil NO_3-N content for all the 0 to 4 foot depths in all N application treatments (50, 100, 150 and 200 lbs N/acre treatments. The positive

numbers seen in the 4 to 8 foot zone of the soil profile in the higher applied N treatments potentially indicate there was more NO_3-N moved down into that deeper part of the soil profile during the course of the season. Again, other transformations can also account for part of the observed changes. If the cotton or subsequent crops cannot access this N source, it would be subject to leaching losses if moved further by water moving through the soil profile. Higher beginning soil NO_3-N prevailed in most sites during the 1996 trials, but similar trends were seen in the 1999 and 2000 data (not shown).

Due to soil surface infiltration characteristics, soil water storage capacity and timing of irrigations, half of the sites in this study (Shafter REC, Kern County, Tulare County, West Side REC) had relatively limited potential for significant leaching of NO_3-N into the lower profile. Other sites (data not shown) had soil types which allow significant downward water / solute movement under some crop, weather and management conditions. Careful attention to soil water storage capacity and irrigation timing and amounts could reduce potential downward solute movement beyond the 4 to 8 foot zone in many of these sites.

Irrigation water contributions to the N source available to the crop were monitored at all sites using monthly replicated water sampling and estimates of average water applications per irrigation. In general, most sites had relatively low irrigation water NO_3-N, as mountain snowmelt was a predominant irrigation water supply for many irrigation districts. Most of these sites had consistently less than 20 lbs N/ac as NO_3-N per summer growing season that could be attributed to irrigation water sources, however, there were some sites with higher contributions (up to 32 lbs/ac) from irrigation water N within each year.

A primary goal of this study was to develop some basis for use of soil residual NO_3-N levels as part of the decision process in estimating crop N application needs each year. The pre-plant or immediate post-planting soil samples from the upper 2 feet of soil profile were selected as a minimal amount of soil sampling that would be easily collected and inexpensive enough to be accepted by growers and consultants. In an effort to relate yield response data to general ranges of soil residual nitrogen, data were grouped according to soil NO_3-N levels in the upper 2 feet of soil at or within a short time period after planting. Three levels were chosen and the data partitioned into sites differing in likelihood (probability) of crop responses to increasing levels of applied N. These levels chosen were: (1) less than 65 lbs NO_3-N /acre 2 feet of soil (Fig. 1); (2) between 65 and 110 lbs NO_3-N/acre 2 feet (Fig. 2); and (3) over 110 lbs NO_3-N/acre 2 feet (Fig. 3). Although there are several forms of soil N that could be measured, we chose to group the data using soil NO_3, since it is readily measured, thus analyses of soil NO_3 could be readily available to growers from commercial soil testing laboratories.

Some generalizations can be observed with these groupings based on early-season soil NO_3-N, that are useful in assessing the likelihood of yield responses to applied N. When residual soil NO_3-N was less than 65 lbs NO_3-N/acre in the upper 2 feet of soil at planting, cotton yields increased significantly with increasing N applications in 13 of the 16 sites (Fig. 3) ($P < 0.05$). When planting time soil residual NO_3-N was between 65 and 110 lbs NO_3-N/acre in the 2-feet soil depth, yields were significantly affected by increasing N applications in 7 out of 12 sites (Fig. 4). Only 3 out of 11 sites showed significant yield increases to increasing applied N when residual soil NO_3-N exceeded 110 lbs NO_3-N/acre 2 feet (Fig. 5).

Cotton yield response to N rates was affected by environmental conditions among the years when tests were done. Lint yields in 1996 were moderate across all sites with a range of about 1000 to 1550 lbs lint/acre. In all but one of the field sites in 1996, there were no significant effects of nitrogen treatments on lint yields. (i.e., increasing N applications did not increase yields). Soil residual N in the upper two feet as well as the lower profile were generally higher than in other years of the five-year study. In 1997, there were more locations with significant yield reductions at the lowest two N application rates (50 and 100 lbs N/acre). In 1997, each location showing significant yield responses to increasing applied N had high lint yields (> 1500 lbs lint/acre), and planting-time soil NO_3-N levels in sites with lint yield responses were (not uniformly low. 1998 was a very difficult cotton production year, with poor weather during much of the season resulting in low yield potentials at most sites and in the state. Under reduced yield potential, less nitrogen is required for growth and yield, resulting in the expectation that responses to applied N would be less than in years with moderate to high yields. In 1998, out of 8 field sites, only 2 showed signficant yield responses to increases in applied N, and those yield responses were small. Yields at most sites in 1999 and 2000 were moderate to high in comparison with 1998, resulting in a higher N demand for growth and fruit production. In these final two years of the study, 4 out of 7 sites (1999) and 5 out of 8 sites (2000) showed significant yield responses to increasing applied N. However, only 3 of 7 (1999) and 2 out of 8 (2000) had significant yield responses to N applications in excess of 100 lbs N/acre. The largest yield responses were from low-N plots at sites where spring residual soil NO_3-N (were depleted) was low (< 60 NO_3-N/acre in the upper 2 feet of soil) due to repeated use of the same treatments over several consecutive years.

