ABILITY OF COTTON (*Gossypium hirsutum* L.) TO RECOVER FROM EARLY SEASON NITROGEN STRESS, AND MAIZE (*Zea mays* L.) GRAIN YIELD RESPONSE TO DISTANCE NITROGEN IS PLACED AWAY FROM THE ROW

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CHAPTER I

ABILITY OF COTTON (*Gossypium hirsutum* L.) TO RECOVER FROM EARLY SEASON NITROGEN STRESS

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 18.33^0C 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. 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 ^{TM} 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.

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 3). 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.3).

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 4). 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. 5).

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 5).

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 6). 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 6). The same trend was recorded at 30DAWF growth stage, where high N stress was experienced by cotton with 0 kg N ha^{-1}.

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).

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.7). 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). 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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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

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

Trt±	Preplant (kg N ha^{-1})	Side dress N (kg N ha^{-1})	Total N (kg N ha^{-1})	Growth stage§
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[†]	30DAWF[ź]	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

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

TRT[∫]	Preplant (kg N ha^{-1})	Side dress (kg N ha^{-1})	Application time	..…..…..Lint yields (kg ha^{-1})……….			
				2009		2010	
				Altus	LCB[†]	Altus	LCB[†]
1	0	0	Planting	744^{f}[ź]	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.

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.

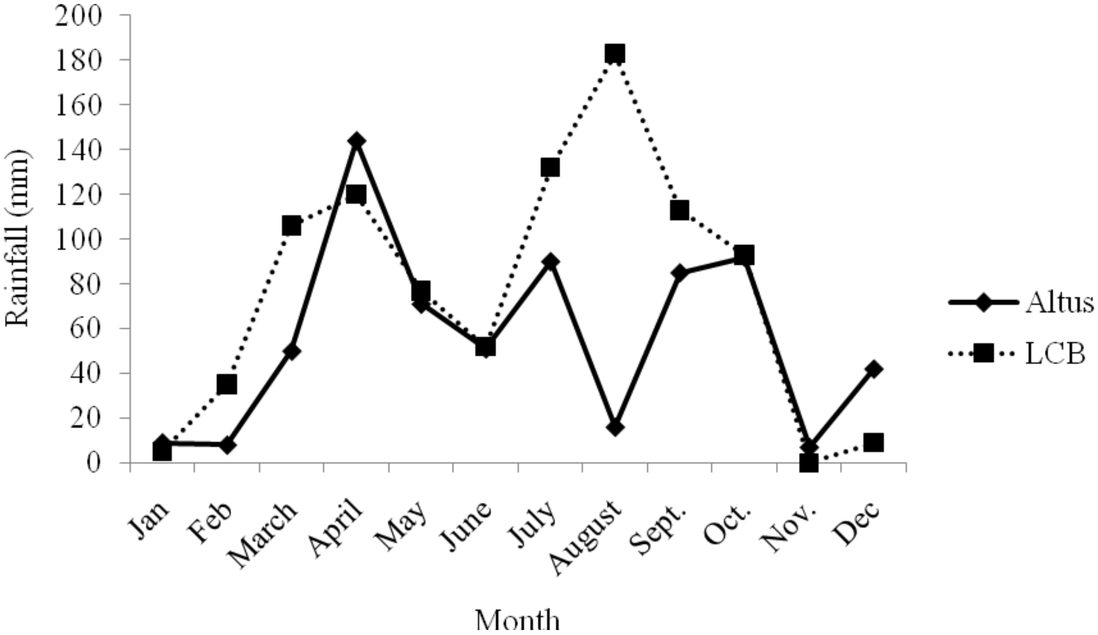

Fig 1: Rainfall distribution at Altus and Lake Carl Blackwell, OK, 2009.

