ABILITY OF COTTON (*GOSSYPIUM HIRSUTUM* L.) TO RECOVER FROM EARLY SEASON NITROGEN STRESS

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Abstract

Nitrogen (N) is an important plant nutrient for cotton production but if poorly managed it can lead to poor lint yield and low nitrogen use efficiency. This study was conducted to evaluate cotton's ability to recover from early season N stress and determine if sensor based nitrogen rate calculator (SBNRC) could be used to make mid-season N recommendations in cotton. The effect of preplant (0, 33, 67 and 101 kg N ha^{-1}) and side dress (0, 33, 67, 101 and 134 kg N ha^{-1}) N fertilizer applied at early pinhead square (EPHS), white flower (WF) and 30 days after white flower (30DAWF), on cotton lint yield was investigated at Lake Carl Blackwell (LCB) and Altus. The results indicated that, cotton suffered N deficiency if 0 kg N ha^{-1} preplant N was applied. However, regardless of site and season cotton recovered from early season N deficiency and attained near maximum lint yield, as long as side dress N fertilizer was applied by EPHS cotton growth stage. Delaying N application to 30 DAWF, cotton was unable to recover from N stress and lint yields were significantly ($P<0.05$) reduced. The increase in NDVI with preplant N application showed that sensor based nitrogen rate calculator (SBNRC) could be used to make precise side dress N recommendation for cotton at EPHS or WF growth stage, using farmers practice and N rich strip NDVI values. This will improve in season N recommendations; hence increasing lint yields prediction and nitrogen use efficiency.

Introduction

Cotton (*Gossypium hirsutum* L.) is a domesticated crop, which it's wild ancestors were perennial vines that inhabited several parts of Africa, Arabia, Australia and Mesoamerica. Today, it is a crop of global importance not only in terms of fiber production but ranked second best potential source of proteins after soybeans and fifth best oil-producing plant after soybean, palm-tree, colza and sunflower (Texier, 1993). The cotton plant has a unique growth habit of producing fruit on two different types of branches, which makes its management complicated. In addition, cotton growth is very sensitive to temperature and soil conditions (Stewart, 1986). After seeding it takes cotton about 4-14 days after planting to germinate, and reaches its maximum photosynthetic capacity at around 20 days of age, under warm and moist soil conditions (Constable et al., 1980). Low temperature and inadequate rain may hinder cotton germination.

In the US cotton belt, it is recommended that soil temperatures at 10.2 cm deep be 18.33^{0}C for 3 consecutive days for good cotton germination to be achieved. Root systems are important in cotton growth and development and sensitive to soil temperature, soil pH, water stress, herbicides injury and lack of nutrients, therefore inadequacy of these factors especially in early stages of cotton can affect lint yields and quality. A cotton plant typically blooms for 6 weeks, going through 5 developmental stages namely; pinhead square, match-head square, square growth midpoint candle and white bloom. Approximately 5 to 7 days after a flower appears it usually dries and falls from the plant exposing the developing boll, which last about 3 weeks, during which the fibers are elongated and the maximum volume of boll and seeds attained (Stewart, 1986). At this stage the demand for carbohydrates is high, hence adequate moisture and nutrients especially N and potassium (K) is paramount.

Cotton has an indeterminate growth habit and can grow very tall especially when excess N is applied. Growth regulators, such as mepiquat chloride, are generally applied to cotton to slow internode elongation (Stewart, 1986).

This is an added cost to the producer and could be avoided with proper management of N fertilizer. Cotton crop under optimal conditions can be harvestable in as little as 7 days after defoliation.

Nitrogen and Cotton Production

In cotton production nitrogen plays the most important role in building the amino acids and protein, hence stimulates the creation of the plant dry matter, and energy rich compounds, thereby, regulating photosynthesis and cotton development. Nitrogen is also required for fat synthesis during seed development (Boquet et al., 1993; FeiBo et al, 1998), thus influencing boll development, number of bolls per plant, boll weight, cotton lint yield and quality. Studies have indicated that, early N deficiency is associated with elevated levels of ethylene, and leads to increased boll shedding if this is not corrected in time (Lege et al., 1997)).

