2003 BELTWIDE COTTON CONFERENCES, NASHVILLE, TN – JANUARY 6-10

NITROGEN USE EFFICIENCY IN COTTON: REQUIREMENTS AND DIAGNOSTICS

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Abstract

Nitrogen (N) management of cotton has arguably not kept pace with other areas of cotton management such as varietal development, minimum-tillage, and subsurface drip irrigation. We present here an update of N management of irrigated cotton, with special reference to the Southern High Plains. Nitrogen fertilizer response in cotton differs by tillage system. For example, conservation-till cotton may require more N than conventional-till cotton. Nitrate soil tests to 2 feet are a useful predictor of cotton response to N in the Western US. The high internal use efficiency of cotton in the Southern Plains means that 40 lb N is required in the cotton plant for every bale of lint produced. More N is probably required per bale for humid areas of the cotton belt. Recovery efficiency of N fertilizer is low in cotton, usually < 50% N of applied throughout the cotton belt. Finally, in-season sensing of N status in cotton, such as the chlorophyll meter and proximal spectral reflectance sensing has potential to guide in-season N fertilization of cotton.

Introduction

Nitrogen is the nutrient required in the greatest amounts in cotton, followed by K and P. Water, however is the greatest limitation to cotton production, especially in the Western US (Morrow and Krieg, 1990, Bronson et al., 2001). The adoption of center-pivots in the Southern High Plains, and more recently subsurface drip irrigation, have greatly improved water use efficiency in cotton production (Lyle and Bordovsky, 1981; Bordovsky, 2001). Conservation-tillage is becoming more widespread and transgenic varieties are now commonplace in cotton production.

Nutrient management in these newer cotton production systems has not received as much attention. Nitrogen fertilizer is usually delivered with irrigation water through center-pivot subsurface irrigation systems. Morrow and Krieg (1990) and Bronson et al. (2001) demonstrated that N supply should increase as irrigation capacity increases for cotton in the Southern High Plains. Over-fertilization, however can result in NO_3-N buildup in the subsoil, even at high irrigation rates (Bronson, et al., 2001). Groundwater and surface water levels of NO_3 are increasing in many areas, although it is unclear how much NO_3 is transported or leached from cotton fields.

In this overview, we provide an update on the best N management practices for irrigated cotton. Most of our examples come from the Southern High Plains, however, many of the approaches discussed can probably apply to the humid Mid-South and Southeastern regions of the cotton belt.

Results and Discussion

Response of cotton to N did not differ between surface-applied and subsurface drip irrigation in Lubbock, TX (Fig. 1). In these studies that we have conducted for several years, surface applied water is delivered 2 or 3 times a week during the growing season, and subsurface water is applied daily. Fig. 2. shows that response of cotton to N fertilizer differs by tillage system. About 30 lb N/ac more is required to achieve the optimum lint yield with conservation-tillage vs. conventionally tilled cotton (Bronson et al. 2001). The terminated wheat residue in the conservation till system apparently results in immobilization of some added N. We should note however, that this difference in N response may diminish after several seasons of conservation-till. Response of cotton to N fertilizer is more likely in the western US with adequate irrigation levels (Table 1). Bronson et al. (2001) also reported response to N with 50 or 75% ET irrigation, but not with dryland or 25% ET replacement.

Spring soil NO_3 tests to 2 feet are recommended in most Western states to guide N feritlization of cotton (Zelinski, 1985; Zhang, 1998). Oklahoma, for example recommends subtracting 2-ft NO_3 levels (in lbN/ac) from 120 lb N/ac to derive N fertilizer needs for 2-bale cotton (Zhang et al., 1998). In seven site-years of study in West Texas, we studied the relationship between N fertilizer response in cotton and soil profile NO_3 (Table 2). With the exception of the low-yielding Ropesville site-year, it appears that 75 and 50 lb NO_3-N/ac may be a critical 2-ft soil test NO_3 level for sandy and loamy to clayey, sites, respectively.