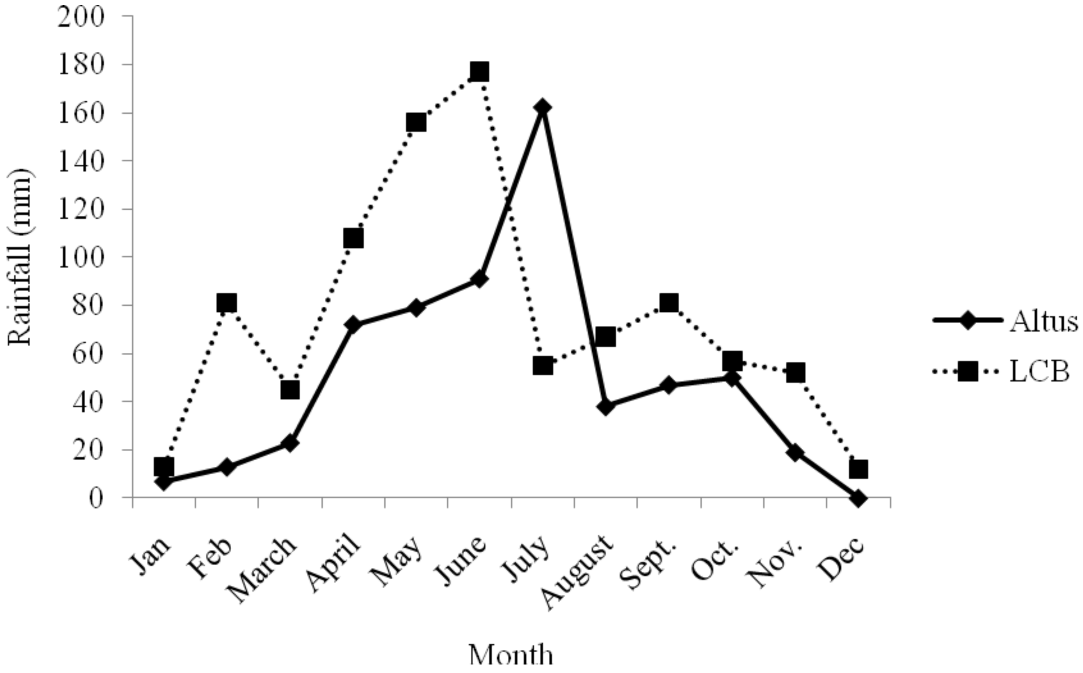

Fig 2: Rainfall distribution at Altus and Lake Carl Blackwell, OK, 2010

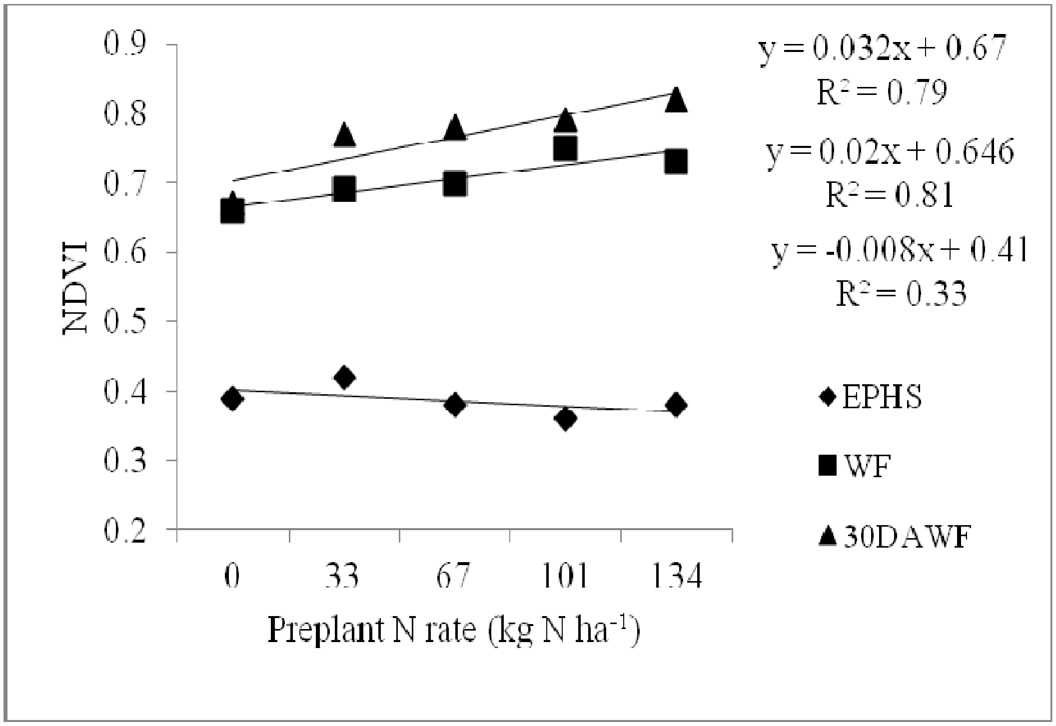

Fig 3: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2009, Altus, OK.