Research by Zhao and Derrick, (2000) found that, insufficient N supply during cotton reproductive growth depressed leaf area, leaf net photosynthetic rate, and leaf chlorophyll content, but increased leaf total nonstructural carbohydrate concentration leading to increased fruit abscission and decreased lint yield. These findings point out the need to timely correct N deficiencies in cotton, if optimum yields are to be achieved. The question however is, to what extent can N applications be delayed without compromising cotton productivity? This concern was addressed in this study.

Remote Sensing and N Application

Precision agriculture employs the use of remote sensing technology to allow timely and precise application of N fertilizer. This technology assesses the crop N status by comparing the plants grown under farmers practice, and where N is not limiting (N rich reference) based on the principles established by Schepers et al., (1992a,b). Random field variability in soil test and plant biomass has been documented at resolutions less than or equal to 1 m^2 (Solie et al,. 1996). Therefore a technology that tries to establish a precise N fertilizer rate has to consider these facts in order to meet maximum crop yields while considering plant needs which vary from one farm to the other due to infield variability. Past research has indicated that the variability present at 1 m^2 resolution can be detected using GreenSeeker™ Hand Held Optical Sensor Unit (NTech Industries, Inc.) sensors, to obtain normalized difference vegetative index (NDVI), which is an index used to estimate green biomass (Tucker, 1979) and computed using the following formulae:

$$NDVI = \frac{\rho_{NIR} - \rho_{\mathrm{Re}\,d}}{\rho_{NIR} + \rho_{\mathrm{Re}\,d}}$$

Where:

ρ_{NIR} – Fraction of emitted NIR radiation returned from the sensed area(reflectance)

ρ_{Red} – Fraction of emitted red radiation returned from the sensed area (reflectance)

The use of remote sensors to determine mid-season N rates and response indices in cereals grain production has made great advances in the past (Raun et al., 2002; Johnson and Raun, 2003; Morris et al., 2006). In cotton, Arnall, 2008 showed that, mid-season NDVI readings of the cotton crop biomass can be used to estimate lint yields, and from that the correct N rate the crop needs to achieve maximum yield.

However, the evaluation of cotton's ability to recover from earlier season N stress and using Sensor Based Nitrogen Calculator (SBNRC) to make mid-season precise N recommendations is yet to be fully explored.

Nitrogen Use Efficiency (NUE)
A fundamental aspect to improve nutrient management is the utilization efficiency with which plants capture nutrients applied in different forms, rates, placements and times. Nitrogen use efficiency and/or fertilizer recovery in crop production systems can be computed using, The Difference and Isotopic Methods (Sanchez et al., 1987; Varvel and Peterson, 1990). This is important in order to determine how much of the total N applied the plant actually used with respect to the total yields obtained; thereby helping the producer to achieve maximum production, protect the environment and economically apply N fertilizers. Recent studies indicate low world nitrogen use efficiency in cereals of 33% (Raun and Johnson, 1999) and estimated $750,000,000 of excess N flowing down Mississippi river (Malakoff, 1998).

This in turn signals the urgent need to embrace farm practices which encourage better management of nitrogen, not only in cereals but in cotton production. Studies have shown that, side dress N applications in the middle of the season can result in greater NUE's >50% (Vetsch and Randall, 2004), hence looking for better ways of refining N application will be more beneficial to the producer. It is also important to recognize that not always do all producers able to supply adequate N to cotton during its earlier stages of development, which eventually leads to N deficiency and reduced yields and quality of the cotton. The questions are, will in-season N application salvage this crop even after going through earlier N deficiency stress? and at what stage of cotton growth will that be possible?

In winter wheat Morris et al., (2006) observed that, complete yield recovery could be made even when N application was delayed until Feekes 7 in wheat. Wright *et al*., (2003), showed that, cotton can recover from slight N deficiencies but cotton recovery from more acute deficiencies is unknown and this is a problem that has to be addressed.