Fig.3 shows the relationship between N uptake and lint yield for irrigated cotton in West Texas. The slope of the regression line is 40 lb N uptake per bale of cotton lint yield, and this is therefore the N requirement for cotton in West Texas. This is quite a bit less N required than other published results, especially those from the humid Southeastern US (Mullins and Burmester, 1990). The high internal use efficiency of N (and high harvest indices) in the Southern High Plains is probably due to the deficit irrigation and breeding for short internode lengths.

Mass balances can then be constructed for cotton production in the Southern High Plains of Texas. Our research suggest that net N mineralization from residues and humus (old soil organic matter) ranges from 20 lb N/ac on sandy soils up to 60 lb N/ac on higher organic matter clay soils (Table 3). Additions of NO_3-N in irrigation water can be significant and should be measured and calculated as well. These balances assume 8 ppm NO_3-N and 12 inches of irrigation. The critical 2-ft. soil test levels should probably be rounded up to 50 lb N/ac to 80 lb N/ac for clayey and loamy soils, respectively. This means that for sandy soils, for example, that no N fertilizer is needed if the spring 2-ft. soil NO_3 –N test is greater than 80 lb N/ac. This also means that these values are the maximum N fertilizer levels that should be applied. These guidelines are consistent with our observations that no additional N fertilizer response has been observed beyond 60 and 90 lb N/ac on our loamy and sandy soils, respectively. The qualifier we must emphasize here is that this is for 2-bale/ac cotton. We hear reports of 3 to 4 bale/ac cotton in West Texas in subsurface drip irrigation. For these higher yield goals, we would recommend an additional 40 to 60 lb N fertilizer/ac for each bale above 2 bal/ac.

This brings us to the issue of N fertilizer use efficiency, or the percentage of N fertilizer applied that the cotton plant takes up. Table 4 indicates that N fertilizer use efficiency in irrigated cotton is low, i.e less than 50%. These low recoveries have also been reported by Torbert and Reeves (1994) in Alabama and by Karlen et al. (1996) in South Carolina. Chua et al. (2002) suggested that denitrification is a major loss pathway of added N in drip irrigated cotton. In an effort to improve the efficiency we conducted a timing of N fertilizer study in West Texas in 2002. Here we hypothesized that avoiding N fertilization at planting, and restricting N fertilizer to the period of rapid growth of cotton between squaring and bloom will result in the greatest N use efficiency. We did observe a lint yield and N uptake response to N timing and rate in this study (Table 5). However, all N-fertilized treatments were similar in terms of yield and recovery of N fertilizer. More years of study are needed however, before conclusions can be made about timing of N fertilizer at this site.

There is a need for inexpensive, rapid techniques of sensing the in-season status of N in cotton. Petiole NO_3 analysis is used in many states. However, turn-around time is required and further more, no information on cotton biomass is generated by petiole analysis. The chlorophyll meter is a rapid measurement that correlated well with leaf N (Table 6). However, like petiole analysis it does not relate well to plant biomass. Spectral reflectance (green vegetative index is the ratio of percent reflectance at 820nm to percent reflectance at 55 nm), on the other hand, provides rapid information on both leaf N status and biomass (Table 6).

We conducted three-site years of study where we tested the chlorophyll meter and spectral reflectance as in-season aids to N fertilization. At Ropesville in 2000, yield potential was low, due to insect pressure, nematodes, and low soil test P. In this site year, 75 to 90 lb N fertilizer/ac were saved with in-season sensing, compared to soil test –based management (Table 7). When yield potential was high, such as in Lubbock, 2001, in-season monitoring resulted in similar N fertilizer applications as the soil test recommended (Table 7). Residual soil NO_3 at harvest was high in these studies, when N fertilization did not match plant demand, such as with the soil test treatment in Ropesville, 2000 (Table 8). In-season N sensing-based management, on the other hand, has the potential to reduce residual soil NO_3, especially in low-yielding seasons.

