ACALA COTTON RESPONSES TO LIMITING NITROGEN: PLANT AND SOIL N STATUS, GROWTH

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Abstract

Concern for the potential impact of nitrogen (N) fertilization practices on nitrate contamination of groundwater and changes in predominant cotton varieties in California spurred interest in a joint project of the USDA-ARS and University of CA to assess growth, yield and N uptake responses of cotton to a range of nitrogen applications. Plants were grown under subsurface drip irrigation and irrigated daily to avoid water deficits. Phosphorus, potassium as well as nitrogen fertilizers were injected into the water. Nitrogen treatments were 0, 60, 120 or 180 kg N per hectare (ha) combined with pre-plant applications of 0 or approximately 53 to 56 kg N per ha. Soil NO_3-N levels in the upper 1.2 m of the soil profile were in the 10 to 30 mg $N0_3$-N kg^{-1} range in the first and second years of the study. In the third year, soil N levels were significantly lower, and petiole nitrate-N levels in 120 kg and lower N application treatments were in the borderline deficient or deficient range of University of CA recommendations for cotton. Leaf area and height were reduced in all treatments receiving 60 kg N or less (even with pre-plant N). Peak lint yields (between 1600 and 2100 kg lint per ha) occurred in 120 and 180 kg N treatments, with no difference in yields with applications in excess of 120 kg N ha^{-1} and significant differences in treatment yield levels across years. Residual soil N levels have significantly influenced the response to amounts of applied N over the three years. Results indicate that when residual soil N is accounted for, high cotton yields can be achieved with between 120 and 180 kg of applied N per ha.

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1366-1373 (1996)
National Cotton Council, Memphis TN

Introduction

The potential impact of nitrogen (N) fertilization practices on nitrate contamination of groundwater is of increasing interest in areas where both municipalities and farmers share groundwater resources. With improved irrigation practices and better knowledge of the relationships between soil water holding capacity, effective root zones and irrigation uniformity, it is possible to reduce potential for deep percolation and loss of soluble nutrients below the root zone. Reductions in nutrient losses can also be achieved through improvements in our understanding of the actual amount of fertilizer N required to achieve yield goals for specific crops.

A number of studies conducted at the USDA-ARS Water Management Research Laboratory in Fresno, CA (Hutmacher et al, 1993, 1994, 1995) have shown that although high crop yields can be achieved with drip irrigation, maintenance of acceptable nutrient availability is critical in achieving high growth rates and favorable yields. Under furrow irrigation, fertilizers, including nitrogen, are typically broadcast or banded pre-plant, with one or more supplemental side-dress applications made later in the growing season. Soluble nutrients are more susceptible to losses via deep percolation when plant uptake is separated for a long time from the time of application. In subsurface drip irrigation studies of Bar-Yosef et al (1992) and Hutmacher et al (1993), nitrogen and phosphorus fertilizers were injected continuously, in small amounts per unit time period, with the irrigation water. Such high frequency water and nutrient applications can prevent even minor water or nutrient deficits if appropriately scheduled.

Where harvestable yield is highly correlated with total biomass (such as alfalfa) or where fruit production is highly sensitive to water deficits (some vegetables), avoidance of minor water or nutrient deficits can be beneficial in achieving high yields. In cotton, where a balance between vegetative and reproductive growth is critical in producing and retaining bolls, an irrigation and nutrient management program that minimizes chances of any water or nitrogen deficits may achieve high total dry matter production but may not achieve high lint yields or high water use efficiency (Phene et al, 1992; Hutmacher et al, 1993). Nitrogen applications must be timed appropriately and in moderate amounts to meet crop N requirements and avoid excessive vegetative growth or deep percolation losses.

Halevy et al (1987) in Israel, Hutmacher et al (1993, 1994) and Bassett et al (1970) in California and others have identified above ground dry matter N, P and K content per unit lint yield under moderate and high yield conditions. Data of Halevy et al (1987) and Hutmacher et al (1994) indicate higher efficiency and lower requirements of N, P and K per unit lint yield than observed with lower-yielding varieties in other production areas and production conditions (Hodges, 1991). More information is needed regarding crop responses to a range of N applications under high-yielding conditions with more-recently developed varieties to avoid deficient or excess nutrient applications.

This drip irrigation experiment is part of a series of three to five year cooperative projects between USDA-ARS and University of CA with the long-term goal of identifying growth-stage-specific levels of plant and soil nitrogen under specific management practices and their relationships to specific physiological processes, growth and yield limitations. Other projects associated with this drip project will investigate methods to split fertilizer applications under surface irrigation rather than drip irrigation.