Our hypothesis was that, cotton would positively respond to N application, recover from early season N stress and show N deficiency that will be detected using NDVI , recover and produce maximum or near maximum yields after mid-season N application.

Objectives

To evaluate the ability of cotton to respond to N application, recover from early season nitrogen stress and determine to what extent N application can be delayed and maximum yields still be achieved.

Materials and Methods

Site Description

Altus Research station
A field experiment was established at Altus in the southwest part of Oklahoma. The annual average precipitation in this area is 741 mm, evenly distributed throughout the year. The temperature is hot during summer with 26^0 C and cold during winter with temperatures as low as 4^0 C. The predominant soil profile in this study area was Hollister clay loam (Fine, smectitic, thermic Typic Haplusterts), which consist of very deep, well drained, very slowly permeable soils.

Lake Carl Blackwell Research station
Lake Carl Blackwell (LCB) is located in north central Oklahoma, 14 km west of Stillwater. Air temperature ranges from -20.8^0 C. to 47.5 ^{0}C and mean annual rainfall is 831 mm (Oklahoma Water Resources Board, 1972). Most of the precipitation occurs in the spring and early summer. Many different soil profiles are represented at varying degrees of slope, with Pulaski Fine Sandy Loam (coarse-loamy, mixed, superactive, nonacid, thermic Udic Ustifluvent) and Port Silt Loam (Fine-silty, mixed, superactive, thermic Cumulic Haplustolls) being dominant (USDA / NRCS soil taxonomy).

Experiment and management

The experiments were established, in a randomized complete block design. The plots size was 4 rows wide and 6 m in length, with a row spacing of 75 cm at LCB and 100 cm at Altus. Soils samples (0-60 cm) from each site were collected and characterized before application of treatments (Table 1).

Table 1: Soil Chemical properties determined from initial soil samples (0-15 cm) at four locations, Oklahoma.

Site	Year	pH	Total N	Organic C	NO_3-N	P	K
			-------g kg $^{-1}$--------		--------------mg kg $^{-1}$------------		
Altus	2009	8.0	na§	8	5	16	280
LCB¥	2009	5.9	1.0	3.2	11	22	138.0
Altus	2010	8.2	0.4	10	10	29	282
LCB	2010	6.5	0.8	3.8	15	10	101

pH- 1:1 soil: water; K and P-Mehlich III; NO_3-N- 2 M KCL, Total N and Organic C-dry combustion

§ Data was not determined

¥ Lake Carl Blackwell

The cotton varieties, planting, sidedress, sensing and harvesting dates, are indicated in Table 3 and the treatment structure used in Table 2. At planting, preplant N was applied using urea (46-0-0) as nitrogen source while mid-season N was applied using UAN (28-0-0) dribbled along the rows, at early pinhead square (EPHS), white flower (WF), and 30 days after white flower (30DAWF). Sensing using Green Seeker ™ was done at the above mentioned cotton growth stages. At maturity, the two center rows of each plot were harvested with a plot harvester. Seed cotton weight was measured, then the cotton was ginned and lint weight per plot determined. Later, the lint yield per hectare basis was then calculated.

Table 2: Treatment structure and description of the trials conducted at Altus and Lake Carl Blackwell, Oklahoma, 2009-2010.

Trt±	Preplant	Side dress N	Total N	Growth stage§
	(kg N ha^{-1})	(kg N ha^{-1})	(kg N ha^{-1})	
1	0	0	0	-
2	67	0	67	-
3	134	0	134	-
4	0	134	134	Early pinhead square
5	0	134	134	White flower
6	0	134	134	30 days after white flower
7	34	101	134	Early pinhead square
8	34	101	134	White flower
9	34	101	134	30 days after white flower
10	67	67	134	Early pinhead square
11	67	67	134	White flower
12	67	67	134	30 days after white flower
13	101	34	134	Early pinhead square
14	101	34	134	White flower
15	101	34	134	30 days after white flower