Conclusions

- Lint yield response to N is similar between surface and subsurface drip irrigation at Lubbock. Terminated wheat cotton has about a 30 lb N/ac greater N fertilizer requirement than conventional cotton.
- 0-24 in. spring NO_3-test is useful in predicting N fertilizer response in the Western US. Critical levels may be 50 and 75 lb N/ac for loamy/clayey and sandy surface soils respectively.
- Forty lb N/ac is required in the cotton plant per bale of lint yield in the Southern High Plains. This high internal N use efficiency reflects deficit irrigation and breeding for small plants. Internal N requirements are probably greater in the humid sections of the cotton belt.
- Recovery efficiency of N fertilizer for irrigated cotton is low across the cotton belt, i.e. < 50 %, but is probably higher with daily fertigation in drip.
- Nitrogen applied with in-season sensing can reduce N applications in low-yielding seasons and reduce residual soil NO_3.

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Table 1. Lint yields as affected by N and water management, AGCARES Lamesa, TX, 2002.

	Water management (%ET)			
	50	**75**	**100**	**Means**
N treatment	**lb/ac**			
Blanket-rate	796	940	1090	942
Variable-rate	870	912	1120	967
Zero-N	796	883	1003	894
Means	820	912	1071	
LSD	NS	NS	76	43

Note: Spring soil NO3--N in 0-24 and 0-36 in. was 65, and 87 lb N/ac.
NS is not significant at $P = 0.05$.

Table 2. Spring Soil Test Nitrate and N response to Cotton by Site-Year.

	Site-year						
	Lamesa 98	**Lamesa 99**	**Lamesa 02**	**Ropesville 00**	**Lubbock 00**	**Lubbock 01**	**Lubbock 02**
	lb NO_3-N/ac						
0-24 in. NO_3-N	113	71	65	43	33	14	39
0-36 in. NO_3-N	155	107	87	88	86	38	47
N fert response	No	Yes	Yes	No	Yes	Yes	Yes

Note: surface soils are sandy in Lamesa and Ropesville, and are loamy in Lubbock.

Table 3. Mass balance approach to N fertilizer needs in irrigated cotton.

N Source	Acuff loam	Amarillo sandy loam	Pullman clay loam
	------------------------ lb N/ac ------------------------		
Critical 0-24in soil NO_3-N	50	75	40
Net N mineralization	50	20	60
Irrigation NO_3-N	20	20	20
Sum	120	115	120

Table 4. Nitrogen-15 recovery in cotton.

Treatment	Ropesville 2000	Lubbock 2000	Lubbock 2001
	------------------ % ------------------		
Reflectance	33.0 a	27.3 a	33.0 a
Chlor. Meter	38.2 a	28.3 a	29.7 0 a
Soil Test	23.7 b	21.8 b	33.7 a
Well-fertilized	18.9 b	19.2 b	25.5 a
LSD	6.7	5.8	NS

Table 5. Surface-drip irrigated cotton lint yields as affected by timing of N fertilizer, Lubbock, TX, 2002.

Treat-ment	N fertilizer applications: Planting	1st square	Mid bloom	Peak bloom	Total	Lint yields lb/ac	N uptake lb N/ac	Recovery efficiency %
	------------------ lb N/ac ------------------							
1	0	0	0	0	0	1016	66.9	
2	0	30	30	0	60	1178	84.8	43.5
3	30	30	30	0	90	1169	93.4	36.3
4	0	30	30	30	90	1227	95.8	40.0
LSD						NS	19.9	NS
Contrasts						------------ P > t	------------	------------
N-fertilized vs. zero-N						0.02	<0.01	NS
Trt 3 vs. Trt. 4						NS	NS	NS
60 vs. 90 lb N/ac						NS	NS	NS

Note: Spring soil NO_3^--N in 0-24 and 0-36 in. was 39, and 47 lb N/ac, respectively.

Table 6. Correlation of N rate, leaf N, biomass, lint yield, chlorophyll meter readings (SPAD), and green vegetative index (GVI), early bloom, Lubbock, 2000.