Materials and Methods

Cotton (var. "Maxxa") was planted in early to mid-April in 1993, 1994 and 1995. Mepiquat chloride (PIX) was applied uniformly to all plots at a rate of 0.7 to 0.9 L ha^{-1} in mid-July of all years, with the rate used each year dependent on crop status as monitored using plant mapping. The drip laterals were spaced 1.52 m apart in alternate furrows and 40 to 45 cm below the average soil surface. Drip emitters (turbulent-flow, in-line design) were spaced 0.91 m apart along the laterals, and had a nominal flow of 2 L h^{-1} at 120 to 140 kPa operating pressure. The subsurface drip system is being used in this portion of the study to deliver precise amounts of nitrogen fertilizer over time and identify plant responses to different severities and timing of nitrogen deficits. In 1993 and 1994, each plot consisted of 12 rows spaced 0.76 m apart and 9.3 m in length. Due to substantial damage and nutrient leaching caused by a break in an irrigation mainline, the entire experiment was moved to a larger field site in 1995. Row spacing, drip line placement and specifications were the same as prior to 1995, but plot size changed to 10 rows by 28 m in length. All N fertilizer treatments were replicated four times in 1993 and 1994 and six times in 1995.

The subsurface drip irrigation (SDI) system was programmed to replace 100% of the evapotranspiration (ET_c) on a daily basis, with the system operated at a frequency corresponding to every 2 mm of accumulated ET_c. The ET_c was calculated using a crop coefficient developed earlier at the same site in conjunction with the grass reference evapotranspiration (ET_o) determined at the on-site weather station. Plant water status resulting from irrigation treatments was monitored using a crop water stress index (CWSI) approach using an infrared thermometer and hand-held psychrometer, according to the methods of Idso (1982). Measurements of crop water status were made at one to two week intervals throughout the season.

An average of 521 mm (1993), 506 mm (1994) and 489 mm (1995) of drip irrigation water was applied to all treatments during the growing seasons. About 140 mm of water was applied by sprinklers during the period 60 days prior to planting through seedling establishment. Sprinklers were kept on the field and irrigations timed to assure successful seedling establishment, after which time the sprinklers were removed and the drip system was used for all subsequent irrigation.

Nine fertilizer treatments were imposed in this study, including a control with no N added (T1), and combinations of patterns of N application (linear (T8 and T9) versus growth-stage and uptake rate-dependent (T2 through T7) (Table 1). Target amounts of applied N were 60 (T2 and T5), 120 (T3 and T6), 180 (T4, 7, 8, 9) kg N ha^{-1}. Actual N amounts applied are shown in Table 1. All nitrogen applications were an aqueous solution of calcium ammonium nitrate (CAN-17, 17 % N) injected in the irrigation water through the drip systems. Treatments T5 through T9 received supplemental N as a CAN-17 application close to the timing of seedling emergence and after spring soil sampling.

Nitrogen uptake patterns determined in earlier studies at the same field site (Fig. 1) were used to determine the rate of application of nitrogen in treatments designated as "uptake" application pattern (Treatments T2 through T7 in Table 1). If a treatment received 180 kg N ha^{-1} in an uptake pattern, the relationship between heat units and N uptake shown in Fig. 1 was used to define N application amounts during each 7 day period during the growing season. Treatments receiving smaller total applications (60 kg N or 120 kg N) received N applications at 1/3 or 2/3 of the full application treatments during each 7-day period. The approach with treatments T8 and T9 (labelled "linear" application pattern in Table 1) was to apply N at the 180 kg ha^{-1} rate during a very compressed time period, relatively early in crop development in T8 and during flowering and boll development in T9. T8 did not receive the full amount proposed in 1994 due to a late start in injecting the fertilizer.

All treatments other than T8 and T9 commenced N applications on about day 180 of each year and ended on day 226 to 242. N was applied using a venturi-type injector. Potassium thiosulphate was applied once per week (and separate from the phosphoric acid application) to supply potassium fertilizer (205 kg K ha^{-1} to all treatments) needs. Phosphoric acid and calcium ammonium nitrate were used to apply phosphorus and nitrogen, respectively. A total of 63, 73, and 71 kg P ha^{-1} was applied uniformly to all treatments in 1993, 1994 and 1995, respectively.. Nitrogen and phosphorus fertilizer were supplied continuously during the season with all irrigations, while potassium was applied once each week.

Soil samples were collected after seedling emergence and again within 3 weeks after harvest to a depth of 3 m in 22.5 cm increments to a depth of 90 cm and in 30 cm increments to 3m. Chemical analyses of soil samples were done to establish initial and ending soil nutrient and salinity levels in each block of the field. All samples will be analyzed for soil water content, electrical conductivity, pH, NO_3-N, P, K, Total N, and Cl. The orientation for the sampling was under the plant rows, approximately 35 to 40 cm laterally from a drip line and emitter at each sample location.

Petiole samples were collected at 7 to 10 day intervals throughout the season and dried at 50 to 55 degrees C for a minimum of 48 hours prior to grinding and analysis. A minimum of 25 petiole samples were collected per treatment block from separate plants at the uppermost fully-expanded leaf node. Samples were analyzed for NO_3-N, PO_4-P, and K.

