SUMMARY REPORT
California Department of Food and Agriculture
Fertilizer Research and Education Program

PROJECT: **RESIDUAL SOIL NITROGEN AND NITROGEN MANAGEMENT FOR ACALA COTTON**

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Introduction.
The drive for greater efficiency in fertilization practices in cotton requires improved evaluations of. (a) soil fertility level on a field-by-field basis; (b) a means to evaluate and deal with field-by- field variation in crop growth and nutrient status conditions (some measure of plant N status, plant vigor and fruit retention that is adjusted for stage of growth); and (c) an understanding of the required timing for split fertilizer applications in meeting critical plant needs.In this type of system, adjustments in nutrient applications are made depending on levels of residual soil N, irrigation water N, and crop condition, which has been referred to as a "feedback" approach to fertilizer N management. This is in contrast to a "scheduled" approach where fertilizer N is applied more on a routine basis determined by stage of growth or month. The "feedback" approach" should have improved potential to reduce losses, improve nutrient use efficiencies, and provide more specific guidelines for use in making N management decisions.

Objectives.
A field-based research and demonstration project was initiated to provide further evaluation of the concepts developed in recent University of CA nitrogen management studies in cotton and to begin evaluations of several methods to estimate mineralizable soil N. Goals are to demonstrate an integrated N management system based upon soil and plant N status measurements, incorporating: (1) estimates of crop growth and yield potential; (2) lower initial N applications to reduce potential for leaching losses; and (3) use of split soil N applications and/or foliar applications to supplement supplies when plant sampling indicates high enough yield potential to warrant additional N supply.

Project Description and Approach Used.

Fields were planted with Acala cotton *(Gossypium hirsutum L.)* varieties at four locations each year for the studies, but only 3 locations were followed to completion in 2002. Sites represent a range of initial soil residual nitrogen levels and soil types, and were located in the central and southern San Joaquin Valley at UC Research Centers at Shafter and Five Points, plus grower fields in Kern, Tulare and Fresno Counties. The following nitrogen application treatments were utilized:

(1) Trt. #1 :one-time (early vegetative growth) baseline application of fertilizer N (between 110-115 lbs applied N/acre application, minus an amount adjusted based upon residual soil nitrate-N in the upper 2 feet of the soil profile;
(2) Trt #2: one-time treatment receiving a full 175-180 lb N/acre application, minus an amount adjusted based upon residual soil nitrate-N in upper 2 feet of the soil profile;
(3) Trt #3: initial 100 to 125 lbs N/acre application at the timing of first within-season irrigation of the growing season (adjusted to account for residual soil nitrate-N in the upper 2 feet), plus one subsequent N application (by water run or side-dress) made between 1 '/2 and 3 weeks after first bloom.
(4) Trt #4: as in Trt #3, but with the Trt #2 initial application rate (supplemental N added over and above initial application level in Treatment #2).

The first fertilizer application was typically made during the period from early May through early June, depending on planting date, crop development stage and limiting weather conditions that restricted tractor and implement traffic, and was followed by the first within-season irrigation within I to 4 days. Fertilizer N rates were at rates as just described, with correction for measured soil residual nitrate-N in the upper 2 feet of the soil profile. Actual total N fertilizer application amounts determined using these adjustments for residual soil nitrate-N were as shown in Table 1 Fertilizer applications were either as liquid urea dripped through tubes behind a shank pulled to a depth of 8 to 10 inches, or as a granular dry urea applied with a shank pulled to depths ranging from 4 to 8 inches at some sites.

Table 1. Residual soil nitrate-N in the upper two feet of the soil profile as a function of year and site, and resulting actual nitrogen fertilizer application amounts (in lbs total N per acre) as a function of treatment.

YEAR/ Treatment	SITE OF TRIAL			
2001	**Site A (Kern)**	**Site B (Shafter)**	**Site C (Fresno)**	**Site D (WSREC)**
Residual nitrate-N upper two feet soil	69	41	113	58
T1 115 lb N/ac)	46	74	7	57
T2 (175 lb N/ac)	106	134	67	117
T3 (115 plus **supplemental**	101	129	62	112
T4 (175 lb plus **supplemental**	161	189	122	172
T5 no N fertilizer	0	0	0	0
2002	**Site A (Fresno)**	**Site B (Shafter)**	**Site C** (WSREC)	
Residual nitrate-N upper two feet soil	44	92	60	
T1 (115 lb N/ac)	71	23	55	
T2 (175 lb N/ac)	131	83	115	
T3 (115 plus **supplemental**	131	83	115	
T4 (175 lb plus **supplemental**	191	143	175	
T5 no N fertilizer	0	0	0	
2003	**Site A** (**Kern**)	**Site B (Shafter)**	**Site** C (WSREC)	**Site D (Tulare)**
Residual nitrate-N upper two feet soil	41	58	45	69
T1 (115 lb N/ac)	74	57	70	46
T2 (175 lb N/ac)	134	117	130	106
T3 (115 plus **supplemental**	134	117	130	106
T4 (175 lb plus **supplemental**	194	177	190	166
T5 no N fertilizer	0	0	0	0

The second, supplemental fertilizer applications in Treatments number 3 and 4 were made as either a water run application with the second irrigation, or as a dry sidedress material application (depending upon location and plant size), with applications made during within the period of about 10 to 21 days after the first bloom growth stage (first bloom on a minimum of 25 percent of plants evaluated). In all cases, the second fertilizer application in these treatments was followed within 1 to 3 days with an irrigation.

In addition, experiment sites had treatments included in which no supplemental N was added (Trt 5), in order to allow for yield and petiole nitrate-N analyses where only residual soil N supplies could be utilized. In many cases, zero N plot sizes were smaller, with fewer reps in some locations (noted in yield table) in order to reduce yield loss potential in these experiments.

Sites selected differ in soil texture (Table 2) and in estimated effective rooting depth, but were generally selected to represent the difficult management range of "low" to "intermediate" in soil residual N in the upper 2 feet versus 4 feet of profile, where the ability of soil nitrate tests to accurately predict plant-available N carries more risk to potential yields. Pre-season soil samples to a depth of four feet were collected for analysis of residual soil N03--N levels, P04-P, exchangeable-K, and Zn. In all fields utilized in this study, soil P04-P, exchangeable-K, and Zn were found to be at levels not considered limiting for cotton in the San Joaquin Valley (Reisenauer et al, 1978).

Table 2. Soil textural classification of sites used in field studies in 2001, 2002 and 2003.

Kern 2001	Shafter REC 2001, 2002, 2003	Fresno 2001	West Side REC 2001, 2002, 2003	Kern 2003	Tulare 2003
Silty clay loam	Sandy loam	Clay loam	Clay loam	Fine sandy loam	Silty clay loam

Soil samples were collected at all sites within two weeks after planting to a depth of four feet for initial NO3- N tests to allow for the comparison of residual nitrate-N in the upper 2 feet, upper 3 feet and upper 4 feet of the profile. The reason for this was that two foot sampling depths are commonplace among advisors and agronomists, while recommendations for pre-season or early-season soil sampling to 3 or 4 feet depths would require some convincing evidence that it significantly improves estimates. In addition, in both the spring (early post-plant) and again near harvest in the fall, soil samples were collected to a depth of 8 feet in one- foot increments and analyzed for soil N03-N, Cl-, exchangeable K and PO4-P. Irrigation water samples were taken and analyzed for N03-N, and the timing and amounts of applied water estimated to allow calculation of irrigation water contributions to applied N. Estimates of contributions to field nitrogen inputs from irrigation water are shown in Table 3, with the values expressed as a range to indicate that estimates of applied water were estimated, not measured. Water nitrate-N was measured using an ion selective electrode (Keeney and Nelson, 1982).

Table 3. Estimates of ranges of nitrogen applied with irrigation water (estimates made from range of applied water estimate and measured irrigation water nitrate-N).

Estimated range of nitrogen (as lbs nitrate-N/acre) applied to fields with irrigation water *At each geld site and ear*					
Field site and year					
Kern 2001	Shafter REC 2001, 2002, 2003	Fresno 2001	West Side REC 2001, 2002, 2003	Kern 2003	Tulare 2003
19 to 23	11 to 13	16 to 18	7 to 9	10 to 12	23 to 26

Soil Mineralizable Nitrogen Evaluations.

One of the primary problems with soil N tests is the general uncertainty many agronomists, soil scientists and consultants express in assessing the accuracy and adequacy of soil nitrate tests to explain the likely dynamics of plant-available N. Since NO3-N is just part of the soil N pool, and ammonium-N tests are highly variable and of limited value in many of our western soils, there remains interest in other tests that might be better-correlated with plant-available N. One primary mineralizable N analysis method (the "hot KCl method" - see reference below) was evaluated as part of this experiment on a limited number of soil samples from the first two feet of the soil profile, strictly for comparison with the amounts of residual nitrate-N determined with our current sampling methods on field- collected soil. Gianello and Bremner (1982) developed a "hot KCl" method to assess potentially available organic N in the soil. The procedure involves air-dried soil samples that are heated with 2N KCl to I OOC for a 4-hour period, followed by cooling and determination of ammonium-N. An alternative method developed by Franzluebbers et al (1996) was evaluated on a more limited number of samples for comparison, with potential N mineralization estimates made using a 24-hour incubation of soil samples placed in airtight tubes and a 24-hour incubation done at 25 C. After this period, the amount of CO2 evolved is determined by titration.