Growers trying to maximize yields and financial returns during difficult economic times are reluctant to reduce relatively inexpensive fertilizer applications and risk yield losses due to N deficiencies. In attempting to reduce applied N to make better use of residual N reserves in the soil, growers will need to use information concerning cropping history, and measurement of soil N , and possibly in-season measurements of crop N status such as petiole nitrate analysis. Crop N management recommendations must balance agronomic and economic issues. It makes sense to measure soil N status, adjust N application rates, and monitor in-season plant N status. Economically the cost of management time and analytical services may not represent a

saving compared to at-plant application of an addition increment of inorganic N fertilization, especially if the application an excess amount of N fertilizer will avert yield limitation, that might ocurr if there were problems with management.

Plant nitrogen uptake data was collected at selected sites in three out of the five years in this study, and analyses indicated that with current SJV Acala cotton varieties, about 50 to 60 lbs total N are taken up by plants per bale of cotton produced. Some of that total N in plants will be returned as crop residue in root, shoot and leaf tissue, while some will be removed with harvest, primarly as protein in cotton seed. These results are important in light of the lack of yield response noted in current studies across a wide range of applied N. The results of the current study do not indicate that only 50 or 100 lbs of N/acre are needed to produce high cotton yields under San Joaquin Valley conditions, but rather indicate that soil residual N (from various forms) can serve as a major source of N in addition to applied fertilizer N in meeting crop nitrogen requirements.

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Table 1. Average spring (early post-planting) residual nitrate-N in the upper 2 feet of the soil profile by site and year.

	Location							
	Soil nitrate-N in upper 2 feet of soil (lbs nitrate-N /acre)							
Year	**Shafter**	**West Side REC**	**Merced County**	**Madera County**	**Fresno County**	**Tulare County**	**Kings County**	**Kern County**
1996	69	149	145	154	186	127	226	135
1997	56	43	141	76	48	87	109	47
1998	37	55	57	104	78	60	53	59
1999	46	36	110	245	-	63	55	76
2000	64	36	107	145	112	70	76	64

Table 2. Average changes in soil NO_3-N (lbs N as NO_3-N/acre) shown as the post-harvest (Fall) results minus the post-planting (Spring) soil test NO_3-N as a function of nitrogen application treatments and depths. Data shown is for Shafter REC, Kern, Tulare and Kings County locations in 1997. Soil sample data is grouped as soil surface to 4 feet depth versus the 4 to 8 foot depth. Negative number (-) indicates net reduction in soil NO3-N during the period from planting through post-harvest.

Applied N Treat-ment (lbs N/acre)	Depth in the Soil Profile (feet)	Shafter REC (lbs N/ac as NO_3-N)	Kern County (lbs N/ac as NO_3-N)	Tulare County (lbs N/ac as NO_3-N)	Kings County (lbs N/ac as NO_3-N)	Eight location average (includes other county sites) (lbs N/ac as NO_3-N)
50	0-4	-85.4	-78.5	-98.1	-99.8	-87.6
	4-8	-7.3	-1.5	3.8	-2.8	-6.0
100	0-4	-61.3	-59	-66.9	-102.8	-75.4
	4-8	1.6	-7.3	-1.2	-2.7	-5.8
150	0-4	-46.4	-37.4	-69.5	-55.9	-47.3
	4-8	-0.1	-3.7	0.8	21.1	11.1
200	0-4	-38.6	-48.2	-14.4	-28.1	-26.0
	4-8	7.1	5.2	23.3	27.5	15.1