Above-ground plant samples were collected three times during the growing season to identify above-ground nutrient uptake based upon the average tissue nutrient concentrations and dry matter sampling of component plant parts. Main stem and sympodial leaves at different positions within the canopy were sampled at intervals through the season and analyzed for gas exchange rates, total-N, chlorophyll levels, and incident photosynthetic photon flux density (PPFD) at different levels within the crop canopy. Plant growth and development were monitored as plant height, node counts, nodes above white bloom, boll counts and position, plant leaf area, and dry matter partitioning.

Leaf abaxial and adaxial resistances and transpiration rates were monitored at 7 day intervals at specific leaf positions using a Li-Cor 1600 series steady-state porometer. Incident photosynthetic photon flux density (PPFD) was monitored for each leaf monitored, and only leaves with PPFD levels in excess of 1200 umoles m^{-2} s^{-1} were used in this analysis. Single leaf photosynthetic rates were determined at 7 day intervals using an ADC infrared gas analyzer and Parkinson leaf chamber in the flow-through mode with a constant flow rate of 0.6 L min^{-1}. The third, fifth or sixth, and eighth or ninth leaf from the uppermost node were monitored in order to determine the relative sensitivity of leaves of different stages of maturity and different ages to the imposed N fertilizer treatments. For the sake of brevity, only results collected from the first fully-expanded recently mature leaf (fifth or sixth leaf from the uppermost node) will be discussed. However, general findings for the fifth or sixth leaf also apply to the other leaf ages.

Plots were machine harvested in late-October or early-November of each year with a modified commercial spindle picker and seedcotton yields were determined on two rows per plot. Yields were corrected for moisture content and gin percentage. Gin turnout was determined at the USDA-ARS Cotton Laboratory in Shafter, CA.

Results and Discussion

The cotton field used in 1993 and 1994 had prior crops of cotton (grown without fertilizer in 1992) following four years of alfalfa (1987 through 1991). Prior crops in the field used in 1995 were four years of cotton, the first three receiving a uniform 177 (1991), 192 (1992) and 187 kg N ha^{-1} (1993) as Calcium Ammonium Nitrate (CAN-17) through the drip system, and no applied N across the entire field in 1994. This information on pre-existing conditions is important in interpreting differences in responses to applied N during the three years of the study.

Calculated crop evapotranspiration (ET_c, including measured soil water depletion) averaged 735 mm (1993) and 706 mm (1994) and ranged from a low of 678 mm in the no nitrogen treatment (1994) to over 770 mm in the high nitrogen treatments (T7 in 1994). Soil water balance data analyses for 1995 were incomplete at the time this report was prepared, so 1995 ET_c values are not reported. Leaf water potential (LWP) and infrared thermometer / CWSI measurements in 1993 and 1994 did not indicate water deficits producing moderate water deficits or any treatment differences in water status (data not shown). LWP values did not fall below -1.8 MPa nor did CWSI values exceed 0.17 in treatments until after the second week in August either year. During late-July through August in 1995, CWSI values in no N (T1) and low N (T2) treatments were significantly higher than other treatments (data not shown). Increases in CWSI in the mid- and late-season in treatments T1 and T2 in 1995 were positively correlated with reductions in leaf conductance but were also in part a reflection of large reductions in leaf area and plant height occurring in no N and low N treatments (growth data shown in Table 2).

Petiole Nutrient Status

The most significant reductions in petiole NO_3-N were consistently observed in the untreated control (no nitrogen treatment, T1) and in the low nitrogen treatment without pre-emergence application (Fig. 2a, 2b). These reductions were relatively small in 1993 or 1994, but with the lower soil NO_3-N levels in 1995, the differences became quite large (Fig. 2c). Petiole NO_3-N levels were significantly higher in treatments T3, T4 than in T1, T2 during most of the season in all three years (Fig. 2b, 2d). Treatments T8 and T9, with N applications made during short periods beginning in early and mid-season, respectively, did not exhibit significantly higher petiole NO_3-N than other high N treatments (T4, T7) until late in the season (data not shown).

In the 1993 and 1994 seasons, petiole NO_3-N levels in all but the no N and low N treatments without pre-emergence application (T1, T2) remained within the University of CA recommended petiole NO_3-N levels during all growth stages. Even T1 and T2 treatments in 1993 and 1994 were close to the lower levels of the range for "sufficient" NO_3-

N. Petiole NO_3-N levels in no and low N treatments in 1995 were below the "sufficient" range from University of CA recommendations for much of the season (Fig. 2c). Application of supplemental N in pre-emergence treatment T5 (60 kg N ha^{-1} plus supplemental N) resulted in significantly higher petiole NO_3-N than with no supplemental N in treatment T2 (data not shown). Supplemental pre-emergence N applications did not consistently increase petiole NO_3-N levels in other treatments.

All PO4-P and K levels were consistently within the University of CA recommended petiole levels for each growth stage. The only significant interaction between petiole PO4-P or K levels and the N treatments was for treatment T4 (high N application), which had significantly lower petiole PO4-P and K levels than other treatments in 1993 and 1994, but not in 1995. No ready explanation was proposed for this finding.