Results and Discussion: Field Nitrogen Management Studies - 2001, 2002, 2003

In the field test sites, residual soil nitrate-N analyses done on soil samples collected within 3 to 6 weeks following planting yielded (Table 1) average quantities in the surface two, third and fourth foot depths of the soil profile (0-60 cm, 60-90 cm, 90-120 cm, respectively).

90-Based upon our prior five-year nitrogen fertilizer rate study (Hutmacher et al, 2004 (1996-2000)), recommendations for nitrogen fertilization for this study (based upon spring soil nitrate data in the upper two feet of the soil profile) would be:

- if soil residual nitrate-N in the upper two feet showed less than 55 lbs N as NO3-N/acre, then fertilizer application would be recommended at a rate of 125-175 lbs N/acre unless low yields were predicted due to late planting or field history
- if between 55 and 100 lbs N as NO3-N/acre, then reduce fertilizer application recommendation to 100 to 125 lbs N/acre, and use plant mapping and petiole nitrate analyses to assess yield, plant N status
- if over 100 lbs N as NO3-N/acre in the upper two feet of soil profile, lower fertilizer recommendation to 75 lbs N/acre or less, use plant mapping and petiole nitrate analyses to assess likelihood of response to supplemental nitrogen applications

Soil Residual N. The data shown in Table 4 indicate the dilemma in use of soil test data for the upper two feet of soil profile. For the four sites shown in 2001, the percent of total soil nitrate-N in the upper four feet accounted for if sampling was restricted to the top two feet ranged from about 40 to slightly over 60 percent. For the 2002 sampling year, the percent in the upper four feet accounted for if sampling was restricted to the top two feet ranged from about 45 percent to over 70 percent, depending upon location. In 2003, the percent of total soil nitrate-N in the upper four feet accounted for if sampling was restricted to the top two feet ranged from 44 percent to 65 percent, averaging 53 percent of the total nitrate-N accounted for in the upper four feet of the soil profile.

If a crop (such as cotton) is expected to have roots active in water and nutrient uptake below two feet, there is an advantage in collecting deeper soil samples in order to attempt to account for deeper, potentially available N. An additional advantage to early post-plant information on deeper (to three or four feet) soil nitrate-N would be that it provides some incentive to avoid application of large amounts of early-season irrigation that could leach soil nutrients. Based upon these results, it would significantly improve nutrient management information to collect soil samples to a depth of three or four feet, instead of only two feet.

Table 4. Site average soil nitrate-N in upper 60, 90 or 120 inches of soil at planting as function of location.

Depth of soil **sampled (inches)**	***2001 Field Study Sites*** Average Soil Nitrate-N (**lbs N/acre as** N03-N on soil **d wt basis)**							
	Site A (Kern)		Site B (**Shafter**)		Site C (Fresno)		**Site** D (WSREC)	
	Avg.	S.E.	Avg.	S.E.	Avg.	S.E.	Avg.	S.E.
0-60	69	7	41	3	113	17	58	9
60-90	15	4	20	2	15	5	14	3
90-120	32	10	25	4	48	11	25	6
	2002 Field Study Sites							
	Site A (Fresno)		**Site B** (**Shafter**)		Site C (WSREC)			
0-60	44	10	92	16	60	13		
60-90	16	3	24	2	17	4		
90-120	19	4	8	3	9	3		
	2003 Field Study Sites							
	Site A (**Kern)**		**Site B** (Shafter)		Site C (WSREC)		**Site** D (Tulare)	
0-60	41	8	58	10	45	6	69	13
60-90	30	10	19	4	31	7	27	5
90-120	12	3	12	2	26	6	36	7

Avg. = average; S.E. = standard error across samples

It is important to note, however, that since soil nitrate losses can occur and since there are other potential sources of N represented in the soil N pool, identification of potential soil nitrate-N reserves will still not fully represent plant-available N for making fertilization decisions. This is where estimates of crop yield potential (from plant mapping) and plant nutrient status (from petiole nitrate analyses) can play an important role. Based on prior plant N uptake studies (Hutmacher et al, 2004), assumptions in this study were that each additional bale of lint yield per acre would require an additional supply of 55 lbs N/acre from some source such as supplemental fertilizer. Therefore, if total N supply in the upper 4 feet of soil equaled about 165 lbs, this would be assumed adequate for a 3 bale/ acre yield. If plant map data suggested a 4 bale/acre yield was possible, an additional 55 pounds of N/acre would need to be supplied from some source.

Petiole Nitrate-N Analyses. Petiole data and yield potential estimates can be used to assess need for supplemental fertilizer applications, and growers could use data to make decisions on potential for favorable responses to side-dress fertilizer applications, or more likely, supplemental moderate water-run nitrogen applications. Tables 5 through 7 show some petiole nitrate-N data for the late supplemental N treatment (Treatment #3) to illustrate both growth stage and site differences in prevailing petiole nitrate-N levels.

Table 2. Petiole nitrate-N as a function of growth stage in 2001 sites for treatment 3 (late supplemental N

Date of petiole sampling (by growth stage)	*2001 Field Study Sites*							
	Petiole Nitrate-N (mg/kg x1000 as N03-N on dry wt basis)							
	* data from treatment # 3 only (low initial N / supple e tal N treatment)							
	Site A (Kern)		Site B (Shafter)		Site C (Fresno C)		Site D (WSREC)	
	mg/kg x 1000		Mg/**kg** x 1000		Mg/**kg** x 1000		Mg/**kg** x 1000	
	Low	High	Low	High	Low	High	Low	High
Early bloom (first bloom +/- 5 days)	14.7	18.9	13.3	15.2	13.0	18.4	12.2	14.1
15-20 days after first bloom	7.7	12.9	9.1	11.5	7.3	11.6	7.7	10.5
28 to 35 days after first bloom	6.3	8.8	4.5	6.9	5.7	9.3	6.0	7.4

Data shown shows the range of values for averages within reps of the treatment; low = low average; high = high rep average

Table 6. Petiole nitrate-N as a function of growth stage in 2002 sites for treatment 3 (late supplemental N)

Date of petiole sampling (by growth stage)	2002 Field Study Sites Petiole Nitrate-N (mg/kg x1000 as N03-N on dry wt basis) * data from treatment # 3 only (lower initial N / supplemental N treatment)							
	Site A (Fresno)		Site B (Shafter)		Site C (WSREC)			
	Mg/kg x 1000		Mg/kg x 1000		Mg/kg x 1000			
	Low	High	Low	High	Low	High		
Early bloom (1st bloom +/-5 days)	14.0	15.8	15.0	16.7	16.9	18.6		
15-20 days after first bloom	9.1	10.9	10.4	13.6	8.8	12.3		
28 to 35 days after first bloom	5.3	7.2	5.3	7.0	6.1	8.6		

I Data shows range of values for averages within reps of treatment; low = low average; high = high rep

Table 7 Petiole nitrate-N as a function of growth stage in 2003 sites for treatment 3 (late supplemental N).

Date of petiole sampling (by growth stage)	2003 Field Study Sites Petiole Nitrate-N (mg/kg x1000 as N03-N on dry wt basis) * data from treatment # 3 only (lower initial N / supplemental N treatment)							
	Site A (Kern)		Site B (Shafter)		Site C (WSREC)		Site D (Tulare)	
	Mg/kg x 1000		Mg/kg x 1000		Mg/kg x 1000		Mg/kg x 1000	
	Low	High	Low	High	Low	High	Low	High
Early bloom (1st bloom+/-5 days)	13.1	16.5	12.7	15.0	13.4	13.9	12.0	15.6.
15-20 days after first bloom	10.2	11.6	9.3	12.1	9.6	10.8	9.1	10.4
28 to 35 days after first bloom	6.6	8.9	6.8	10.4	8.7	9.4	5.8	7.3

Data shows range of values for averages within reps of treatment; low = low average; high = high rep

The ranges found across different field replications as shown in tables 5 through 7 demonstrate a consideration when dealing with utility of petiole nitrate data for decision-making in nutrient management. The averages shown as "low" represent the treatment # 3 average for the field replication with the lowest average, while the "high" value is the treatment # 3 average for the field replication with the highest average. Depending upon the approach growers want to use, petiole sampling either needs to be used to (1) provide a good assessment of field average and the likelihood of the field in general to be deficient in N to levels that could impact yields, or (2) "target" the deficient areas of the field for limited area supplemental N applications. When efforts are made to sample multiple areas of the field separately for petiole nitrate-N, growers and consultants should at least look at the replication variability rather than just determining a field average. That extra information could be helpful in assessing the extent of deficient areas in the field and any additional factors (plant size, soil differences, poor fruit set areas) that could impact responses.

Figures 1 through 6 illustrate some of the range of petiole nitrate-N data observed at field sites in 2001 and 2003. At the Kern-2001 site (Fig. 1), treatments #1 and #3 were borderline N deficient during early bloom (FP I through about FP5), but there was no significant yield response, most likely since yield potentials were moderate and soil nitrate-N levels in the top 4 feet were moderately high. At the Shafter REC-2001 site (Fig. 2), even though soil N levels were low, but yield potentials were also low, and petiole nitrate-N levels did not approach deficient in treatment # I until later in flowering. With high yield potentials and moderate soil nitrate-N at the West Side REC -2001 site, the borderline deficient petiole nitrate-N levels in treatment #1 was a good indicator of the significant yield response seen with supplemental N applications in treatment #3.