	Leaf N	Leaf N Acc.	Biomass	Lint yield	SPAD	GVI
N Rate	0.64**	0.54**	0.42*	0.42*	0.66**	0.48**
Leaf N		0.82**	0.60**		0.83**	0.77**
Leaf N Acc.			0.94**	0.61**	0.63**	0.88**
Biomass				0.71**	0.43*	0.82**
Lint yield						0.69**

Table 7. Lint yields as affected by in-season N sensing management.

Treatment	Ropesville 2000	Lubbock 2000	Lubbock 2001
	------------------ lb/ac ------------------		
Well-fertilized	609 (180)	946 (180)	1326 (120)
Soil Test	629 (120)	953 (120)	1276 (90)
Reflectance	613 (45)	916 (45)	1200(90)
Chlorophyll meter	556 (30)	922 (75)	1246 (75)
Zero	631 (0)	792 (0)	1038 (0)
LSD (*P*=0.05)	NS	80	123

N rates applied are in parenthesis.
NS is not significant.

Table 8. Residual NO_3 (0-24 in.) as affected by N management.

Treatment	Ropesville 2000	Lubbock 2000	Lubbock 2001
	------------------- lb/ac --------------------		
Well-fertilized	163	142	99
Soil test	106	81	88
Reflectance	38	58	69
Chlorophyll meter	41	71	69
Zero	32	39	33
LSD (*P*=0.05)	21	25	22

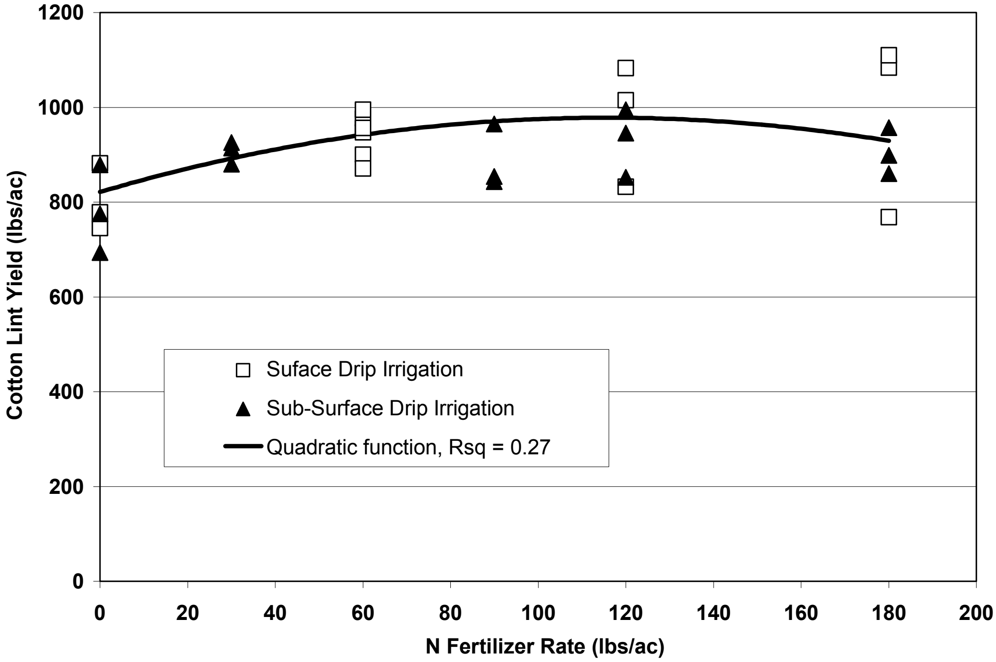

Figure 1. Nitrogen response in surface and subsurface drip irrigated cotton, Lubbock, 2000.