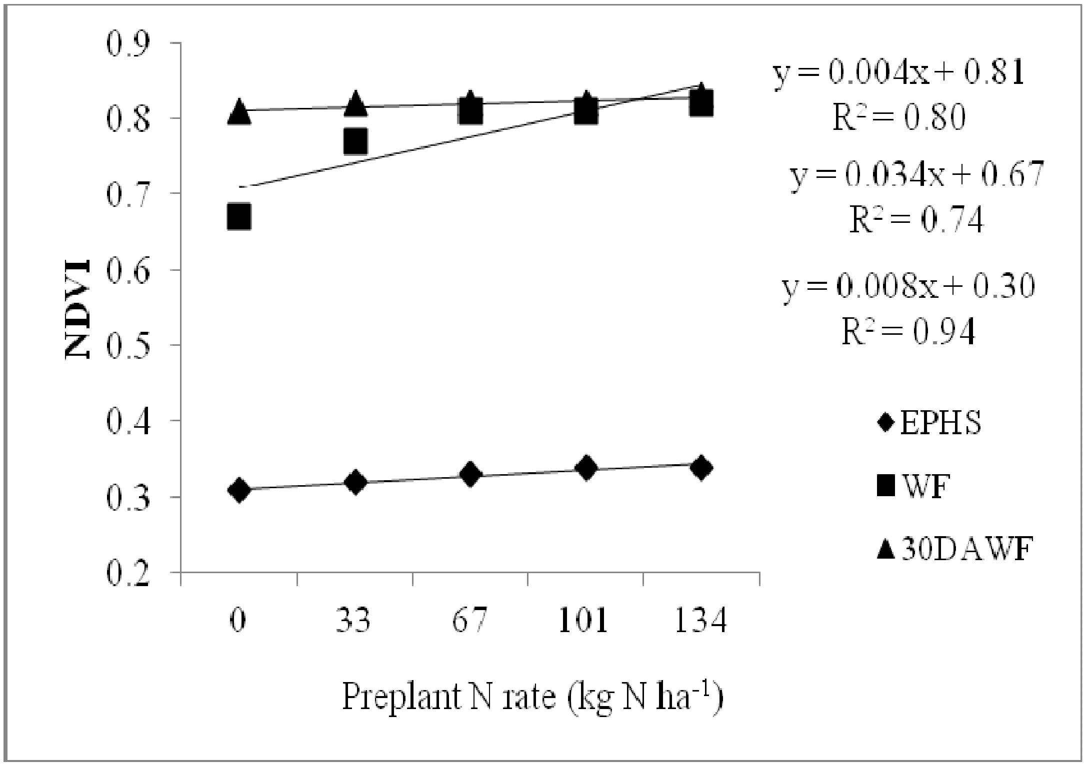

Fig 4: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2010, Altus, OK

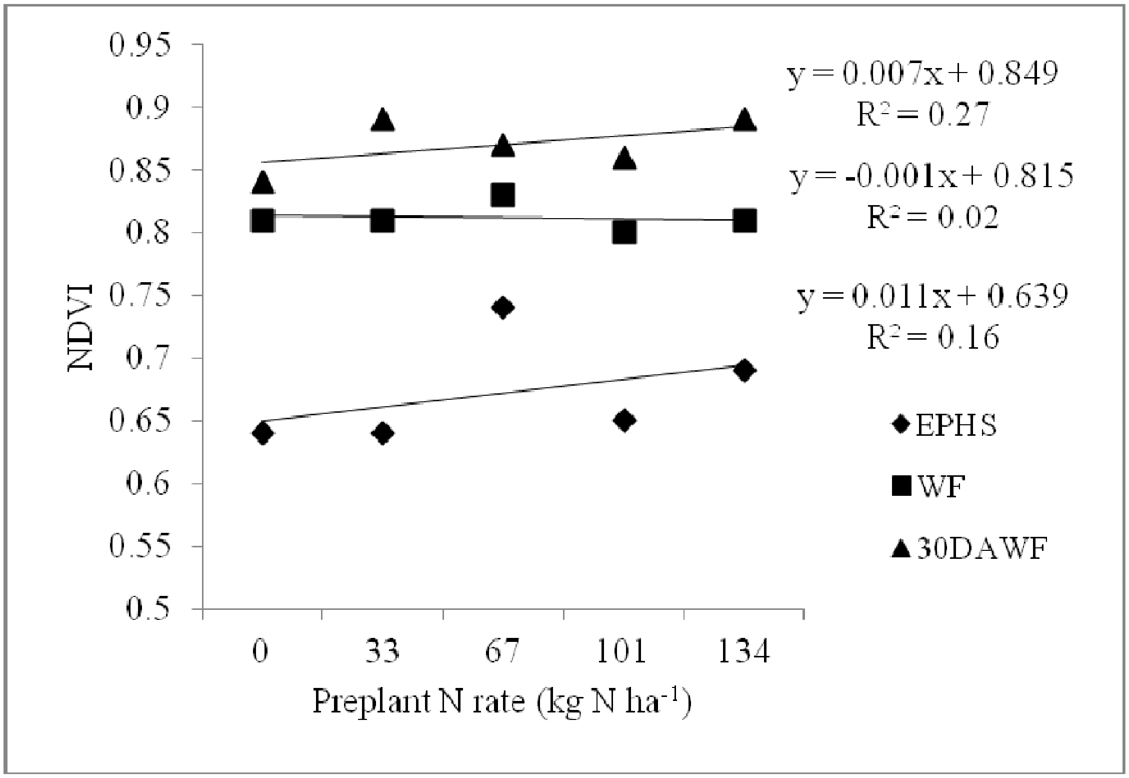

Fig 5: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2009, Lake Carl Blackwell, OK.

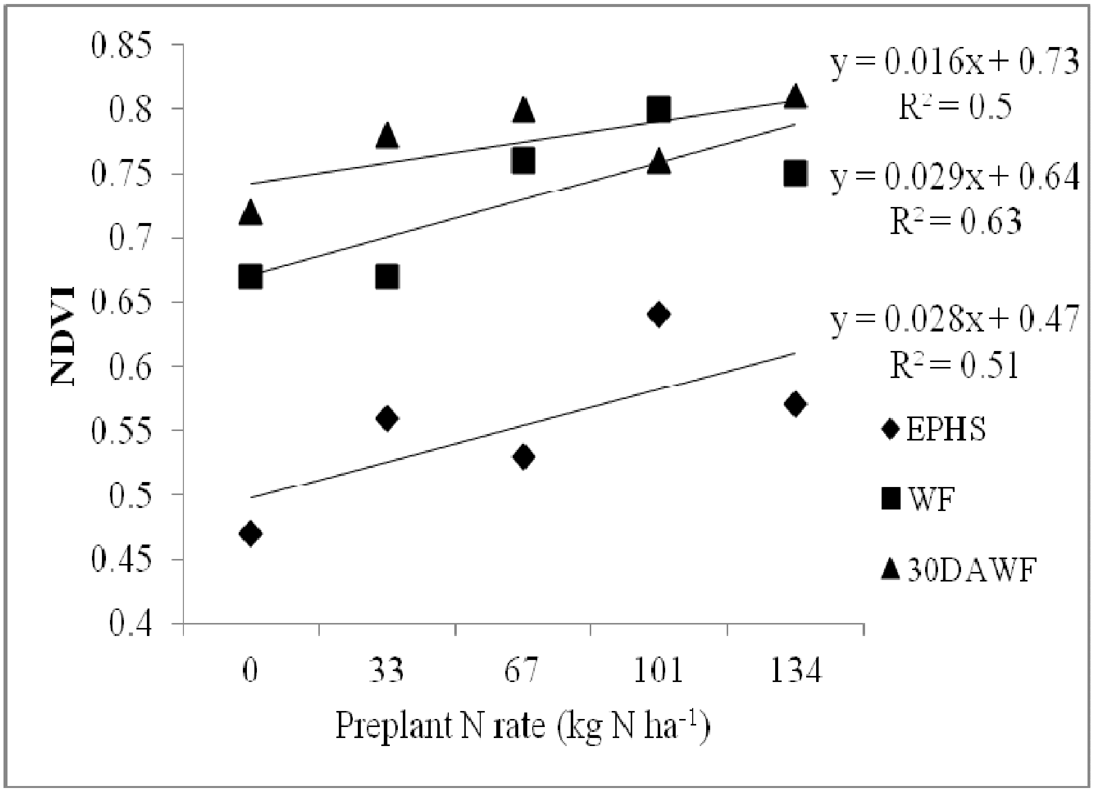

Fig 6: Effect of preplant N application at 0, 33, 67,101 and 134 kg N ha^{-1} on Normalized Vegetative Index (NDVI) at early pinhead (EPHS), white flower (WF) and 30 days after white flower (30DAWF) cotton growth stages in 2010, Lake Carl Blackwell, OK.

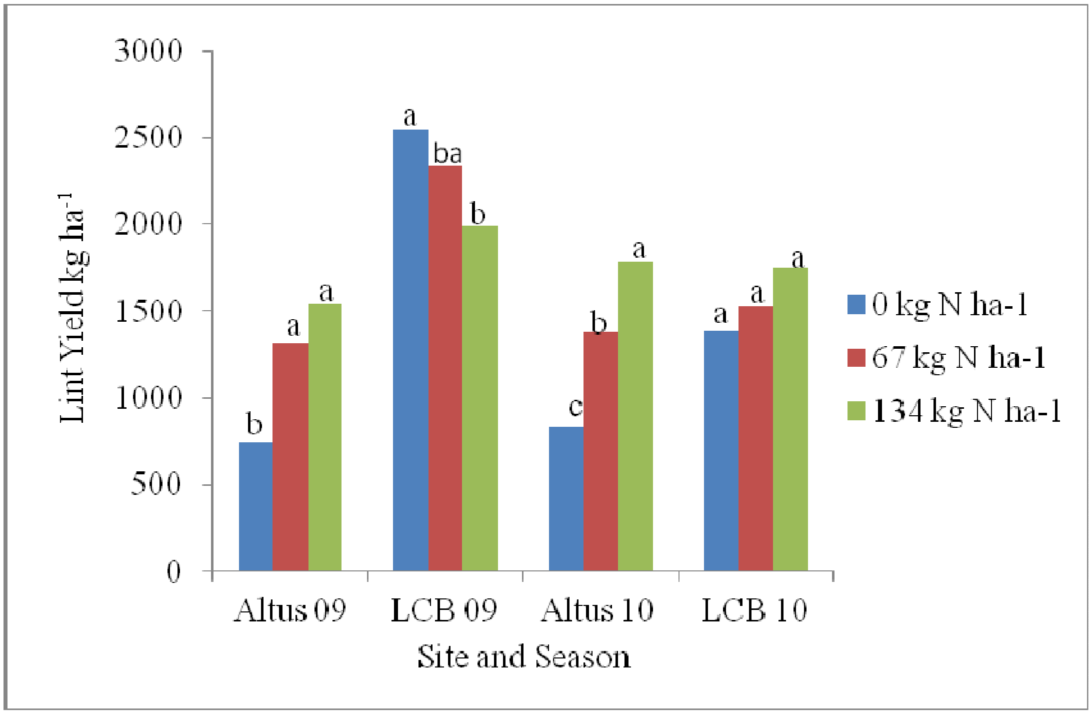

Fig 7: Cotton lint yield N response to Preplant fertilizer application, in 2009 and 2010 at Altus and Lake Carl Blackwell, OK