At the Kern-2003 and Tulare-2003 sites, petiole nitrate-n levels were borderline deficient, and were useful as indicators that there might be a positive yield response to supplemental N applications in treatment# 3 (which did occur).

Table 8 shows a summary of the yield and petiole data sorted into categories of deficient, adequate or excess in comparing whether or not treatment #1 (the 115 lb N/ac treatment) showed deficient petiole nitrate-N levels during bloom and whether or not there was a yield response to the supplemental fertilizer added in treatment #3 (115 lbs initial treatment plus 60 lbs supplemental N/ac). The table also shows the same comparison for treatment # 2 (initial 175 lbs N/ac treatment) versus treatment #4 (which received supplemental secondary N application). The table 8 summary shows that many of the test sites had borderline deficient treatment#1 petiole nitrate-N levels, and in most of those sites, there was a positive yield response. In contrast, higher initial N applications of treatment #2 produced petiole nitrate-N levels that were "adequate", and few sites showed a yield response to supplemental N when comparing treatment # 4 to treatment # 2. Under moderate to higher yield levels typical of a lot of cotton production and under conditions of low to moderate soil nitrate-N, petiole nitrate measurements were useful as relative indicators of likely yield responses to supplemental N, particularly when reduced initial N applications were made.

Table 8. Yield and petiole data sorted by year/site, sorted according to the range in which petiole nitrate data for treatment 1 fell in the categories of "deficient", "adequate" or "excess" as determined by prior petiole nitrate-N studies by Bassett and Mackenzie (1978). The three columns on left / center of table show differences in yield (lbs lint/acre) between treatments # 3 and # 1, while right most three columns show yield differences between treatments # 4 and # 2.

YEAR	SITE	**Yield Response to Supplemental N applications** *(yield response (increased L+) or decreased (-)) with additional N supplied in Trt # 3 compared with Trt. #1; yield response to additional N in Trt. # 4 com ared with Trt. # 2)*					
		Treatment 3 compared to Treatment 1 --- **Petiole Nitrate-N Status of Trt # 1 From First to Peak Bloom**			**Treatment 4 compared to Treatment 2** --- **Petiole Nitrate-N Status of TO # 2 From First to Peak Bloom**		
		Deficient or Borderline	Adequate	Excess	Deficient or Borderline	Adequate	Excess
2001	A	+ 98 NS *				+ 66 NS	
	B		-64 NS			-82	
	C		+299				-185
	D	+89				-48	
2002	A	+ 44 NS				+ 23 NS	
	B	+752				-35NS	
	C	+315				-IONS	
2003	A	+333				+ 56 NS	
	B	+ 42 NS				- 38 NS	
	C		-101			- 49 NS	
	D	+152					- 85 NS

* numbers shown represent a statistically significant yield difference between treatments 3 and 1 (left group of columns or between treatments 4 and 2 (right group of columns) unless marked with "NS" which = non-significant difference

Plant Map Data and Estimating Yield Potential . Cotton is a plant with a relatively indeterminate growth habit under production conditions in California, with a relatively long vegetative development phase, an active flowering period that can be as little as about 4 weeks to over 6 weeks in duration, and a long boll maturation period prior to harvest. Plant mapping tools have been developed and widely described for cotton for use in managing plant growth and utilizing plant growth regulators and harvest aids, and for making decisions on the need for insect control and assessments of relative plant damage to yield resulting from ongoing insect damage. As stated previously in discussion of past research on timing of supplemental N fertilizer applications (Weir et al, 1996), a critical period for avoiding nitrogen deficiencies is usually thought to occur during the first to peak bloom period (the first 3 to 4 weeks of bloom) when plants are undergoing rapid shifts in carbohydrate and nutrient allocations from a prior period of primarily vegetative growth to primarily reproductive (fruit) growth. Because developing retained fruit can represent such a strong competitive sink for nutrients and carbohydrates, it was decided that the plant mapping efforts need to focus on some measures of fruit retention and plant vigor. With this in mind, our plant mapping efforts in this study focused on the following:

- Measurement of fruit retention on first position fruit (those closest to the main stem) on the bottom five fruiting branches of the plants (counts done to assess retention or abortion/loss of squares (flower buds) and young bolls) - indicates whether or not early fruit retention will help hold back vegetative growth
- Measurement of fruit retention on the first position fruit (those closest to the main stem) on the to five fruiting branches of the plants (counts done to assess retention or abortion/loss of squares (flower buds) and young bolls) - gives a current indication of whether or not plants are tending to hold onto more recently produced flowers or bolls
- The ratio of plant height (in inches) to the number of main stem nodes on the plant (counted up to the uppermost node with a leaf 1" diameter or greater)

Although in this study the treatments #3 and #4 received the supplemental N applications (over and above amounts given treatments #1 and #2) whether or not the petiole data or any plant mapping data would suggest a favorable response, plant mapping data was collected to provide some evaluation of the potential for use of this type of data to suggest likely responses to supplemental N fertilizer applications. A summary of plant mapping data is given in Table 10, and a suggested point system to consider in evaluating this plant map data is given in Table 9. Only data for treatment #3 was collected and presented, as it received the lower initial application 115 lbs N/acre treatment plus the supplemental 55-60 lbs N/acre. The basis for using such a point system would be:

1. more pluses (+) indicated in mapping data would suggest a greater likelihood of a positive response to additional applied nitrogen; conversely, more negatives (-) suggest less chance of (+)yield response
2. target yield potentials of 3 bales /acre (1460 lbs lint/acre) or more, with requirements of 50 to 60 lbs total N from all sources per bale of lint produced
3. residual N plus applied fertilizer are estimated to be less than plant N needs based on yield targets

Table 9. Point system considered for use of plant mapping data to decide on likelihood of higher yield potentials based on plant growth vigor (height to node ratios), early fruit retention (bottom five fruiting branch first position fruit retention), and later fruit retention (upper five fruiting branches first position fruit retention); FB = fruiting branch number (counted from bottom).

LEVEL FOR PARAMETER	Bottom 5 Fruiting Branches First position square (flower bud) or boll retention (%)				Height (inches) to Main Stem Node Number Ratio				Top 5 Fruiting Branches First position square (flower bud) or boll retention (%)			
	Timing of measurement (*fruiting branch with first osition flower*)				Timing of measurement (*fruiting branch with first osition flower*)				Timing of measurement (*fruiting branch with first osition flower*)			
	FB I		FB 6		FB 1		FB 6		FB 1		FB 6	
	range	points	Range	points	range	points	range	points	range	points	range	points
LOW	< 40	-2	< 40	-1	< 1.2	+1	< 1.7	+1	< 40	-1	< 40	0
MODERATE	40 to 70	- 1	40 to 70	0	1,2 to 1.6	0	1.7 to 2.1	0	40 to 70	0	40 to 70	+1
HIGH	> 70	0	> 70	+ 1	>1. 6	- 1	> 2.1	-1	>70	+1	>70	+2

Supplemental fertilizer applications (in terms of the plant map data shown in Table 10) would have been about 5 to 10 days prior to the data collection at FB 5 to 6 (first position flower on 5''' or 6th fruiting branch), so there would have been relatively limited time for plant growth responses to the fertilizer applications at the time of those measurements. The plant map data and suggested points will be further discussed after yield data is presented later in this report.

Table 10. Average bottom and top five fruiting branch first position fruit retention and height to node ratios for treatment #3 plants as a function of site and year (points that would go along with each reading based on Table 9 are shown in parentheses).

Year	Site	Bottom 5 Fruiting Branches First position square (flower bud) or boll retention (%)		Height (inches) to Main Stem Node Number Ratio		Top 5 Fruiting Branches First position square (flower bud) or boll retention (%)	
		Timing of measurement (*fruiting branch with first osition flower*)		Timing of measurement (*fiwiting branch with first osition flower*)		Timing of measurement (*fruiting branch with first osition flower*)	
		FB 1 to 2	FB 6 to 7	FB 1 to 2	FB 6 to 7	FB 1 to 2	FB 6 to 7
2001	Kern	54 (-1)	52 (0)	1.59 (0)	1.94 (0)	61 (+1)	53 (+1)
	Shafter	38 (-2)	45 (-1)	1.66 (-1)	1.89 (0)	58 (0)	39 (0)
	Fresno	78 (0)	73 (0)	1.51 (0)	1.67(+1)	59(0)	46 (+1)
	West Side	72 (0)	66 (0)	1.43(0)	1.79 (0)	57 (0)	61 (+1)
2002	Fresno	74 (0)	77 (+1)	1.51 (0)	1.77 (0)	69 (0)	58 (+1)
	Shafter	59 (-1)	58 (0)	1.68 (-1)	2.04 (0)	67 (0)	49 (+1)
	West Side	81(0)	73 (+1)	1.54 (0)	1.88 (0)	76 (+1)	64 (+1)
2003	Kern	56 (-1)	59 (0)	1.64 (-1)	1.94 (0)	66 (0)	47 (+1)
	Shafter	52 (-1)	55 (0)	1.67(-1)	2.12 (-1)	59 (0)	46 (+1
	West Side	78 (0)	67 (0)	1.51 (0)	1.86 (0)	69 (0)	59(+1)
	Tulare	49 (-1)	56(0)	1.62 (-1)	1.86 (0)	37 (-1)	43 (+1)

Lint Yield **Responses to Treatments**. Yield responses to the applied N treatments indicated significantly higher yields with all N application treatments when compared with no supplemental N in three of the four locations in 2001, and all locations in 2002 and 2003. This yield response data comparing the no N to other treatments indicates that at the initial residual N levels shown in Table 1 in the upper 2, 3 or 4 feet, additional N fertilizer was needed to achieve moderately high yields (Table 11). The comparison of yield levels attained with treatments # 2 versus # 3 offers a chance to determine if essentially the same amount of fertilizer N applications made at one time (treatment #2) versus a split application (treatment #3) had any impact on yields, and the result was: few consistent differences. In only two out of the eleven site:year combinations was there a yield difference between treatments # 2 and # 3, and in those cases, treatment # 2 was higher in one case, treatment #3 higher in the other. Overall, averaged across the eleven sites, treatment #2 averaged 1658 lbs lint/acre, while treatment #3 averaged 1684 lbs lint/acre. From this data set, lint yield responses alone would not be a major reason to move toward split applications.