Soil N Status

Soil samples have been taken prior to and after each growing season, but soil total N and NO_3-N analyses for the 1995 project have not been completed at the time of this report. Proper interpretation of this petiole nutrient and yield data will require analysis of soil samples to identify residual soil N that can also be available in meeting crop N requirements.

Spring 1993 soil NO_3-N levels averaged between 17 and 21 mg kg-1 expressed on a dry soil basis in the upper 67 cm of the soil profile, with values declining to less than 6 to 8 mg kg^{-1} at lower depths (data not shown). In the fall of 1993, after one cotton growing season of differential nitrogen treatments, average soil NO_3-N levels in the upper part of the profile had declined to an average of less than 9 mg kg^{-1} in the 0 and 60 kg N ha^{-1} N treatments (T1, T2) versus about 13 mg kg^{-1} in T5 (data not shown). By Spring of 1994, soil NO_3-N levels had increased from Fall 1993 levels along with the breakdown of incorporated plant residue following the 1993 harvest (Fig. 3). At depths below 45 cm, higher soil NO_3-N levels prevailed in 120 kg and 180 kg N ha^{-1} treatments (T3, T4, respectively) (Fig. 3). After harvest in 1994, soil NO_3-N levels had again declined substantially in all treatments, but the highest depletion of soil NO_3-N had occurred in the no and low N treatments (Fig. 3).

The reduction in soil nitrogen as NO_3-N during the Spring to Fall period of 1993 and 1994 in the upper 1.2 m of the soil profile can be used to indicate much of the use of available soil N in the different treatments (Fig. 4). Although it is recognized there are other forms of N and this will be addressed when other soil analyses are complete, the soil at the experiment site is a mineral soil with low soil organic matter, therefore, soil NO_3-N levels are a useful approximation of levels of soil N. Reductions in soil NO_3-N during the season account for as much as 150 kg N ha^{-1} in the no N treatment in 1993, with lower amounts supplied by soil N as N applications increased (Fig. 4). The large amounts of soil N used in the low N treatments explain how high lint yields could be achieved in 1993 and even 1994 in low N application treatments. In addition, removal of seed and lint even at the high yield levels shown in some years of this study physically remove from 100 to 140 kg N ha^{-1} from the field, with some N returned with incorporation of leaf and stem residue.

Data for 1995 soil NO_3-N has not been thoroughly analyzed, however, beginning soil NO_3-N levels in the spring at the different field site were much lower than in 1993 or 1994 (closer to 10 to 12 mg NO_3-N kg^{-1} in the upper 67 cm of the profile), an indication of much lower available residual soil N than in the previous years (data not shown).

Conductance / Net Photosynthesis

In both 1993 and 1994, leaf conductance was not significantly affected by N treatments except in the no N control in 1994 (data not shown). Prior studies done by Radin et al (1985) in Arizona suggest that severe N deficits result in reduced leaf conductance (similar to a water deficit response), but petiole NO_3-N levels in those Arizona studies were significantly lower than in the no N and low N treatments in 1993 and 1994 of the current study. Petiole NO_3-N levels in the T1 and T2 treatments in 1995, however, were much closer to those reported by Radin et al (1985), and during late July and August of the 1995 season, with much lower prevailing petiole NO_3-N levels than in prior years, the no N (T1) and low N (T2) treatments exhibited 16 and 11% lower conductance than the average of all remaining treatments (data not shown). Leaf age was much more a determinant of leaf conductance, with the highest and most variable conductance in the youngest leaves (third node from the top of the plant) and lowest in the older leaves at the eighth or ninth node from the top (data not shown).

Single leaf net photosynthetic rates were much more variable in 1994 than measured in 1993. We believe this to be due to the significantly greater insect and mite problems in 1994, which caused some moderate to severe foliar damage in some field replications. Although the variability in measurements and late planting date complicate the data interpretation, photosynthetic rates were significantly reduced in the no N (treatment T1) and low N (T2) treatments starting in August in T1 and late August in treatment T2, particularly in the youngest and oldest leaves monitored. There were no significant differences between leaf photosynthetic rates between the plants in the moderate (120 kg N ha^{-1}) treatment (T3) and the high N (180 kg N ha^{-1}) treatments.

If reductions in photosynthetic capacity occur relatively late in the season (when bolls are relatively mature and carbohydrate demands are low), the affects on lint yield would be expected to be minimal. If, however, the reductions in photosynthetic capacity occur with a late boll set, reduced photosynthetic capacity should be more important in being a partial cause of reduced yields. Reduced N applications in the moderate N treatments (120 kg N per ha, with or without pre-emergence supplemental N) did not reduce plant N levels sufficiently to influence net photosynthesis (data not shown).