CHAPTER II

MAIZE GRAIN YIELD RESPONSE TO THE DISTANCE NITROGEN IS PLACED AWAY FROM THE ROW

ABSTRACT

Splitting the total nitrogen (N) application rate can reduce over application and increase nitrogen use efficiency (NUE). The effect of the distance, N is placed away from the row, mid-season on maize grain yields and NUE is not well understood. Field studies were established to evaluate application of midseason (V8 to V10) variable liquid UAN (28%) rates (45, 90,134, and 224 kg N ha^{-1}) applied at different distances (0, 10, 20, 30 and 38 cm) away from the row on maize grain yield and nitrogen use efficiency at Haskell and Hennessey in 2009, Efaw in 2010, and Lake Carl Blackwell in 2008, 2009, and 2010. A randomized complete block design, with 3 replications was used at all 6 site-years. The middle maize rows were harvested at maturity and data statistically analyzed. In four of six site-years, maize grain yields increased the closer N was applied to the row. This was more pronounced at the lower N rates where N availability closer to the row might be more important, especially in N depleted soils. Increased N rate led to a general decline in NUE to as low as 4%, 26%, 45%, 43% at Hennessey, Efaw, LCB (2009), and LCB (2010) respectively. Regardless of cropping season and location, the

best sidedress N application distance, was between 0 and 10 cm. Application of N at distances >10cm away from the row resulted in reduced grain yield, N uptake and NUE.

INTRODUCTION

Nitrogen (N) remains as the most limiting and crucial plant nutrient in crop production since the establishment of its essentiality in 1872 by G.K. Rutherford, a chemist from Scotland (Fageria et al., 1997 a). World food production has increased since the 1950s with the introduction and use of inorganic fertilizers, especially N (Follet, 2001; Fageria et al., 2003 a). Nitrogen in the soil is available as nitrate (NO_3^-) and ammonium (NH_4^+) forms for plant uptake. Nitrates are the most mobile form of N in the soil; thereby excess application of N has been demonstrated to contribute to average leaching losses between 25-50% of N applied in some cropping systems (McNeal and Pratt, 1978), and can end up in surface water.

High levels of N in water bodies have led to eutrophication; a process where excess N in water bodies leads to excess plant growth which depletes oxygen supply in the water. This condition leads to suffocation of aquatic life and development of hypoxic zones such as the one in the Gulf of Mexico. Also, NO_3^- concentrations > 10 mg L^{-1} in drinking water can be dangerous to humans (Comly, 1945). Other pathways, where N is lost include; plant loss, volatilization, denitrification and surface runoff.

The concentration of N forms (NH_4^+ and NO_3^-) in the soil , available soil carbon (C), temperature, and soil moisture are factors that have been established to affect denitrification in the soil (De Klein and Van Logtestijn,1994; Rolston,1981; Mancino et al., 1988; Davidson,1992). Denitrification has also been found to be high under neutral and alkaline soil conditions, compared to acidic soil; a phenomena associated with low amounts of C and mineral N available to denitrifying bacteria, under acidic conditions (Simek and Cooper, 2002). Ammonia volatilization is the process where NH_4^+ is converted to NH_3 gas and lost to the atmosphere. Plants can absorb or lose NH_3 to the surrounding air by volatilization (Stutte et al., 1979). Apsimon et al., 1987, reported a 50 % increase in NH_3 emission across Europe between 1950 and 1980, and this was mainly due to agriculture practices.

Although plant N loss can occur throughout the cropping season (Harper and Sharp, 1995), recent studies have shown that plant N loss could account for 52 to 73 % of the unaccounted N in 15^N balance calculations and takes place at reproductive growth stages (Francis et al., 1997). Other findings have established that, 30-70 % of applied inorganic fertilizers are lost from the fields through crop harvests, 5-10% lost through leaching, 10-30% as gaseous compounds, and 10-40% incorporated into soil organic matter (Foth and Ellis, 1988).

Split N application; can reduce excess application of N fertilizer and increase NUE (Martin et al., 1994; Ritter et al., 1993). Westermann and Crothers, (1993) established that, applying a portion of N fertilizer in corn at planting and the remainder 5 to 6 weeks later should increase both NUE and N uptake by minimizing leaching opportunity time and synchronizing N application with N uptake by the crop. However, the effect of placement distance of the mid season (V8 to V10) applied N on maize yields and NUE has not been extensively studied.

Nitrogen Use Efficiency (NUE)

Nitrogen use efficiency (NUE) can be defined as the ability of a crop to take up and utilize the applied N fertilizer in crop production. The concept of NUE has been classified as agronomic efficiency, physiological efficiency, agro-physiological efficiency, apparent recovery efficiency and utilization efficiency and calculated based on the following formulas (Fageria and Baligar, 2003b; Fageria et al., 2003a):

Agronomic efficiency (AE) = $(G_f - G_u / N_a) = \text{kg kg}^{-1}$

Where G_f is the grain yield of the fertilized plot, G_u is the grain yield in the unfertilized plot, and N_a is the quantity of nutrient applied.

Physiological efficiency (PE) = $(Y_f - Y_u / N_f - N_u) = \text{kg kg}^{-1}$

Where $Y_{f\ is}$ the total biological yield (grain plus straw) of the fertilized plot, Y_u is the total biological yield in the unfertilized plot, N_f is the nutrient accumulation in the fertilized plot in grain and straw and N_u is the nutrient accumulation in the unfertilized plot in grain and straw.

Agrophysiological efficiency (APE) = $(G_f - G_u/N_f\text{-}N_u)$ = kg kg^{-1}

Apparent recovery efficiency (ARE) = $(N_f - N_u / N_{a)}$ x 100 = %

Where N_f is the nutrient accumulation by the yield in the fertilized plot, Nu is the nutrient accumulation by the yield in the unfertilized plot, and N_a is the quantity of nutrient applied.