At the Fresno County site in 2001, high initial residual nitrate-N across all treatments resulted in no difference in yield between no N and moderate applied N treatments (Trts. 1, 3), but resulted in a yield decrease due to excessive vegetative growth in the high N application treatment (Trt. 2). Similarly, at the West Side REC site in 2003, split fertilizer applications (Trt 3, Trt 4) resulted in more vegetative growth and lower net yields than in treatments with one time applications (Trt I and Trt 2). At 2 of 4 sites in 2001, 2 of 3 sites in 2002, and 2 of 4 sites in 2003, use of the lower initial application rate plus supplemental Napproach (Trt. 3) resulted in apparent yield improvements over the high N treatment. Use of the reduced initial N/supplemental N approach (trt. 3) significantly improved yields over the low N application treatment (Trt.1) at six sites out of the 11 site:year combinations in these trials, generally at sites with high yields (over 1600 lbs lint/acre).

Figures 7, 8 and 9 show the relationship between lint yield and the sum of residual soil nitrate-N in the top two feet of the soil profile plus total applied N for each site and year. Data plotted in this manner shows the zero applied N treatment data included, clearly showing significant yield reductions with no applied N that occurred under high yield potential conditions and at some sites with moderate to low planting time residual soil nitrate-N. In a previously-reported study (Hutmacher et al, 2004) in which there was a low N application treatment (50 lbs N/acre), it was similarly found to be important to consider possible availability of soil N with depth when estimating likely yield responses to applied N fertilizer.

Table 11. Lint yield as a function of site and treatment in 2001, 2002 and 2003 sites.

	2001 Field Study Sites							
Site / location	Lint Yield (lbs lint per acre)							
	Trt I	Trt 2	Trt 3	Trt 4	No N			
Kem Co.	1517a	1542a	1615a	1608 a	984 b			
Shafter	1291 a	1292a	1227ab	1210b	678 c*			
Fresno Co.	1435 b	1689 a	1734a	1504 b	1665 a			
West Side REC	1807b	1815ab	1896a	1767 c	1331 c			
	2002 Field Study Sites							
Shafter	1740 a	1791 a	1784 a	1814 a	1287 b			
Fresno Co.	1293 c	1912ab	2045 a	1877 b	880 d			
West Side REC	1686 b	2005 a	2001 a	1995 a	976 c*			
	2003 Field Study Sites							
Kern	1154 c	1359 b	1487 a	1415 ab	1088 c			
Shafter	1521 be	1615 a	1563 ab	1577 ab	1444 c			
West Side REC	1871 a	1836 ab	1770 c	1787 be	1791 be			
Tulare	1256 b	1387 a	1408 a	1302 ab	1153 c*			

*only 2 replications; ** yields followed by a different letter were significantly different at 5% level by LSD method.

Residual Soil N and Relationship to Treatments and Crop. Impacts of specific N fertilization treatments on soil nitrate-N accumulation patterns at depths in the soil profile have been analyzed across years and sites (see Figures 10 and 11). A general trend existed toward higher apparent net depletion (reductions in soil nitrate-N during the growing season) in treatments where lower N rates were applied (such as Treatment #1), as would be expected. The magnitude of these differences was less under some conditions, such as with lower yields (Shafter REC-2001) . Consistently, net changes in soil nitrate-N in the most active part of the root zone (0 to 4 foot depth) were largest (most negative) in the lowest application treatment (Trt. #1) and the least in the higher application treatments.

In the lower soil depths (4 to 8 feet), changes in soil nitrate-N between spring and fall consistently showed more apparent reductions in soil nitrate-N during the season (more negative in Figures 10 and 11) in lower N treatments (Trt #1 versus #3 or Trt #2 versus Trt #4). Conversely, the highest net accumulations of nitrate-N in the 4 to 8 foot depth (measured between the spring and fall sampling dates) were in the higher N application treatments, particularly treatment #4, which received the higher initial N application plus a supplemental 55-60 lbs N/acre application (Figures 10, 11).

There are recognized limits in interpreting soil nitrate data, since values of this soluble, mobile form of N are known to change over time and with processes such as mineralization and denitrification. However, for the purposes of this study, we assume that changes in nitrate-N in the soil still represent a general indicator of changing N status that occurs both with crop N uptake as well as other processes such as leaching that can occur during the growing season. While increases in soil nitrate-N in the lower soil profile averaged about 20 lbs nitrate-N/acre in treatment #4 and did not exceed 40 lbs/acre at any site, these levels still suggest potential for nitrate losses below the root zone if rotation crops are not deeply rooted or if irrigation practices don't eliminate leaching potential.

Soil nitrate distribution patterns exhibited a strong (but not always consistent) trend toward the split application in treatment #3 reducing soil nitrate-N levels in the fall measurements made at the 4 to 8 foot depth when compared with the one time higher application rates used in treatment #2 (Figures 10 and 11). Higher soil nitrate-N levels at greater depths may be related to a number of factors. This trend tended to be most evident at the sites thought to have more permeable soils and higher soil infiltration rates prevailing early and mid-season (such as Shafter REC-2001, West Side REC-2001 and 2002, Fresno-2002, and West Side REC-2003). Split N applications were much more inconsistent in producing any crop growth or yield benefit over one time applications, at least growth that resulted in increased fruit retention or growth and eventual lint and seed yield. Since yields were not generally reduced with timely split nitrogen applications in this trial, however, indications of potential to reduce downward movement of soil nitrate-N through use of split applications may provide some incentive to promote split applications as a better practice to limit nitrate N losses below the active root zone.

Mineralizable Nitrogen Analyses

The relationship between mineralizable N analyses made by the hot KCl method (Gianello and Bremner, 1986 and Picone et al, 2002) and soil nitrate-N measurements for the top two feet of the soil profile during the post-planting and post-harvest periods are shown in Figures 12 and 13, respectively. It must be acknowledged that these analyses have been on low organic matter soils with sandy loam and clay loam textures and with one exception, at sites where land application of dairy waste or large amounts of crop residue were not part of the management.

Table 12. Yield responses to supplemental N in treatments # 3 and # 4 as a function of the range of values in analyses done for concentrations of soil nitrate-N versus Hot KCl mineralizable N at field sites shown. Ranges shown are the lows and high field replicates for the same data represented in figure 12.

Year	Site	Range of Values (lowest field replication average versus high average) for: ***Soil** Nitrate -N (mg N03-N/**kg soil** dry wt.)*		Range of Values (lowest field replication average versus high average) for: *Soil Hot KCl **Mineralizable** N (mg N/kg dry wt.)*		Yield Responses to Supplemental N applied in Treatments #3 and #4 (compared with Trt # I and trt #2) S = significant NS = non-significant	
		LOW	HIGH	LOW	HIGH	Trt #3	Trt #4
2001	Kern	8.0	10.0	17.2	20.8	NS	NS
	Shafter	5.0	5.9	8.7	10.1	NS	
	Fresno	12.6	17.1	18.8	31.4	S	
2002	Fresno	4.5	7.4	5.9	9.1	S	NS
	Shafter	10.4	14.8	17.4	26.9	NS	NS
	West Side	6.3	9.7	9.9	14.2	S	NS
2003	Kern	4.2	6.6	5.7	8.9	S	NS
	West Side	5.0	6.7	7.9	10.4	*	NS
	Tulare	7.6	11.0	15.2	25.7	S	NS

* yields significantly reduced with application of supplemental N (usually associated with more vegetative, rank growth and poorer fruit retention in these cases)

The 1:1 lines shown in Figures 12, 13, and 14 demonstrates that these estimates of mineralizable N in the upper two feet of the soil profile ranged from about 1.1 to over 2.4 times the nitrate-N concentrations determined on duplicate subsamples. The ratio of mineralizable N to nitrate-N showed a trend toward increases at higher soil nitrate-N levels, both in pre-harvest samplingbut the relationship still showed a great deal of scatter rather than a tight relationship. The ratio was lower in the soil samples from the third foot (lower graph in Figure 12) in post-planting sampling, perhaps reflecting less movement and deeper incorporation of crop residue potentially contributing to mineralizable N. Fewer samples were evaluated during the post-harvest period (Figure 14), and soil nitrate and mineralizable N levels were generally significantly lower than at post-planting timing. However, the ratio of mineralizable N to soil nitrate exhibited correlations similar to those at post-planting. Relatively limited comparisons of mineralizable N analyses were made by the incubation method (Franzleubbers et al, 1996) due to greater difficulties in consistency of results in making these measurements at our lab. Values obtained were generally higher than those obtained with the hot KCl method, but differed by as much as 30 percent (data not shown).