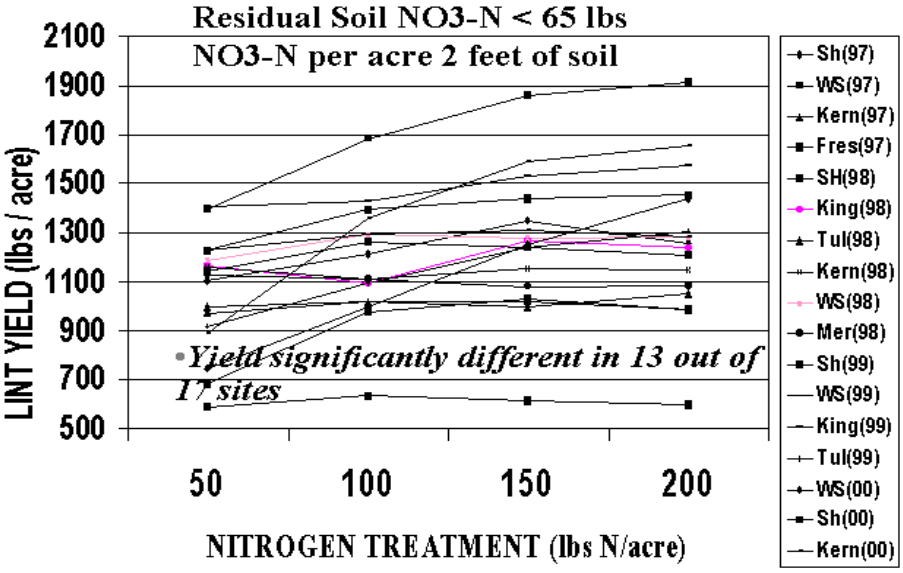

Figure 1. Lint yields as a function of nitrogen treatment for 17 sites where the lowest N treatment had a residual soil NO_3-N level was less than 65 lbs NO_3-N in the upper 2 feet of soil. Locations and years of the data sets included in the plots are shown in the legends (WS=West Side REC, Fresno County; Sh = Shafter REC, Kern County; Fres = Fresno County; Tul = Tulare County; Mer = Merced County; Mad = Madera County; King = Kings County).

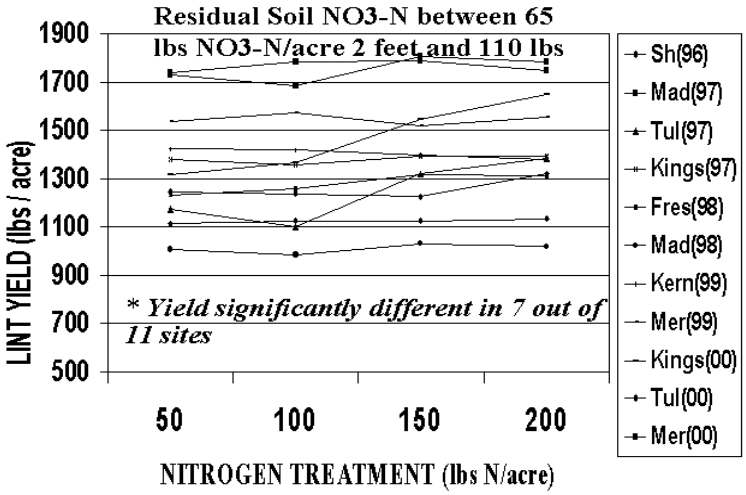

Figure 2. Lint yields as a function of nitrogen treatment for 11 sites where the lowest N treatment had a residual soil NO_3-N level was between 65 and 110 lbs NO_3-N in the upper 2 feet of soil. Locations and years of the data sets included in the plots are shown in the legends (WS=West Side REC, Fresno County; Sh=Shafter REC, Kern County; Fres=Fresno County; Tul=Tulare County; Mer=Merced County; Mad=Madera County; King=Kings County).

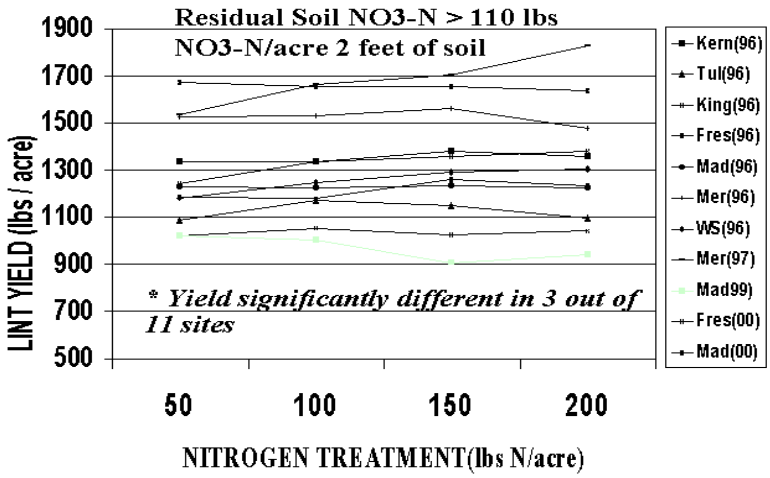

Figure 3. Lint yields as a function of nitrogen treatment for 11 sites where the lowest N treatment had a residual soil NO_3-N level was greater than 110 lbs NO_3-N in the upper 2 feet of soil. Locations and years of the data sets included in the plots are shown in the legends (WS=West Side REC, Fresno County; Sh = Shafter REC, Kern County; Fres = Fresno County; Tul = Tulare County; Mer = Merced County; Mad = Madera County; King=Kings County).