§ Cotton growth stages when side dress N was applied

± Treatment

Table 3: Field trial information for Altus and Lake Carl Blackwell, 2009-2010

Site	Year	Variety	Dates§				
			Planting	EPH±	WF†	30DAWFŹ	Harvesting
Altus	2009	Deltapine DP 0924 B 2RF	03-05-09	02-07-09	20-07-09	19-08-09	11-13-09
LCB¥	2009	Deltapine DP 0924 B 2RF	27-05-09	13-06-09	13-07-09	12-08-09	13-12-09
Altus	2010	Deltapine DP 0924 B 2RF	05-05-10	09-06-10	19-07-10	13-08-10	19-10-10
LCB¥	2010	Dyna Gro DG 995 B 2RF	25-05-10	07-12-10	27-07-10	25-08-10	15-11-10

§ Date in month-day-year
¥ Lake Carl Blackwell
± Early pinhead square
† White flower
Ź 30 days after white flower
Note: Normalized vegetative index (NDVI) and side dress N application was done at EPH, WF and 30DAWF

Data management and analysis
Lint yield and NDVI data was analyzed using SAS package (SAS Institute, 2003) and correlation between lint yield and NDVI determined. Means were separated using protected LSD procedures.

Results

Nitrogen Response Measured in Season
Initial cotton response to applied preplant N was determined by measuring NDVI, at EPHS, WF and 30DAWF from the plots prior to receiving side-dress N. Plots that had been fertilized at a prior stage where not included. Generally, NDVI values taken at EPHS were low across season and years due to low crop biomass at that stage. At Altus in 2009, NDVI taken EPHS indicated no response to preplant N application (Fig 1). However, NDVI values taken at WF and 30DAWF showed an increase in NDVI by 0.02 and 0.03 respectively with each kg increase in preplant N applied. Nitrogen stress was observed at WF and 30DAWF with 0 kg N ha^{-1} preplant (Fig.1).

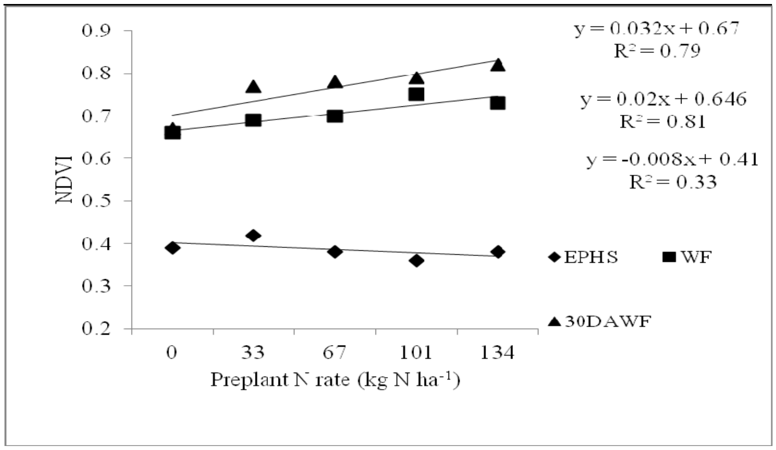

Figure 1: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2009, Altus, OK.

In 2010, different levels of preplant N rate did not significantly ($P<0.05$) affect NDVI values taken at EPHS and 30 DAWF, but a significant ($P<0.001$) linear increase in NDVI with N rate was recorded at WF growth stage (Fig 2). However, NDVI values taken at all the three cotton growth stages indicated that, with each kg increased in preplant N applied, NDVI values taken at EPHS, WF, and 30 DAWF increased by 0.008, 0.034, and 0.004 units respectively. Plots with no preplant N recorded low NDVI at WF indicating some level of N deficiency. The NDVI values recorded at WF and 30DAWF NDVI values remained fairly constant indicating that NDVI reached saturation limit (Fig. 2).