Table 12 shows the range of soil nitrate levels and mineralizable N estimates for the upper two feet of soil during the spring, post-planting sample timing.along with an indication of whether or not treatment #3 or treatment #4 plants showed yield responses to the supplemental N applied over and above the one N application treatments (Treatment #1 and Treatment #2).

We hypothesized that those sites where yields did not respond to the supplemental N supplied with treatment #3 could have low soil nitrate-N values, but much higher mineralizable N that could become available during the season. The analyses shown in table 12 demonstrate a high ratio of mineralizable N to nitrate-N in some sites which were unresponsive to supplemental N applications in treatment #3 (Kern-2001, Shafter-2001 and 2002), but also demonstrated that some other sites with a high ratio of mineralizable N to nitrate-N still showed a significant yield response. In this series of experiments, while the mineralizable N data appeared to be useful as an indicator of additional N sources over and above soil nitrate-N measurements alone, it was considerably more time-consuming and expensive currently than soil nitrate-N tests. Based upon the results of this and prior experiments (Hutmacher et al, 2004), we would be more inclined to recommend deeper soil sampling (to 3 or 4 feet where possible) and analysis for nitrate-N at post-planting time to better assess additional potential sources of N. Our mix of test sites was not sufficient to test how variable these results might be at a wider range of soil organic matter levels such as those occurring with different crop rotations or with manure applications. There has been much research activity in recent years in mineralizable N measurement method comparisons (Picone et al, 2002), and these evaluations may help in making decisions regarding the future utility of these tests as part of an N management plan.

Summary

A three year study with three to four field sites per years was conducted to evaluate a proposed feed-back approach to improve nitrogen management decision-making in Acala cotton production in the San Joaquin Valley. Under conditions where soil nitrate-N levels in the upper two to four feet of the soil profile were in the low to moderate range as determined from prior cotton nitrogen management studies, treatments were established to supply a total of residual N plus applied N of either 115 or 180 lbs of N/acre, with supplemental applications of an additional 55 to 60 lbs N/acre made during early bloom. Plant petiole nitrate-n was monitored during bloom, and limited plant mapping was done during the same period to assess crop growth vigor and fruit retention. Methods were proposed in which these plant measurements could be used in combination with soil nitrate-N measurements to assess likelihood of positive yield response to supplemental N. An evaluation comparing soil mineralizable N measurements with soil nitrate-N demonstrated a way to measure additional N sources over and above nitrate-N, but was somewhat difficult to measure.

Advantages could be gained in soil sampling to greater depths as an alternative way to also account for other potential crop-available N sources. Although this approach would require a targeted number of soil nitrate, petiole nitrate and plant mapping measurements and associated costs, this feedback management approach could reduce occurrences of un-needed fertilizer applications, or conversely, N deficiencies damaging to yield potential.

PUBLICATIONS

Hutmacher, R.B., R.L. Travis., D.W. Rains, R.N. Vargas, B.A. Roberts, B.L. Weir, S.D. Wright, D.S. Munk, B.H. Marsh, M.P. Keeley, F.B. Fritschi, D.J. Munier, R.L. Nichols, and R. Delgado. 2004. Response of Recent Acala Cotton varieties to Variable Nitrogen Rates in the San Joaquin Valley of California. Agron. J. 96: 48-62. (based in part on this research, and on prior study)

Hutmacher, R.B., R.L. Travis, B.A. Roberts, R.N. Vargas, S.D. Wright, B.H. Marsh, D.S. Munk, B.L. Weir, D.W. **Rains**, R.L. Nichols, M.P. Keeley, F. Fritschi, D.J. Munier, R. Delgado. Nitrogen **Management** Guidelines for Acala Cotton in the San Joaquin Valley. In preparation: publication to be jointly sponsored by Cotton incorporated and the University of CA , based on this and other recent UC research by the authors on revisions to N management practices to consider under CA conditions. Text is in preparation, should go to co-authors for review during April,
2005.

Other publications may be planned, based upon co-author comments and review of data, including petiole nitrate data and patterns of soil N uptake and concentrations.

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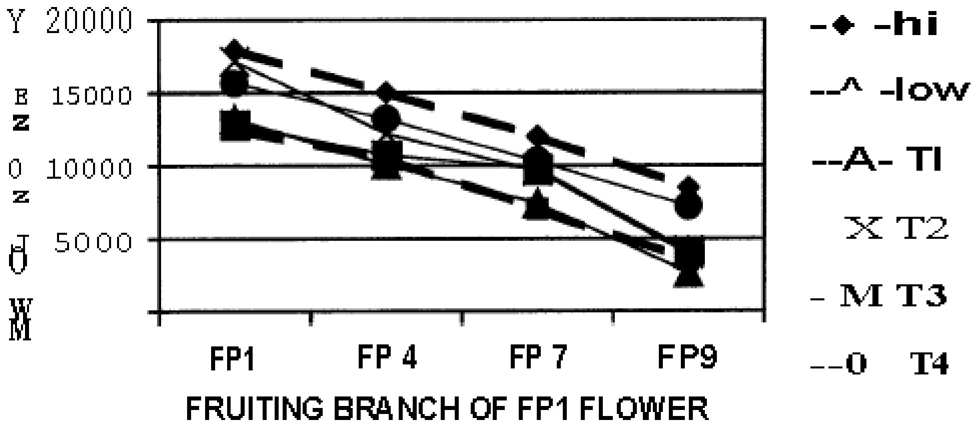

Figure 1. Petiole nitrate-N as a function of nitrogen treatment and growth stage (fruiting branch of first position open bloom) at Site A (Kern County) in 2001. Residual spring soil nitrate-N in the upper 2 feet and upper 4 feet of soil profile during first weeks after planting averaged 69 and 116 lbs nitrate-N/acre, respectively, at this site.

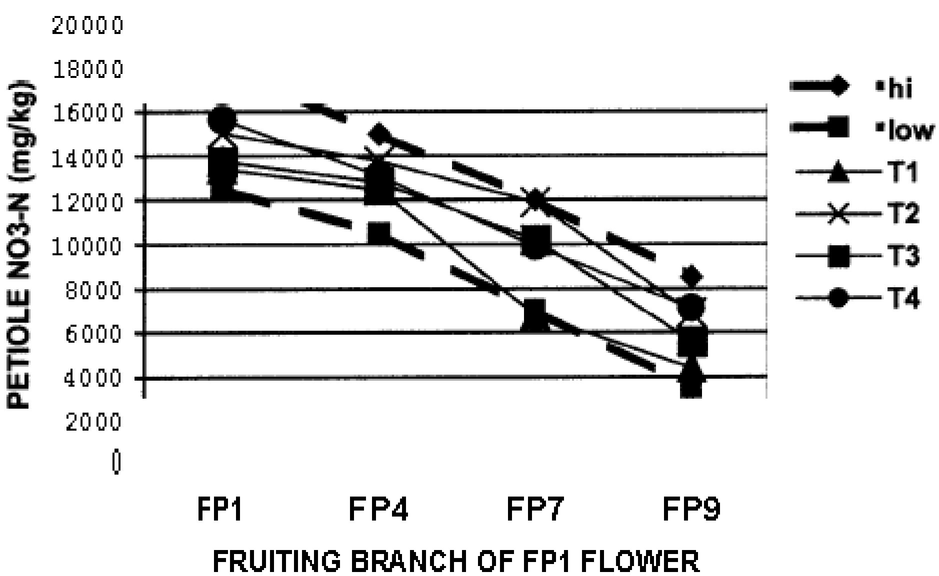

Figure 2. Petiole nitrate-N as a function of nitrogen treatment and growth stage (fruiting branch of first position open bloom) at Site B (Shafter REC) in 2001. Residual spring soil nitrate-N in the upper 2 feet and 4 feet of soil profile during first weeks after planting averaged 41 and 86 lbs nitrate-N/acre, respectively, at this site

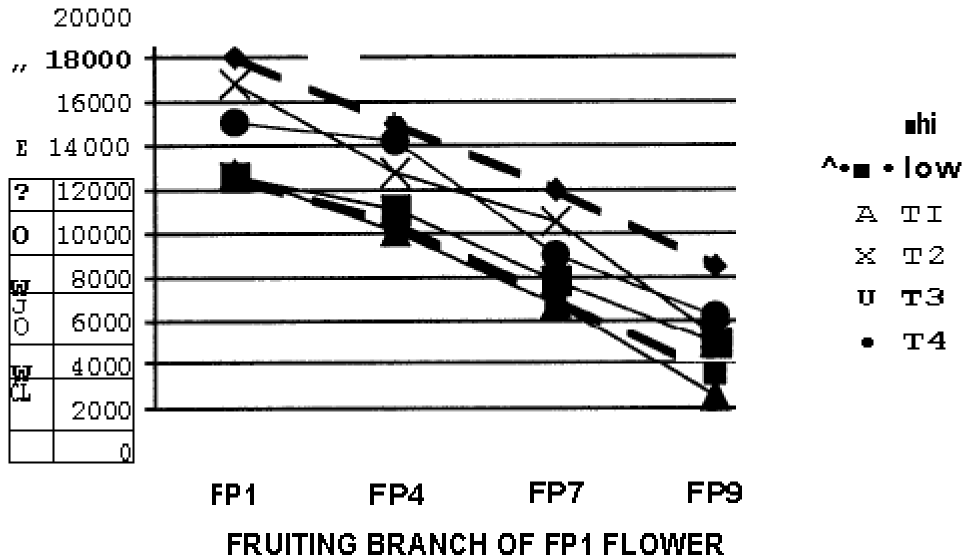

Figure 3. Petiole nitrate-N as a function of nitrogen treatment and growth stage (fruiting branch of first position open bloom) at Site D (West Side REC) in 2001. Residual spring soil nitrate-N in the upper 2 feet and 4 feet of soil profile during first weeks after planting averaged 58 and 97 lbs nitrate-N/acre, respectively, at this site