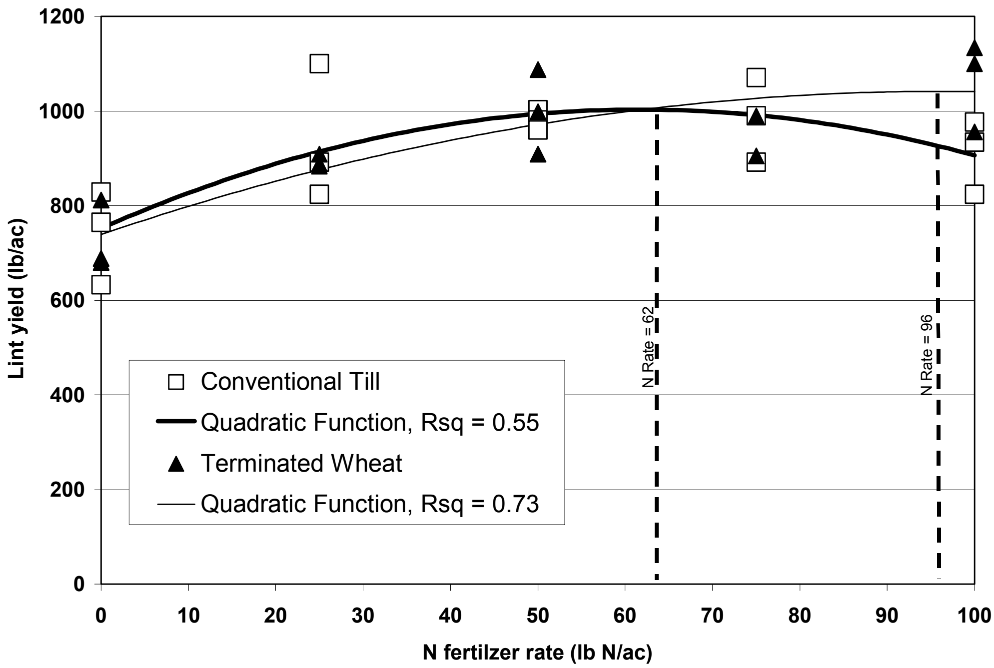

Figure 2. Nitrogen response in conventional and conservation-till cotton, Lubbock, 1997.

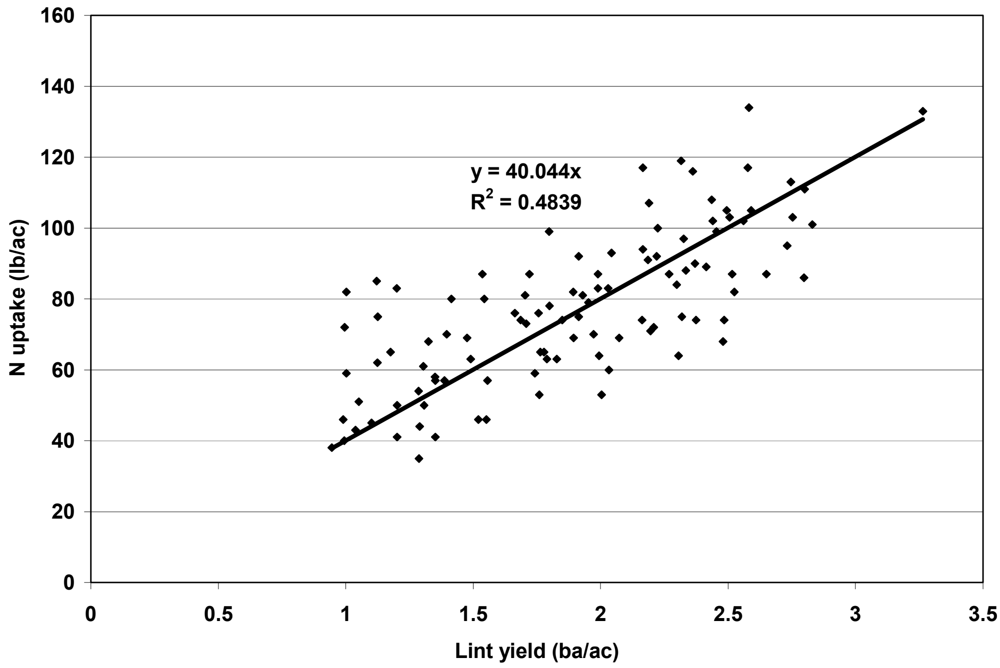

Figure 3. Plant N requirements vs. cotton lint.yield.