Photosynthetic rate reductions were not correlated with reductions in leaf conductance other than in T1 and T2 treatements in 1995, but rather were due to nonstomatal limitations, resulting in significantly lower net photosynthesis per unit leaf conductance in the no N treatment (data not shown) and low N treatments. This reduction was particularly accentuated during the period of rapid boll development.

Growth and Yields

Plants in the treatment not receiving any nitrogen were significantly shorter than all other treatments by early-July, while the low N treatments (treatments T2 and T5) were significantly shorter by later in July (data not shown). By the period after vegetative cutout, reductions in overall growth were evident, particularly in treatments T1 and T2 in 1994 and 1995 (Table 2). Individual leaf expansion rates and the number of main stem nodes and the extension of sympodial branches were only significantly reduced in treatments T1 and T2 in 1994 and 1995 (data not shown). Nodes above white bloom (as an indicator of plant maturity and vegetative cutout) indicated a significantly more rapid progression toward cutout only in treatment T1.

These reductions in growth parameters in treatments T1 and T2 averaged in excess of 30 percent in 1995 while they were generally less than 15 percent in earlier years. Within any level of within-season N application, there were no significant differences in growth responses to pre-emergence N applications in 1993 and 1994. In 1995, late-season total dry matter was significantly higher in T5 (receiving pre-emergence N) than in T2 (Table 2).

Lint yields were quite high in most treatments in 1993 and 1995 (Fig. 5). Treatment T1 (no N) had a significantly lower yield than all treatments. A general trend existed toward lower yields at N applications of 60 kg N ha^{-1} and below, and no change in yields at N applications above the 120 kg N ha^{-1} treatments. Addition of supplemental N at pre-emergence did not significantly increase yields except in treatment T5 (60 kg N ha^{-1} plus supplement) when compared with T2 (Fig. 5). In 1993 and 1995, the treatment receiving the 180 kg N ha^{-1} rate in the mid-season (linear application pattern, treatment T9) had significantly lower yield than other treatments receiving the same total N (T7, T8). Application of the high N amount in the early season in treatment T8, however, did not result in lower lint yields than in treatments where the "uptake" pattern of N application was used (Fig. 5).

The relatively high lint yields obtained in 1993 and 1994 even with 0 or 60 kg ha^{-1} of applied N were not repeated in 1995, when much lower soil NO_3-N levels were available for plant uptake (Fig. 5). When lint yield is plotted against the sum of applied N plus the amount of soil NO_3-N depletion during the Spring versus Fall soil sampling, it is evident that although 0 and 60 kg N ha^{-1} treatments were included in this study, residual soil N supplied a substantial amount of nitrogen to promote plant growth in 1993 and 1994 (Fig. 6). Even in 0 and 60 kg ha^{-1} applied N treatments, in excess of 100 kg N ha^{-1} could have been available from the upper soil profile in any year. The importance of residual soil N in supplying crop N requirements and potential impact on NO_3-N leaching losses will be evaluated in future efforts in this study.

Acknowledgements

We are grateful for the continued financial assistance to this project provided by Cotton Incorporated and the California Department of Food and Agriculture. We gratefully acknowledge the assistance of staff field associates J. Jimenez, J. Covarrubias, A. Nevarez and other staff of the USDA-ARS Water Management Research Laboratory in Fresno, CA for all their efforts and assistance in installation, operation and analysis in this project. The assistance of the staff of the University of CA West Side Research and Extension Center and Mark Keeley and other staff of the University of CA Cooperative Extension in Shafter, CA and the USDA-ARS Cotton Research Station in Shafter in operating and installing the project is sincerely appreciated.

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Table 1. Treatment designations, pre-plant nitrogen applications, and total nitrogen applications made through the drip irrigation system during the growing season in 1993, 1994 and 1995 drip irrigation-nitrogen study at the University of CA West Side Research and Extension Center near Five Points, CA.

Nitrogen treatment number	Pre-emergence nitrogen applied (kg N ha^{-1})			Post-emergence total nitrogen applied via drip system (kg N ha^{-1})			Patternof within-season nitrogen applic.
	1993	1994	1995	1993	1994	1995	
T1	0	0	0	0	0	0	none
T2	0	0	0	60	67	60	uptake
T3	0	0	0	120	134	120	uptake
T4	0	0	0	180	192	180	uptake
T5	56	53	57	60	67	60	uptake
T6	56	53	57	120	134	120	uptake
T7	56	53	57	180	192	180	uptake
T8	56	53	57	180	118	180	linear (nodes5-11)
T9	56	53	57	180	192	180	linear (nodes 11-17)

Table 2. Mean plant height, total above-ground dry matter and leaf area index during late-August or the first week of September (depending on the year) as a function of year and nitrogen treatment in cotton nitrogen study at the University of CA West Side Research and Extension Center near Five Points, CA.