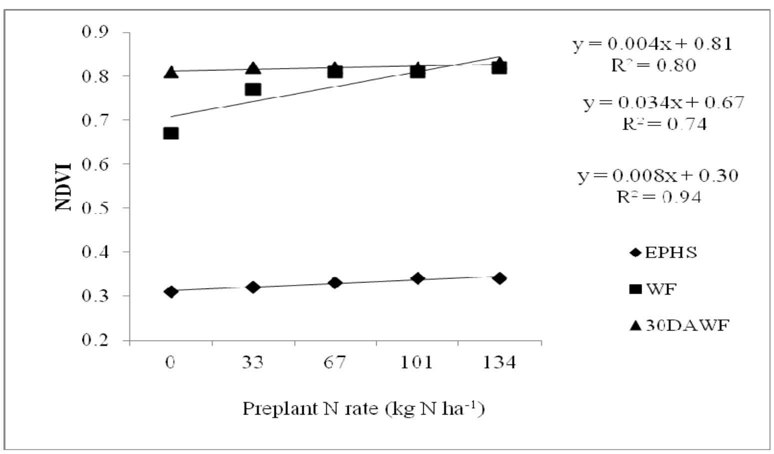

Figure 2: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2010, Altus, OK

At LCB in 2009, there was no significant ($P<0.05$) differences in NDVI due to preplant N application at all cotton growth stages. Nevertheless, the NDVI values taken at EPHS and 30DAWF indicated a slight positive increase in NDVI (EPHS=0.01 and 30DAWF=0.007) with each kg increase in preplant N applied, but the trend was not consistent (Fig 3).

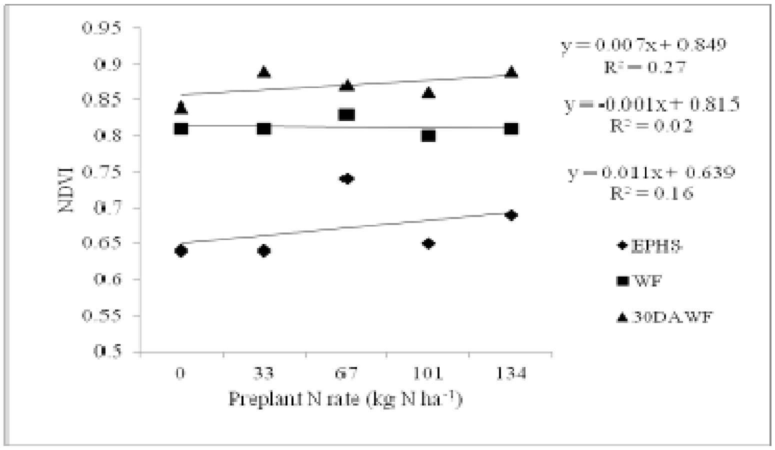

Figure 3: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2009, Lake Carl Blackwell, OK.

In 2010 NDVI values taken at EPHS, WF, and 30DAWF indicated an increase in NDVI by 0.028, 0.029, and 0.016 respectively with each kg increase in preplant applied (Fig 4). The NDVI values from plots that received 0 kg N ha^{-1} (NDVI= 0.47) showed that, cotton experienced N stress as early as EPHS growth stage. Also, at WF, N deficiency occurred in plots with low preplant N rate (0 and 33 kg N ha^{-1}) compared to those that received between 67 and 134 kg N ha^{-1} (Fig 4). The same trend was recorded at 30DAWF growth stage, where high N stress was experienced by cotton with 0 kg N ha^{-1}.

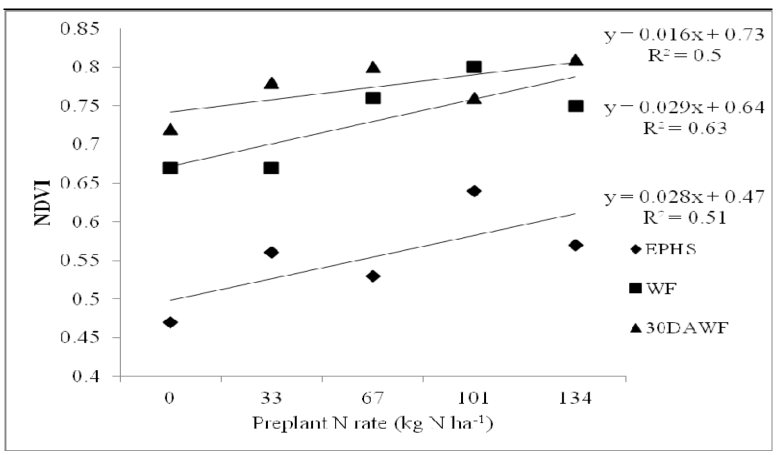

Figure 4: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2010, Lake Carl Blackwell, OK.