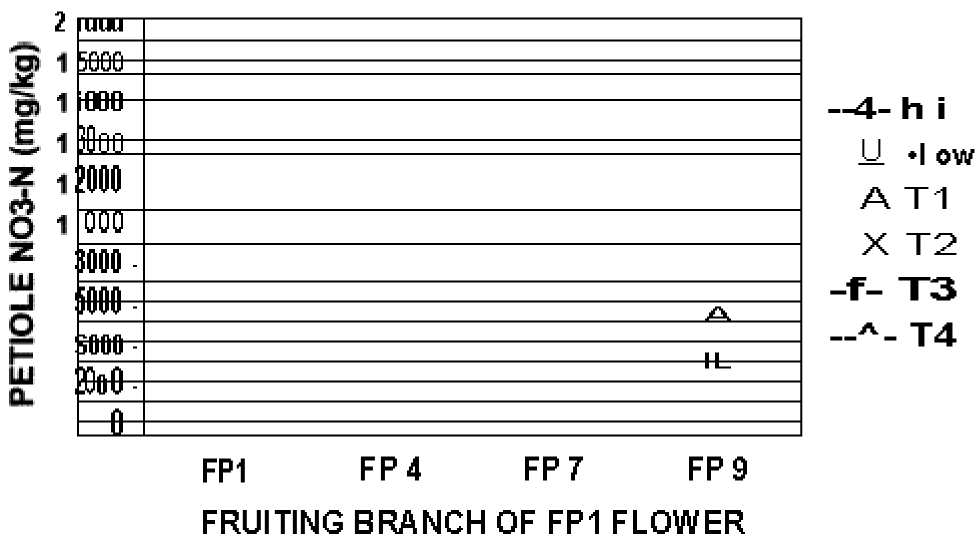

Figure 4. Petiole nitrate-N as a function of nitrogen treatment and growth stage (fruiting branch of first position open bloom) at Site B (Shafter REC) in 2003. Residual spring soil nitrate-N in the upper 2 feet and 4 feet of soil profile during first weeks after planting averaged 58 and 89 lbs nitrate-N/acre, respectively, at this site.

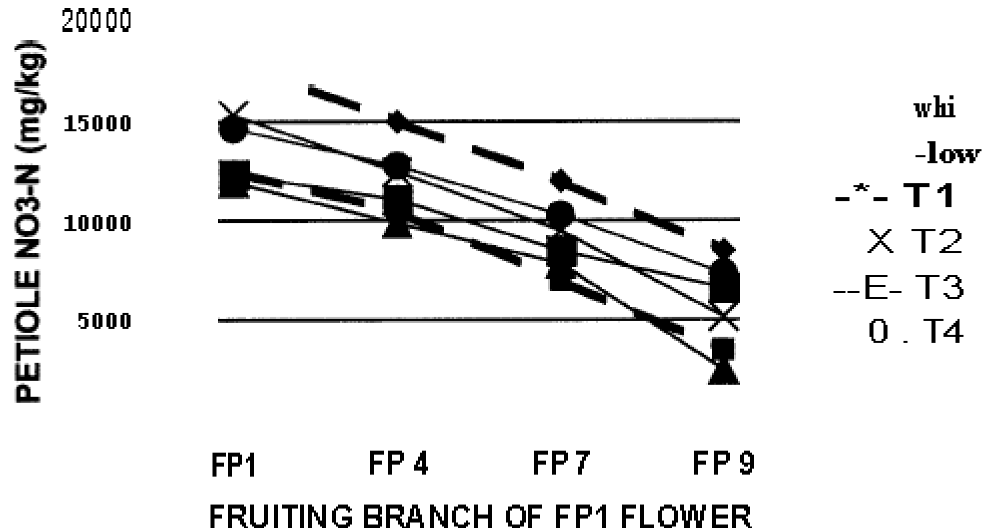

Figure 5. Petiole nitrate-N as a function of nitrogen treatment and growth stage (fruiting branch of first position open bloom) at Site A (Kern Co.) in 2003. Residual spring soil nitrate-N in the upper 2 feet and 4 feet of soil profile during first weeks after planting averaged 41 and 83 lbs nitrate-N/acre, respectively, at this site

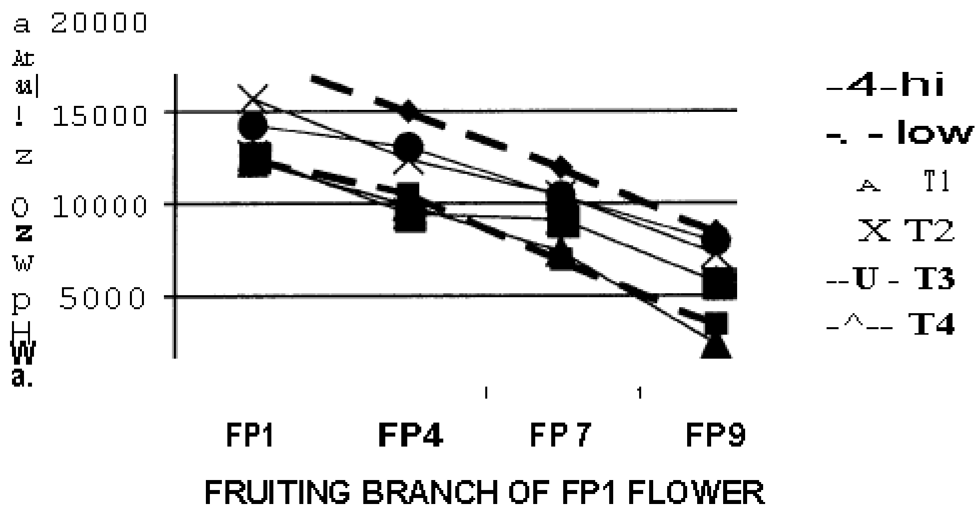

Figure 6. Petiole nitrate-N as a function of nitrogen treatment and growth stage (fruiting branch of first position open bloom) at Site D (Tulare Co.) in 2003. Residual spring soil nitrate-N in the upper 2 feet and 4 feet of soil profile during first weeks after planting averaged 69 and 132 lbs nitrate-N/acre, respectively, at this site

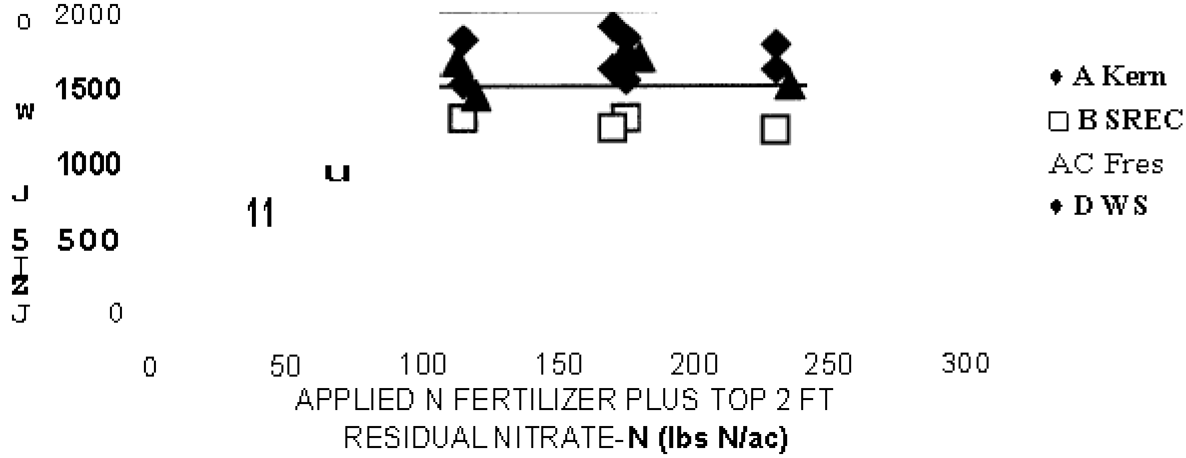

Figure 7. Lint yields **at 2001 test sites as a function** of the sum of applied N fertilizer **plus residual soil nitrate** -N in the upper two feet of the **soil profile.**