Improving Nitrogen Use Efficiency

In order to increase production and reduce environmental pollution due to excess N fertilizer application, improving NUE remains important. Currently, the world nitrogen use efficiency in cereals is approximately 33% and the 67% of unaccounted N represents annual losses of US$15.9 billion (Raun and Johnson, 1999).

In the USA, Booth (2006) estimated that each spring US$391 million in excess nitrogen fertilizer flows down the Mississippi river, while Malakoff (1998) estimated an annual loss of US$750 million, with a lot of this excess N, coming from crop production in the upper Midwest. It is important that such large losses be avoided especially if agriculture production is to keep pace with current world population growth estimated at100 million people/yr (UN 1999).   Enhancing crop production and improving NUE, through the development of sound agriculture technologies that enable better management of N fertilizer will definitely need to be embraced. The established techniques should be able to increase uptake and minimize post harvest soil NO_3^- because most NO_3^- has been found to occur between the fall harvest and spring planting (Martin et al., 1994; Ritter et al., 1993).

Midseason Nitrogen Application

Corn only takes up limited amounts of N prior to four leaf stage and starts accumulating substantial N forty days after emergence (Sawyer et al,. 2006). Application of all N fertilizer at pre-plant, can therefore lead to N losses and reduced NUE. Buzickly, (1983), established that application of all N fertilizer pre-plant could lead to up to 36% N loss of fall applied N fertilizer compared to that applied in the spring.

Research studies have shown that using an optical sensor based algorithm to calculate in-season potential crop yields, and estimates of N responsiveness could lead to improved N recommendations, thus avoiding losses due to excess N (Raun et al., 2005). Voss, (1998), established that fertilizer N recommendation for corn could be improved by calibrating soil nitrate levels. This method required taking soil samples before making the N fertilizer recommendation. However, the practicality of this method remains a challenge; since soil testing takes place on less than 10% of the agricultural land in developed countries (Hailin Zhang, personal communication, May 2011).

Studies by Varvel et al., 1997, demonstrated that mid-season chlorophyll meter readings could be taken and used to calculate a sufficiency index for which in season N recommendations could be based on. He stated that, in-season N fertilizer should be applied whenever the sufficiency index was below 95%. In a separate study, Lukina et al., 2001, proposed that, mid-season N fertilizer required to maximize grain yield for a specific season could be based on NDVI sensor readings collected early in the season.

Raun et al., (2005) showed that, mid-season N fertilizer recommendations could be improved by basing the calculated N rates on predicted yield potential and a response index. Their work using this approach resulted in an increase in NUE of more than 15% in winter wheat, when compared to traditional practices with applied N at uniform rates.

In corn, Tubana et al., (2008) established that, using an algorithm to predict mid-season (V8 to V10) N responsiveness (RI) and predicted yield potential (YP0), plus modifying for stand variation using the coefficient of variation (CV) from sensor readings, contributed to an increase in NUE and net return from applied N fertilizer.

Nitrogen Placement

Nitrate N, is the most mobile N source in the soil and mainly taken up by crops through mass flow and diffusion (Barber, 1995). Therefore available soil moisture and diffusion potential plays a great role in NO_3^--N mobility and subsequent uptake by crops.

Consequently, high moisture and diffusion potentials can result in an increase in N movement in the soil (NaNagara et al., 1975).

This is where the placement of N fertilizer, whether preplant or mid-season becomes a concern. Available soil moisture and how far the N fertilizer is placed away from the row will be a determining factor on whether the crop takes up the applied N and eventually utilizes it for building structural components. For example in an instance where moisture is a limiting factor, like in arid to semi arid regions, mid-season N application (V8 to V10) needs to be synchronized with correct application distance, in order to enhance uptake of the applied N nutrient.

This is because; the low moisture regimes in such environments can hinder N movement in the soil. Inadequate soil moisture can also affect physiological development of corn by hindering development of the root system (Shoup and Janssen, 2009). Therefore, planting closer to nitrogen bands enhances the uptake of N by the crops with poorly developed root system.

Studies conducted by Edmonds, (2007) on mid-season application of N applied to every other row, indicated that, rows that did not have midseason N application had lower yields and did not benefit from midseason N application of the adjacent row. This finding demonstrated that, in an environment where moisture is limiting, mass flow may not be enough to move mid-season applied N great distances in a single growing season (76 cm rows).

Elsewhere, Vyn and West, (2008), established that planting corn using real time kinematics (RTK) 12.7 cm from the pre-plant band of UAN increased yields. Their study showed that, maize planted directly over the 10.2 cm deep band had a higher nitrogen concentration; although in most cases lower yields. The low yields could have been due to local toxicity from direct contact between the seed and fertilizer at planting. These findings identified the need for continued work in N placement distance from the maize row and how it impacts yield and NUE.

OBJECTIVES

The objective of these field experiments were to evaluate midseason (V8 to V10) variable liquid UAN (28%) rates (45, 90,134, and 224 kg N ha^{-1}) applied at different distances (0, 10, 20, 30 and 38 cm) within the row on maize grain yield and nitrogen use efficiency.

MATERIALS AND METHODS

Site Description

Field experiments were established in 2008, 2009 and 2010 at Haskell, Hennessey, Efaw and Lake Carl Blackwell (LCB), Oklahoma, USA. The soil at Haskell is a Taloka silt loam (fine, mixed, active, thermic Mollic Albaqualfs), at Hennessey, Bethany silt loam (fine, mixed, superactive, thermic Pachic Paleustolls). The LCB site generally has different soil profiles represented at varying degrees of slope. However, Pulaski fine sandy loam (coarse-loamy, mixed, superactive, nonacid, thermic Udic Ustifluvent) and Port silt loam (Fine-silty, mixed, superactive, thermic Cumulic Haplustolls) were the common soil types.

Finally Efaw experimental site was composed of mainly, Pulaski fine sandy loam (Coarse-loamy, mixed, superactive, nonacid, thermic Udic Ustifluvents), and Grainola silty clay loam (Fine, mixed, active, thermic Udertic Haplustalfs).
The climatic conditions for each study site during 2008, 2009 and 2010 cropping seasons are presented in Figures 1, 2 and 3.

Experiment and management

At the beginning of each experiment, composite soil samples (0-15 cm soil depth) were taken from all study areas for initial site characterization. The results from initial soil chemical properties are presented in Table 1. For all sites, a randomized complete block design with three replications was used. Plot size was, 20 meters long and four rows wide, with a row spacing of 76 cm. Each site was planted with a John Deere Maxemerge 2, four row vacuum planter. Treatments for each plot and for all locations and years were administered according to the treatment structure (Table 2). Year, varieties planted, spacing and field management dates are described in Table 3.