Overall, the positive correlation of N rate and NDVI at Altus in 2009 and 2010 indicated that the cotton suffered some level of N stress which was confirmed by a significant difference in the lint yields of treatments 1, 2 and 3 (Table 4). Likewise a lack of positive and inconsistent trend in NDVI at LCB in 2009 and 2010 respectively, indicated no response to fertilizer N which was confirmed by the lack of significant difference in lint yields of treatments 1, 2, and 3 (Table 4).

Table 4: Means for lint yield as affected by split N application applied preplant and sidedress at early pin head square, white flower and 30 days after white flower, 2009 and 2010, Altus and LCB, OK.

				……..Lint yields (kg ha^{-1})……….			
				2009		2010	
TRT∫	Preplant (kg N ha^{-1})	Side dress (kg N ha^{-1})	Application time	Altus	LCB†	Altus	LCB†
1	0	0	Planting	744^{fź}	2548^{ab}	829^{g}	1381^{b}
2	67	0	Planting	1317^{cde}	2344^{ab}	1378^{ef}	1531^{ab}
3	134	0	Planting	1546^{ab}	1992^{b}	1785^{bcd}	1751^{ab}
4	0	134	EPH§	1572^{a}	2522^{ab}	1957^{ab}	1788^{ab}
5	0	134	WF¥	1449^{abcd}	2529^{ab}	1320^{f}	1697^{ab}
6	0	134	30DAWF±	857^{f}	2734^{ab}	1460^{def}	1337^{b}
7	33	101	EPH	1583^{a}	2340^{ab}	1918^{abc}	1601^{ab}
8	33	101	WF	1604^{a}	2323^{ab}	1619^{bcdef}	1633^{ab}
9	33	101	30DAWF	1148^{e}	2408^{ab}	1565^{dcef}	1466^{b}
10	67	67	EPH	1465^{abc}	2754^{ab}	1799^{bcd}	1676^{ab}
11	67	67	WF	1555^{ab}	2223^{ab}	1685^{bcde}	2057^{a}
12	67	67	30DAWF	1252^{be}	2665^{ab}	1753^{bcd}	1853^{ab}
13	101	33	EPH	1495^{abc}	2361^{ab}	1717^{bcde}	1665^{ab}
14	101	33	WF	1523^{ab}	2617^{ab}	1630^{cdef}	1735^{ab}
15	101	33	30DAWF	1364^{bcd}	2840^{ab}	1793^{abc}	1300^{b}
Mean				**1365**	**2480**	**1641**	**1631**
SED				**98**	**392**	**177**	**279**

§ Early pinhead square
¥ White flower
± 30 days after white flower
† Lake Carl Blackwell
∫ Treatment
ź Means in the same column followed by the same letter are not significantly different from each other at P<0.05.

Yield Recovery
In 2009 at Altus, the different treatment combination significantly (p<0.0001) affected lint yields (Table 4 and 5) and lint yields generally increased with preplant N application (Fig.5).