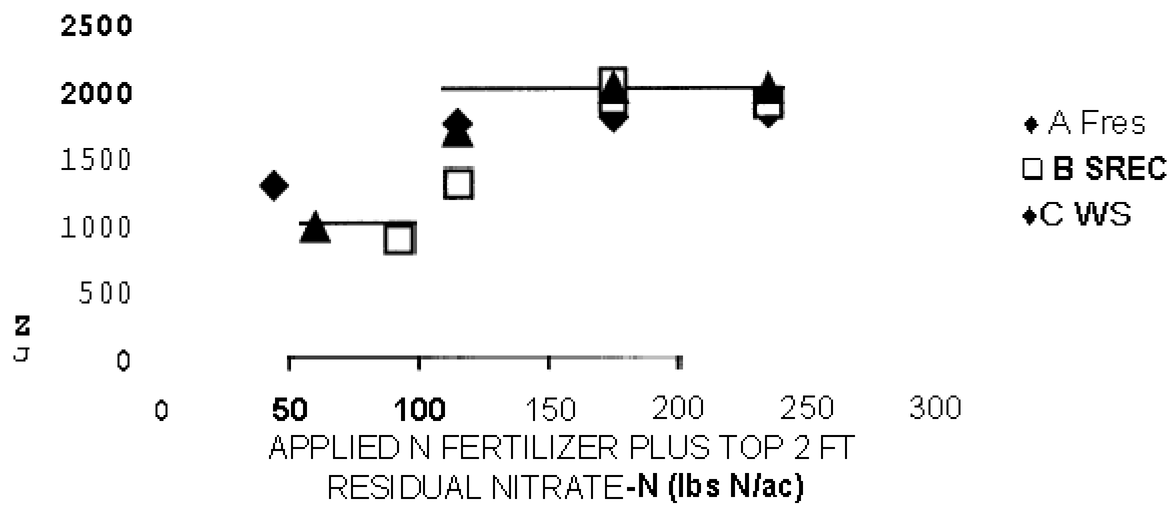

Figure 8. Lint yields at 2002 test **sites as a function** of the sum of applied N fertilizer **plus residual soil nitrate** -N in the upper two feet of the **soil profile.**

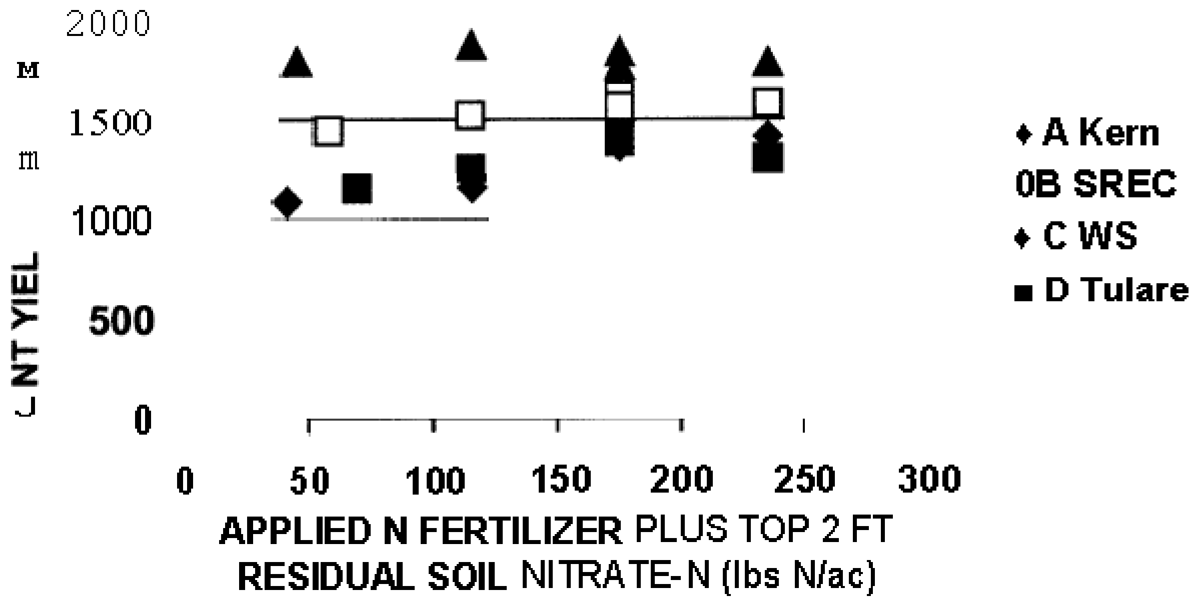

Figure 9. Lint yields at 2003 test sites as a function of the sum of applied N fertilizer plus residual soil nitrate-N in the upper two feet of the soil profile.

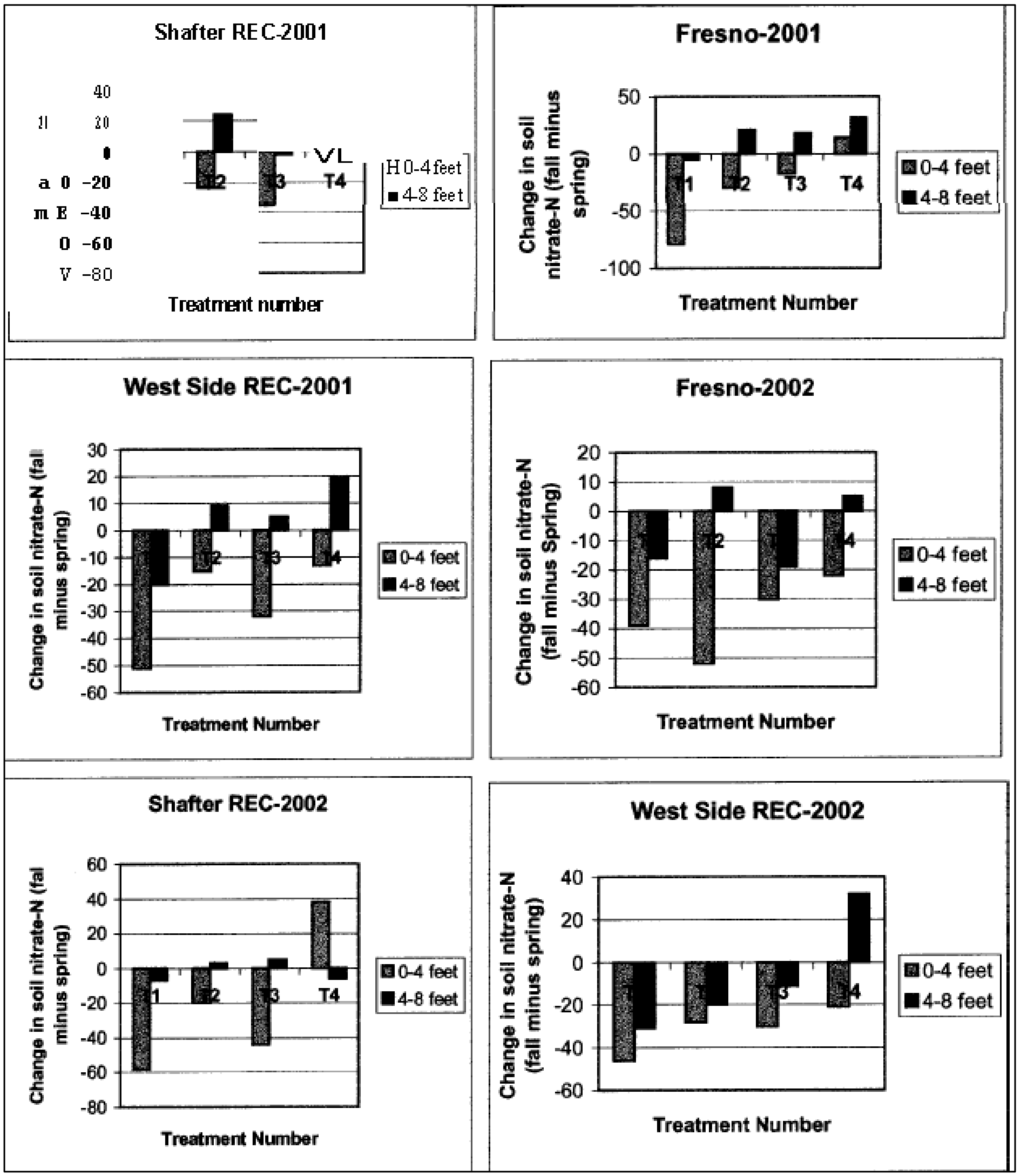

Figure 10. Change in average soil nitrate-N as a function of trial site, treatment number and depth in soil profile (0 to 4 foot versus 4 to 8 foot zone) between spring (post-planting) and fall (post-harvest) soil sampling done on the planting bed shoulder area in sampled fields in 2001 and 2002 at sites shown. Since data is calculated as fall minus spring-time samplings, a negative number (-) indicates net reduction in soil nitrate N between spring and fall, while a plus indicates a net increase in soil nitrate-N in the soil depth range.