Year	Nitrogen treatment	Plant height (cm)	Total above-ground dry wt. (Mg ha^{-1})	Leaf area index (m^{2}m^{-2})
1993	T1	102	14.7	4.5
	T2	104	15.3	4.8
	T3	114	17.0	5.4
	T4	120	17.8	5.8
	T5	116	15.1	4.7
	T6	118	18.1	5.5
1994	T1	101	10.6	3.6
	T2	110	11.8	3.9
	T3	116	13.1	4.5
	T4	123	13.5	4.9
	T5	117	12.7	4.3
	T6	119	13.9	4.6
1995	T1	64	7.8	1.5
	T2	94	10.1	2.6
	T3	106	14.0	4.1
	T4	118	15.1	4.9
	T5	105	13.2	3.7
	T6	114	14.4	4.5

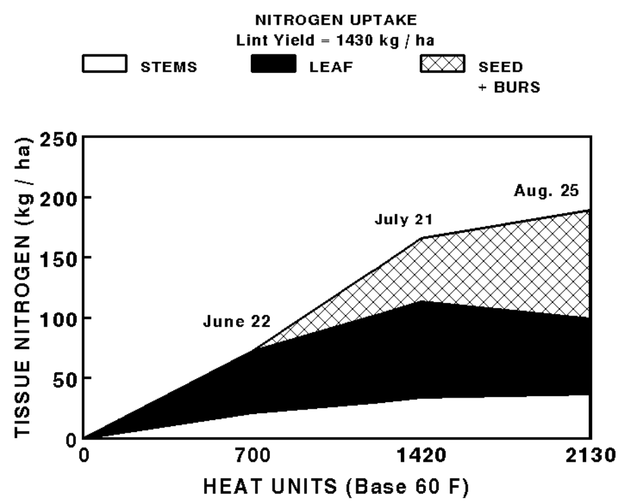


Figure 1. Nitrogen uptake and partitioning in a 1430 kg per ha lint yield cotton crop at the West Side Research and Extension Center as a function of heat unit accumulation and time of year.

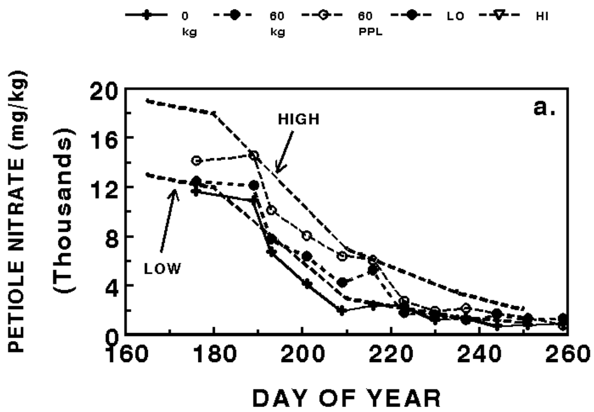


Figure 2. Petiole nitrate-N from uppermost fully-expanded leaves in: (a) 0 kg (treatment T1) and 60 (T2) kg N per ha treatments in 1994.

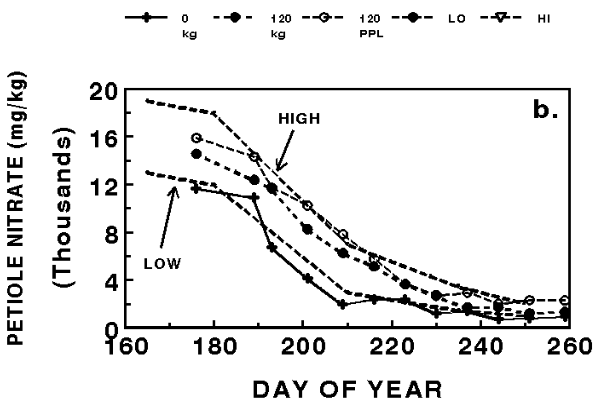


Figure 2. (b) 120 kg (T3) and 120 kg N plus pre-emergence N (T6) treatments in 1994.

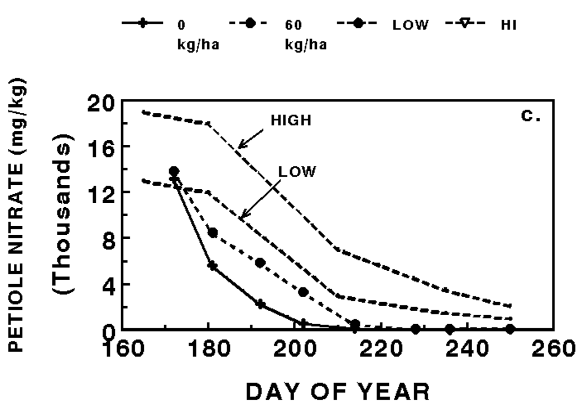


Figure 2. (C) 0 kg (T1) and 60 (T2) kg N per ha treatments in 1995.