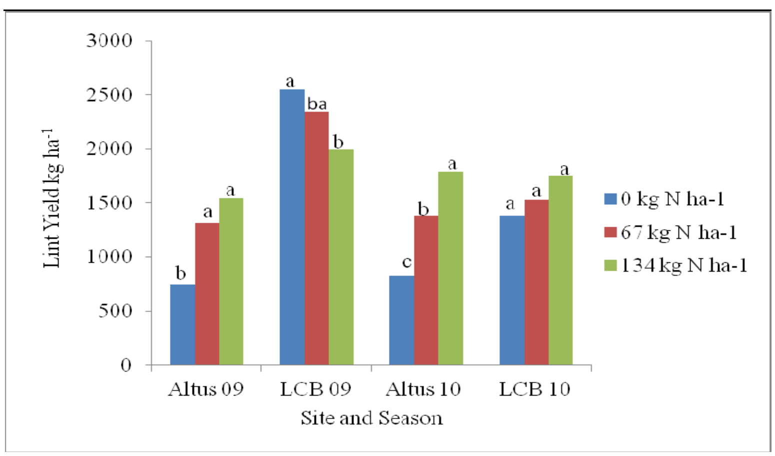

Figure 5: Cotton lint yield N response to Preplant fertilizer application, in 2009 and 2010 at Altus and Lake Carl Blackwell, OK

Treatments 2 through 15 resulted in higher lint yields compared to that of the control. The lint yields from different factorial combinations did not significantly (P<0.05) differ from that of the N rich plot (treatment 3). Lint yields ranged from 744 to 6104 kg ha^{-1} and treatments that received 33 kg N ha^{-1} preplant and 101 kg N ha^{-1} side dress N, applied at EPHS and WF, consistently gave slightly better lint yields. Overall, cotton was able to recover from early N stress experienced at WF (when 0 kg N ha^{-1} preplant was applied) and achieved near maximum lint yields when side dress N was applied at WF cotton growth stages Delaying application of side dress N to 30DAWF cotton growth stage, cotton failed to recover which led to a decline in lint yield (Table 4). When 101 kg N ha^{-1} was applied preplant near maximum yields were reached by EPHS and WF. In 2010, treatments significantly (P<0.0001) contributed to the recorded lint yield which ranged from 829 to 2198 kg ha^{-1} (Table 4 and 5).

Table 5: Analysis of Variance for lint yield as affected by side dress N applied at early pin head square, white flower and 30 days after white flower cotton growth stages, in 2009 and 2010, Altus and Lake Carl Blackwell, OK

		…..…..…...…Mean squares……………….			
		2009		2010	
		Altus	LCB	Altus	LCB
Source of variation	df				
Replication	2	67715	64223	51237	35738
Side dress N rate	3	52791*	120495	112020	181924
Growth stage	2	564777***	180497	248595*	263584
Side dress N* Growth stage	6	55827**	95047	162113*	67783
Residual error	22	14619	268502	54959	116044

*, **, *** significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

Treatments 2 through 15 resulted to higher lint yield compared to that of the control. The lint yields from the different factorial combinations did not significantly differ from each other and that of the N rich plot (treatment 3). Within the 0 kg N ha^{-1} preplant and 134 kg N ha^{-1} side dress N rate group EPHS maximized total yield at 1957 kg lint ha^{-1} while both the WF and 30DAWF applications resulted in significantly less lint yield. There was no significant difference between the timings of the 33 kg N ha^{-1} preplant treatments however there was a trend of decreasing lint with delayed N; 1918 kg at EPHS, 1619 kg at WF, and 1565 kg at 30DAWF (Table 4). Neither the 67 nor 101 kg N ha^{-1} preplant groups demonstrated significant differences in yields. However the EPHS and 30DAWF 67 kg N ha^{-1} treatments had significantly higher yields than the 67 kg N ha^{-1} preplant only treatment in Table 4.

At LCB in 2009, there was no significant (P<0.05) effect of treatments on lint yield (Table 4 and 5). However, the lint yields were actually the lowest in the 134 kg N ha^{-1} plots at 1992kg ha^{-1} while the 0 N plot reached 2546 kg ha^{-1}, suggesting not only no response to N but potentially rank growth induced by high levels of preplant N. In 2010 study site, there was no significant (p<0.05) effect of treatments on lint yield (Table 4 and 5). However, lint yield numerically increased with increasing levels of preplant N. Regardless of preplant and side dress N applied, delaying side dress N application to 30DAWF, led to a decline in lint yield.