At planting, treatments 6 through 17 received pre-plant UAN (28-0-0) fertilizer at 45 kg N ha^{-1}. At V8 to V-10 maize growth stage, UAN side dress N fertilizer was applied to the soil surface in a continuous stream at rates of 45, 90 and 134 kg N ha^{-1} at variable distances of 0, 10, 20 and 30 cm from the plant row.

At harvest, the two middle rows of each plot were harvested using a Massey Ferguson 8XP self propelled combine, equipped with an automated weighing system (HarvestMaster Inc, 1994). Grain yields for all the treatments were expressed at 15.5% moisture.

Data management and analysis

Grain yield data obtained from all locations and years were separately analyzed using GLM in SAS version 9.1 (SAS Institute, 2003) to determine treatment effects. Means were separated using Fishers protected LSD and non-orthogonal, single-degree-of-freedom contrasts were performed. Apparent recovery efficiency of the applied nutrients was calculated using the formula described above.

RESULTS

Grain Yield

Grain yields were obtained for LCB in 2008, 2009 and 2010. In 2008, the results indicated that, N rate, application distance and the interaction between N rate and application distance were significant ($P<0.05$). Grain yields increased linearly with N rate, but a general decline in grain yield was recorded with each increase in application distance. For every 1 cm increase in application distance, yields were decreased by 1079, 466, and 282 kg ha^{-1} at 134, 90, and 45 kg N ha^{-1} side dress N application rate respectively (Fig 4). Overall, with the exception of 90 kg N ha^{-1} applied N rate, the results showed that, application of sidedress N at 0 cm application distance increased yields, with a maximum of 10619 kg ha^{-1}.

In 2009, results indicated that effect of N rate on grain yield was significant ($P<0.05$), while application distance and the interaction between N rate and application distance did not affect yields. Grain yield increased with N rate while application distance had varied effects on yield depending on the N rate applied (Fig 5). High N rate (134 kg

N ha^{-1}) application, contributed to a 329 kg ha^{-1} yield increase with each 1 cm increase in the application distance. However, at a reduced rate of 45 and 90 kg ha^{-1}, yield decreased by 616 and 1604 kg ha^{-1} respectively. Overall, better yield response was obtained by applying the sidedress N 10 cm away from the maize row when high N rates (90 and 134 kg ha^{-1}) were used, and 0 cm for the lower rate (45 kg ha^{-1}).

In 2010, there was a significant ($p<0.001$) linear increase in grain yields with applied sidedress N , however,, increasing the rate to 134 kg N ha^{-1}, reduced grain yield by 255 kg ha^{-1} with each 1 cm increase in the application distance. Application distance on the other hand however, did not significantly affect grain yields ($P<0.05$), although with each 1 cm increase in the application distance, yields increased slightly by 18, and 298 kg ha^{-1} when 90, and 45 kg N ha^{-1} sidedress N was applied respectively (Fig 9). On average, regardless, of the N rate, application of sidedress N 10 cm away from the row led to higher yields compared to that of other application distances.

At Haskell, in 2009, a dry land field experiment with no irrigation was established. The results obtained at this site indicated that, sidedress N, application distance and the interaction between sidedress N and application distance were not significant at ($P<0.05$). Generally, yields were negatively affected by increasing the N rate and no consistent trend observed for varying the application distance. However, it was noted that, at 45 kg N ha^{-1} N application rate, yields were reduced by 533 kg ha^{-1}

with each increase in the application distance and increased by 306 and 502 kg ha^{-1} when 90 and 134 kg N ha^{-1} was applied respectively (Fig. 6).

The experiment at Hennessey in 2009 was also a dryland site with no supplemental irrigation. Overall grain yields obtained from this site were the lowest among all the cropping seasons and locations. Nitrogen rate, application distance and the interaction between N rate and application distance, did not significantly ($P<0.05$) affect grain yields. Overall, poor N response was recorded regardless of the application distance. At the low N rate (45 kg N ha^{-1}) yields were reduced by 112 kg ha^{-1} with each increase in the application distance. However, at high N rates (90 and 134 kg N ha^{-1}), each 1 cm increase in the application distance contributed to a slight increase in yield by 171 and 10 kg ha^{-1} respectively (Fig 7).

The Efaw site was a dry land experiment as well, but compared to Haskell and Hennessey locations, Efaw received a substantial amount of rain in the 2010 cropping season (Fig.2). As a result, increased response to N rate was observed. However, a significant ($P<0.05$) negative linear relationship between yield and application distance was also noted. Each increase in the application distance, contributed to a reduction in yield by 179, 570, and 184 kg ha^{-1} when 134, 90, and 45 kg N ha^{-1} was applied, respectively (Fig 8). The highest yield of 7886 kg ha^{-1} was obtained when sidedress N was applied 0 cm away from the maize row and the lowest (6810 kg ha^{-1}) when the application distance was increased to 30 cm.

Nitrogen Uptake

Nitrogen uptake in maize for 2009 and 2010 cropping seasons was only determined for Hennessey, Efaw and Lake Carl Blackwell (LCB). At LCB 2009, N uptake significantly ($P<0.001$) increased with N rate. Application distance and the interaction between N rate and application distance, were not significant. Apart from 90 kg N ha^{-1} side dress application, application of 45 and 134 kg N ha^{-1} led to N uptake increase by 5.5 and 4.3 respectively (Fig 11), with each 1 cm increase in the application distance. However, on average regardless of the N rate applied, it was evident that applying side dress N 10 cm away from the maize row increased the N uptake to as high as 111 kg N ha^{-1} compared to other application distances.

In 2010 at LCB, there was a linear ($p<0.001$) increase in N uptake with N rate. Application distance and the interaction of application distance and N rate were not significant. However, at 134 and 90 kg N ha^{-1} side dress N application, N uptake was slightly reduced by 6.8 and 0.9 kg N ha^{-1} respectively; with each increase in the application distance (Fig 13). On average, regardless of N rate applied, application of side dress N 10 cm away from the row, led to an increase in N uptake ranging from 69 to 102 kg N ha^{-1}.