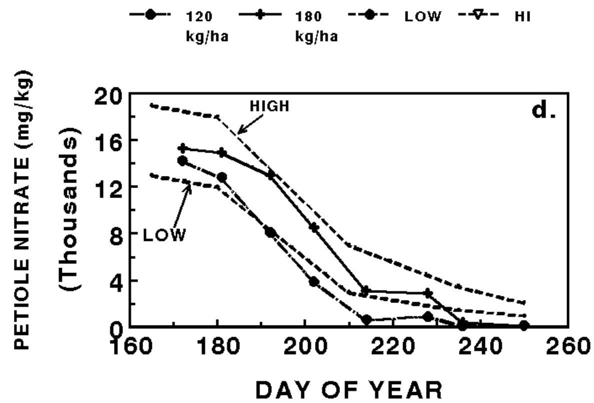
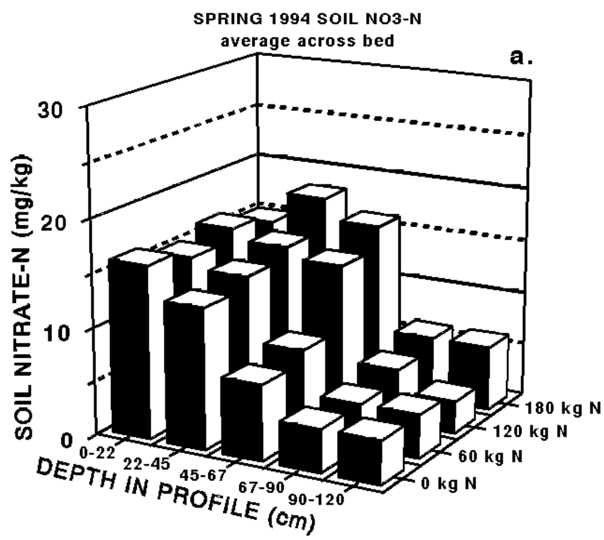


Figure 2. (d) 120 kg (T3) and 180 kg (T4) N per ha treatments in 1995. Dashed lines without markers represent the upper and lower limits for "sufficient" petiole nitrate-N according to the University of California.



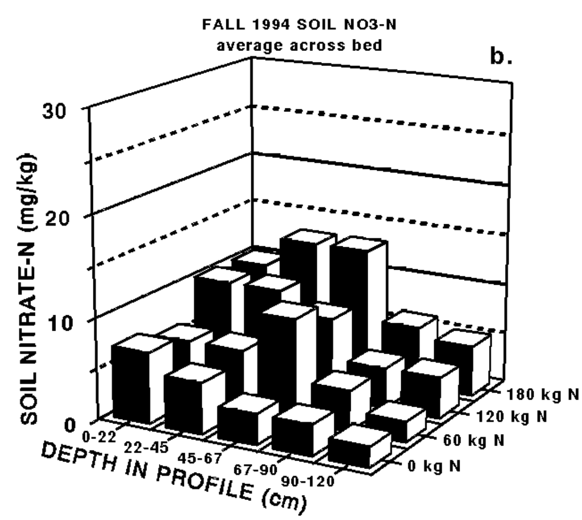


Figure 3. Soil nitrate-N in 0, 60, 120, and 180 kg N per ha treatments (T1, T2, T3 and T4, respectively) as a function of depth in the soil profile during (a) pre-emergence (Spring) soil sampling in 1994 and (b) post-harvest (Fall) soil sampling in 1994.

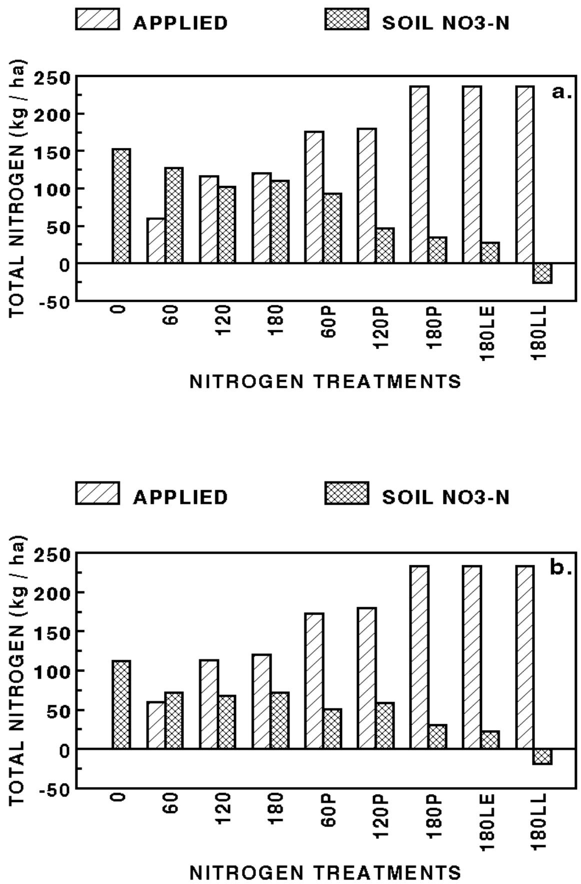


Figure 4. Total applied N (labelled as “Applied”) and the difference between pre-emergence and post-harvest soil NO_3-N (labelled as “Soil NO_3-N”) in the upper 1.2 m of the soil profile as a function of nitrogen treatments in (a) 1993 and (b) 1994. N treatments shown correspond (in sequential order) with T1 through T9, respectively.