Discussion

Nitrogen response in terms of NDVI and lint yields varied with site and cropping season. In 2009 and 2010 at Altus, NDVI values increased with preplant N rate signifying that cotton deficient in N could perform better with additional N. The better N response observed in NDVI obtained at WF and 30DAWF cotton growth stage in 2009, suggested that N deficiency was identified at the WF and 30DAWF growth stages. The increase in lint yields when side dress N was applied at WF showed that cotton positively responded to the additional N and recovered from earlier N stress. On the other hand, lint yield declined when side dress N was applied at 30DAWF; indicating that application of side dress N 30DAWF was too late.

Past finding (Stewart, 1986) have established that, at vegetative growth stage and 3 weeks after flower appearance, cotton requires adequate N for fiber elongation, maximum boll and seed production, due to cotton's high demand for carbohydrates at this stages. Therefore, the timing of side dress N application in cotton production is crucial. In

2010, NDVI taken at the three cotton growth stages increased with preplant N rate with the WF sensing showing the greatest difference in NDVI readings. Based on the lint yields, cotton recovered from an earlier N deficiency experienced at WF with 0 kg N ha^{-1} preplant application and higher lint yields recorded compared to that of the control. However, better lint yields were recorded when side dress N was applied at EPHS, and slightly declined when N side dresses was delayed to WF and 30 DAWF. These results indicated that although cotton recovered from stress when side dress N was applied at WF, but it was already late because the yields were the lowest compared to the rest of treatments.

Although the NDVI taken at EPHS and 30DAWF at LCB in 2009 indicated an increase with preplant N rate, the addition of side dress N did not contribute to any significant differences in lint yield. This outcome was attributed to mineralization of organic N and a subsequent increase in the available N in the soil profile as the season progressed. As a result, high supply of N in the soil favored lush vegetative growth at the expenses of lint yield production. Past findings have established that, cotton has an indeterminate growth habit and if excess N is applied its maturity will be delayed and lower lint yields obtained (McConnell et al., 1996).The excess vegetative growth could also have been contributed to failure to apply growth regulators at LCB site. Growth regulators, such as mepiquat chloride, are generally applied to cotton to slow internode elongation (Stewart, 1986).

However, in 2010 positive response to N application was recorded in the same site. The NDVI values indicated N deficiency at all the three growth stages, and showed no significant differences. High lint yields recorded at EPHS and WF indicated that cotton recovered from an early N stress when side dress N was applied at EPHS and WF growth stages. Delaying side dress N application to 30DAWF was too late, and as a result lint yields were reduced.

Overall, across site and cropping season, it was established that a positive increase in NDVI with preplant application rate, indicated that cotton could benefit from additional N. This implied that, SBNRC could be used to make precise in season N recommendation for cotton using farmers practice and N rich NDVI values. However, the growth stage when to collect NDVI to be used in the calculation will differ from site and cropping season due to spatial and temporally variability widely found in the farming systems (Solie et al., 1996).

Regardless of season and site, cotton suffered N deficiency when no preplant N was applied but was able to recover from early season N deficiency as long as side dress N fertilizer application was made by EPHS. It is important to note that in 2009 at Altus an increase in NDVI with N rate was not recorded until WF yet in 2010 a positive trend developed by EPHS. In each season the stage at which NDVI detected a difference across N rates corresponds with the last growth stage that N could be applied to the treatments receiving 0 N preplant and maximum yield be achieved.

Conclusion

Generally, cotton suffered early season N deficiency when no preplant N was applied, indicating the importance of application of N fertilizer at planting. Apart from at Altus in 2010 cropping season, cotton recovered from N deficiency and attained near maximum lint yields, as long as side dress N fertilizer application was not delayed beyond WF growth stage. Delaying side dress N application up to 30DAWF, lint yields were depressed. The increase in NDVI with preplant N application indicated that additional N could improve cotton growth and development. Based on this finding, SBNRC could be used to make precise in season N recommendations in cotton, using NDVI values collected at EPHS or WF flower, depending on the site and season. This could eventually improve lint production and the efficiency of nitrogen fertilization in cotton.

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