Generally N uptake was low at Hennessey compared to the other two sites. The results indicated that, N rate, application distance and the interaction between the two variables did not significantly ($P<0.05$) affect the N uptake by maize. However, application of sidedress N at the base of the maize row (0 cm application distance), contributed to a higher N uptake (17 kg N ha^{-1}), compared to other application distances. Overall, with each increase in the application distance, N uptake was reduced by 3.6 and 0.2 kg N ha^{-1} when 45 and 90 kg N ha^{-1} was applied. A slight increase in N uptake by 0.2 kg N ha^{-1} was recorded with every 1 cm increase in the application distance when N rate was raised to 134 kg N ha^{-1} (Fig. 10).

At Efaw, N uptake increased linearly ($P<0.01$), with N rate. However, application distance and the interaction between, N rate and application distance, did not affect N uptake. On average, regardless of N rate applied, applying sidedress N at the base of maize row (0 cm application distance), contributed to the highest N uptake of up to 106 kg N ha^{-1}. Each 1 cm increase in application distance, reduced N uptake by 2.1, 9.6, and 0.6 kg N ha^{-1}, when 134,90, and 45 kg N ha^{-1} was applied respectively (Fig 12).

Nitrogen Use Efficiency (NUE)

Nitrogen use efficiencies (NUE) for Hennessey, Efaw and LCB in 2009 and 2010 were calculated based on the total N applied for each treatment. The results for all locations and cropping seasons are presented in Table 4. At LCB in 2009, the highest NUE values were recorded, which ranged from 30 to 113%. Varying application distance did not significantly affect NUE; suggesting that in terms of NUE application distance did not matter. However, 0 cm application distance resulted in a higher NUE of 65%. This was not the case with N rate. A linear decline in NUE with increased N rate was recorded. Application of high rates (179 kg N ha^{-1}) led to NUE reduction to as low as 45% while 45 kg N ha^{-1} resulted in 84% NUE.

In 2010 at LCB, NUE ranged from 34 to 84%. Increased N rate led to a general decline in NUE. Application of high total N rates (179 kg N ha^{-1}) reduced NUE to as low as 43%. Application distance did not significantly affect NUE, although it was apparent that, applying side dress N fertilizer at 0 to 20 cm away from the maize row, NUE was enhanced; beyond that NUE was lower.

Generally, compared to the other two locations, Hennessey had low NUE which ranged from 2 to 31%. The NUE declined with increasing N rate to as low as 4% when 179 kg N ha^{-1} total N was applied. Regardless of the N rate applied, it was evident that applying sidedress N at 0 cm application distance (at the base of the maize row), increased NUE.

At Efaw NUE ranged from 11 to 82 %; with the highest value obtained when sidedress N was applied 10 cm away from the maize row at a rate of 45 kg N ha^{-1}. Regardless of application distance, increasing N rate led to a general decline in NUE to as low as 26% when 179 kg N ha^{-1} total N was applied. Varying the application distance without considering the applied N rate, 10 and 20 cm application distance resulted in higher NUE, 39 and 40 % respectively; suggesting that, the crop was able to utilize N applied at these two distances.

DISCUSSION

The findings presented in this experiment varied with location and cropping season. The poor N response and low NUE at Hennessey was mainly attributed to low and poorly distributed rainfall in 2009 which occurred around V8 to V10, the maize development stage when sidedress N fertilizer was applied (Fig 2). Adequate soil moisture in the soil is crucial for N mobility especially NO_3^--N and plays a great role in uptake of N by the crops (NaNagara et al., 1975). Plants take up N from the soil mainly through mass flow and diffusion (Barber, 1995); hence for proper N uptake to be achieved, sufficient moisture in the soil profile is important.

In a soil moisture limiting environment, closer N placement (near the row) leads to an increase in N uptake and yield (Edmonds, 2007; Vyn and West, 2008). The importance of fertilizer N application on maize grain yield is well documented (Binder et al., 2000). Therefore, the positive response in maize yields with N rate determined at LCB, Haskell and Efaw, across all the cropping seasons; further emphasized the crucial role played by N fertilizer in maize production. Across all seasons and sites, varying sidedress N application distance away from the maize row resulted in different maize yields and N uptake. This is explained by variation in N response by maize from one cropping season to another due to spatial and temporal variability that exists in any particular study location (Solie et al,. 1996).

However, the increase in yield, and N uptake when sidedress N was applied within 0 to 10 cm of the maize row at LCB, and 0 cm at Efaw, was in agreement with past findings determined by Blaylock and Cruise, 1992; Edmonds, 2007; Vyn and West, 2008; Hodgen et al., 2009. They established that, closer placement of mid-season N application contributes to high N uptake and grain yield. In a separate study maize root mass has been established to be greatest in soil surface (0-15 cm), located directly under the plant and root densities decrease as the distance from the planted row increased (Mengel and Barber, 1974).

Therefore, it makes sense to conclude that, the efficiency of the crop to take up and utilize the applied N will be high when N is applied at the base of the plant as opposed to far away from the planted row. This will affect NUE, illustrated in this study; where NUE for the three sites when sidedress N fertilizer was placed at the base of the maize (Hennessey and LCB) and 10 cm away from the maize row (Efaw) consistently increased.

The decline in NUE with increased N rate at Hennessey, Efaw, and LCB indicated that excess N application leads to N losses which generally result in low NUE.

Rapid N uptake in corn has been established to occur near silking stage (Hanway, 1963), therefore applying sidedress N at V8–V10 contributed to the observed increase in N uptake and NUE, since N was applied when crop needs peaked, and losses were minimized. This fact is supported by other research that has established that midseason applied N (Lukina et al., 2001; Raun et al., 2005 and Tubana et al., 2008) and N split application (Boman et al., 1995;Woolfolk et al.,2002) contributes to increased N uptake and NUE. Overall, it was apparent that in order to increase maize grain yields, N uptake, and NUE, sidedress N fertilizer should be placed between 0 and 10 cm away from the maize row.

CONCLUSIONS

Generally, maize grain yield response to N rate and application distance, was unique for each location and cropping season. The role of soil moisture in maize production and N utilization were evident where locations which experienced low rainfall at the time of sidedress N application (V8 to V10 maize growth stage) recorded the lowest N uptake, NUE and grain yield. This finding was attributed to the important role soil moisture plays for N mobility especially NO_3^--N and uptake of N by the crop. At LCB and Efaw the highest grain yields were obtained when sidedress N was applied 0 to 10 cm away from the maize row.