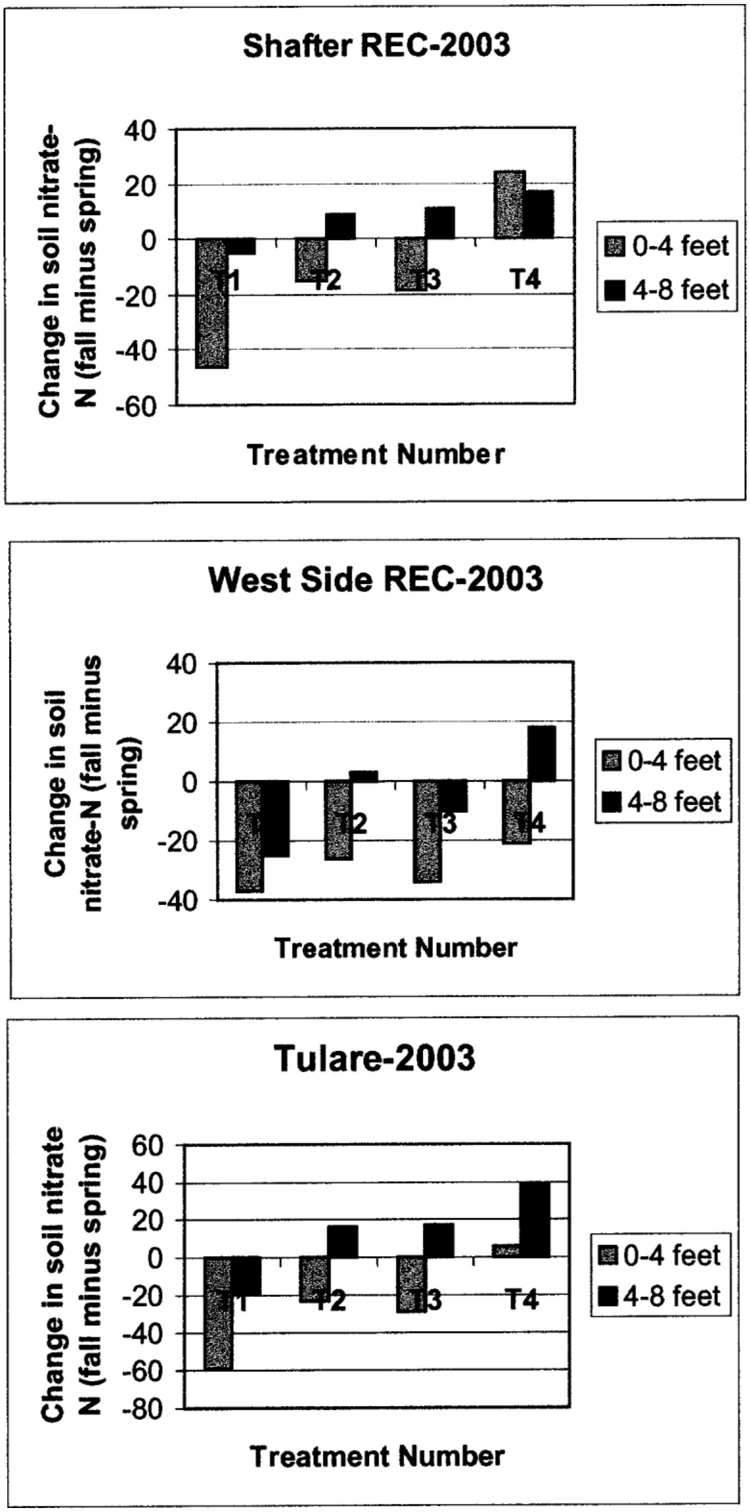

Figure 11. Change in average soil nitrate-N as a function of trial site, treatment number and depth in soil profile (0 to 4 foot versus 4 to 8 foot zone) between spring (post-planting) and fall (post-harvest) soil sampling done on the planting bed shoulder area in sampled fields in 2003 at sites shown . Since data is calculated as fall minus spring-time samplings, a negative number (-) indicates net reduction in soil nitrate N between spring and fall , while a plus indicates a net increase in soil nitrate -N in the soil depth range.

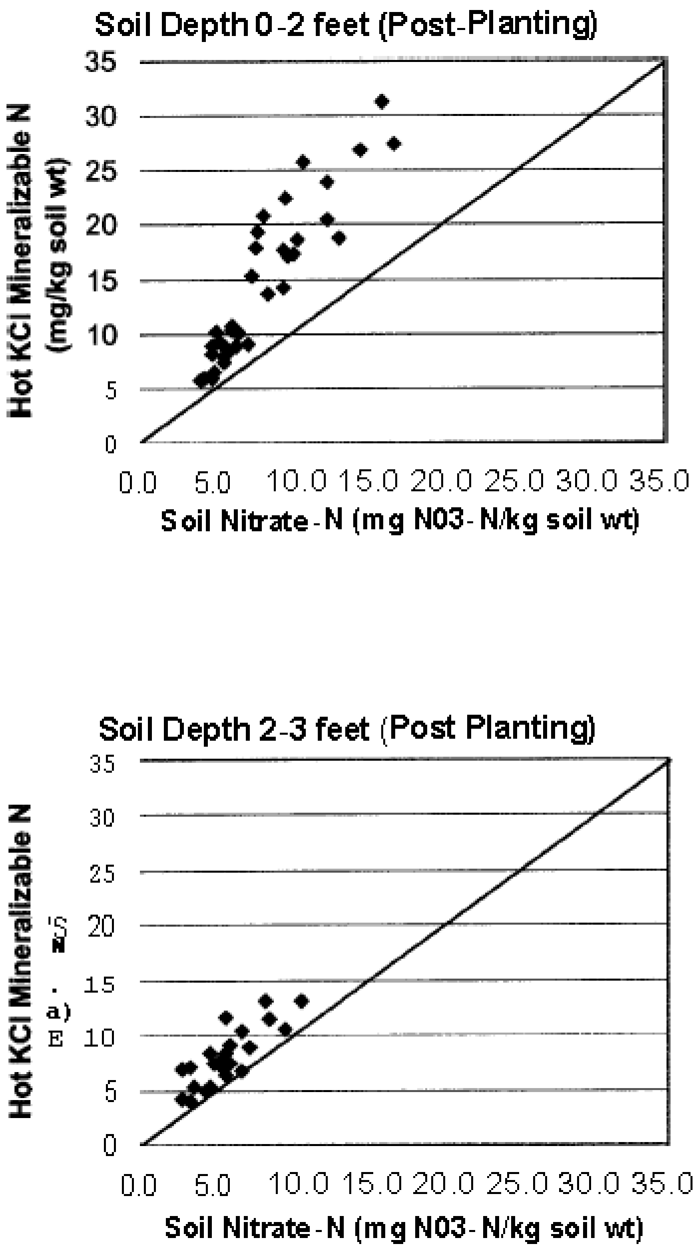

Figure 12. Hot KCl method mineralizable N (three to four field replicate averages at 9 field sites) in the (a) top two feet of soil profile, or (b) third foot of the profile during the post-planting period regressed against soil nitrate-N measurements made at the same time. The 1:1 line is drawn to facilitate observations of the difference in values between the two methods. Three field replicates were measured at all sites in the third foot samples, while four field replicates were sampled at all sites in the first two foot samples.

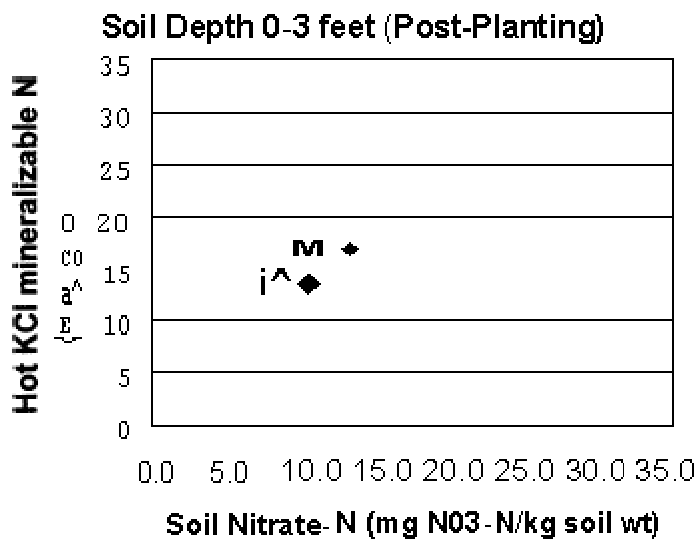

Figure 13. Hot KCl method mineralizable N (three to four field replicate averages at 9 field sites) with all samples within the top three feet during the post planting period regressed against soil nitrate-N measurements made at the same time. The 1:1 line is drawn to facilitate observations of the difference in values between the two methods. Three field replicates were measured at all sites in the third foot samples, while four field replicates were sampled at all sites in the first two foot samples.

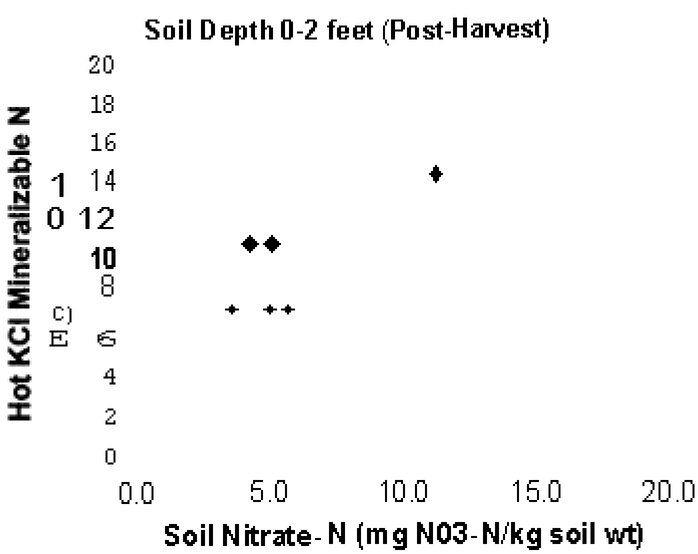

Figure 14. Hot KCl method mineralizable N (three field replicate averages at 9 field sites) with all samples within the top two feet during the post-harvest period regressed against soil nitrate-N measurements made at the same time. The 1:1 line is drawn to facilitate observations of the difference in values between the two methods.