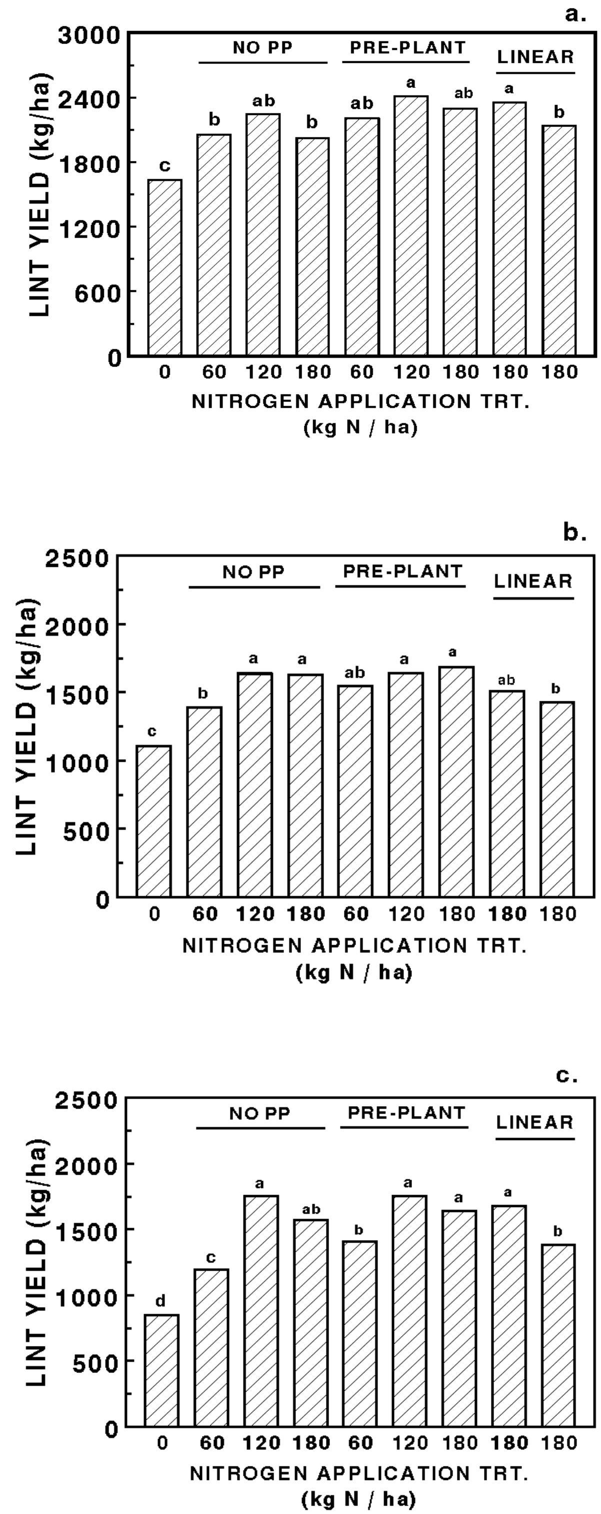


Figure 5. Mean cotton lint yields as a function of nitrogen treatments in (a) 1993; (b) 1994; and (c) 1995. Lint yields for 1993 and 1994 are based on actual gin turnout percentages determined from treatment-specific samples; yields in 1995 were determined assuming a gin turnout of 35%, since sample results were not available when report prepared. Letters at the top of bars indicate mean separation; treatments with different letter designations had significantly different means at the 5% level.

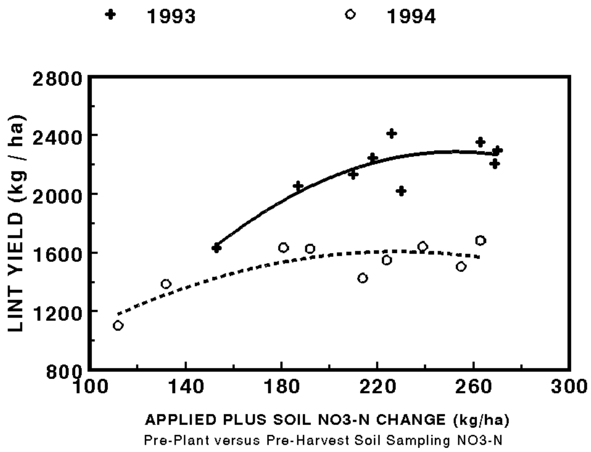


Figure 6. Lint yield in 1993 and 1994 as a function of total nitrogen (defined here as applied N from fertilizer plus change in soil NO_3-N in the upper 1.2 m of the soil profile). Curve fits shown are 2nd-order polynomials.