In general N uptake increased linearly with N rate and was reduced when application distance increased away from the row. Nitrogen uptake was increased to 17 and 106 N ha^{-1} at Hennessey and Efaw respectively, by applying sidedress N at the base of the maize row (0 cm), and to as high as 111 kg N ha^{-1} at LCB with 10 cm application distance. Generally, increased N rate led to a general decline in NUE to as low as 4%, 26%, 45%, 43% at Hennessey, Efaw, LCB (2009), and LCB (2010) respectively. Overall, regardless of cropping season and location, the best sidedress N application distance, was between 0 to 10 cm, beyond that grain yield, N uptake and NUE was reduced.

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

Site	Year	pH	Total N	Organic C	NH_4-N	NO_3-N	P	K
			--------g kg $^{-1}$--------		---------------mg kg $^{-1}$------------------			
LCB[¥]	2008	6.0	0.7	3.0	98	87	37	248
Haskell	2009	4.6	0.6	3.8	21	79	32	75
Hennessey	2009	5.3	1.0	7.6	21	101	358	1608
LCB[¥]	2009	5.9	1.0	3.2	na[§]	11	22	138
LCB[¥]	2010	6.1	0.8	3.8	4	2	6	105
Efaw	2010	6.3	1.0	5.2	2	2	25	120

pH- 1:1 soil: water; K and P-Mehlich III; NH4-N and NO_3-N- 2 M KCL, Total N and Organic C-dry combustion

§ Data was not determined

¥ Lake Carl Blackwell

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

Treatment	Prep-plant N (kg ha^{-1})	Midseason N (kg ha^{-1})§	Application Distance (cm)±
1	0	0	0
2	0	45	0
3	0	45	10
4	0	45	20
5	0	45	30
6	45	45	0
7	45	45	10
8	45	45	20
9	45	45	30
10	45	90	0
11	45	90	10
12	45	90	20
13	45	90	30
14	45	134	0
15	45	134	10
16	45	134	20
17	45	134	30

§ Midseason N was applied between V8-V10 maize growth stages.

± A stream of Urea Ammonium Nitrate (UAN) was applied at varying distances away from the maize row.

Table 3. Field trial information for all the sites, 2009-2010

Site	Year	Variety	Planting Rate (plants ha^{-1})	Date[§]		
				Planting	Sidedress Application	Harvest
LCB[¥]	2008	Pioneer 33B54	84,016	04-18-2004	06-20-2008	09-10-2008
Haskell	2009	DeKalb DKC 52-59	61,776	05- 28- 2009	07- 9- 2009	10-21- 2009
Hennessey	2009	DeKalb DKC 52-59	61,776	04- 22- 2009	06-18-2009	08- 26-2009
LCB[¥]	2010	DeKalb DKC 52-59	86487	04-28-2010	06-24-2010	09-7-2010
Efaw	2010	DeKalb DKC 52-59	61,776	04-28- 2010	06- 24-2010	08- 24-2010

§ Date in month-day-year
¥ Lake Carl Blackwell

Table 4. Nitrogen use efficiency (NUE) in maize as affected by nitrogen (N) rate and application distance (cm), Haskell and Hennessey, OK 2009 and Efaw and Lake Carl Blackwell (LCB), 2010.

Location	Year	Total N rate (kg ha^{-1})	----------------NUE %---------------- Application Distance (cm)±				**Mean§**
			0	10	20	30	
Hennessey	2009	45	31	16	9	24	**20**
		90	18	12	9	6	**11**
		135	8	4	9	6	**7**
		179	6	2	5	5	**4**
		Mean¥	**16**	**9**	**8**	**10**	**11**
LCB	2009	45	113	51	102	71	**84**
		90	49	74	72	70	**66**
		135	65	78	30	69	**61**
		179	34	54	46	45	**45**
		Mean¥	**65**	**64**	**63**	**64**	**64**
Efaw	2010	45	11	82	60	16	**42**
		90	40	19	36	32	**32**
		135	36	37	33	14	**30**
		179	31	19	29	23	**26**
		Mean¥	**30**	**39**	**40**	**21**	**32**
LCB	2010	45	84	36	78	51	**62**
		90	34	58	58	49	**50**
		135	51	63	39	58	**53**
		179	48	46	42	37	**43**
		Mean¥	**54**	**51**	**54**	**49**	**52**

± Application distance was measured away from the maize row.
§ Average NUE % for each N rate
¥ Average NUE % for each application distance

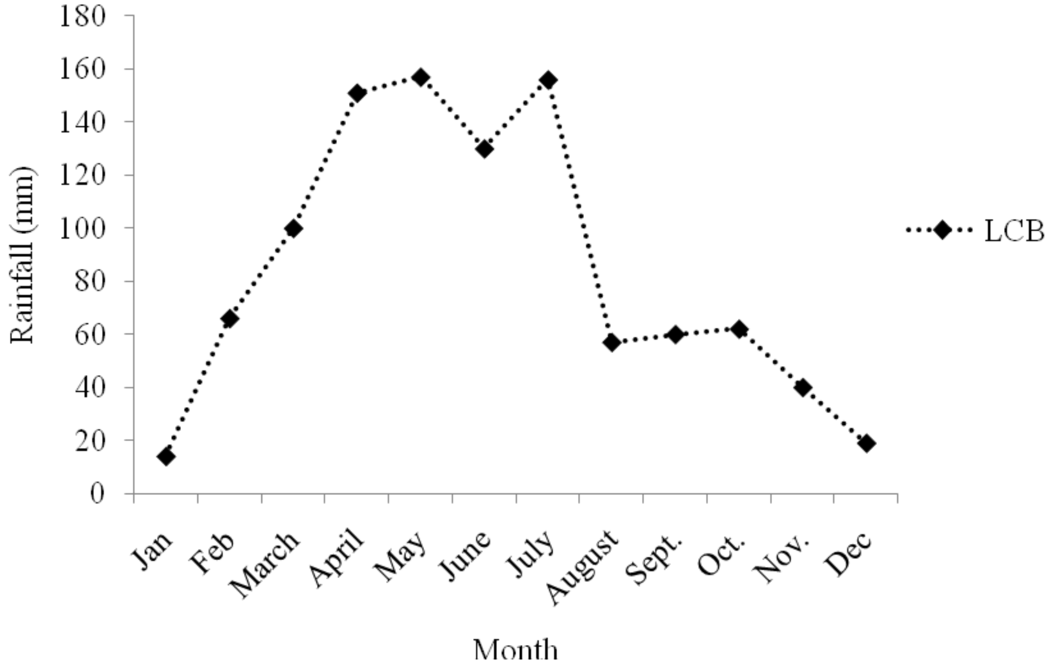

Figure 1. Rainfall distribution at Lake Carl Blackwell (LCB), OK, 2008

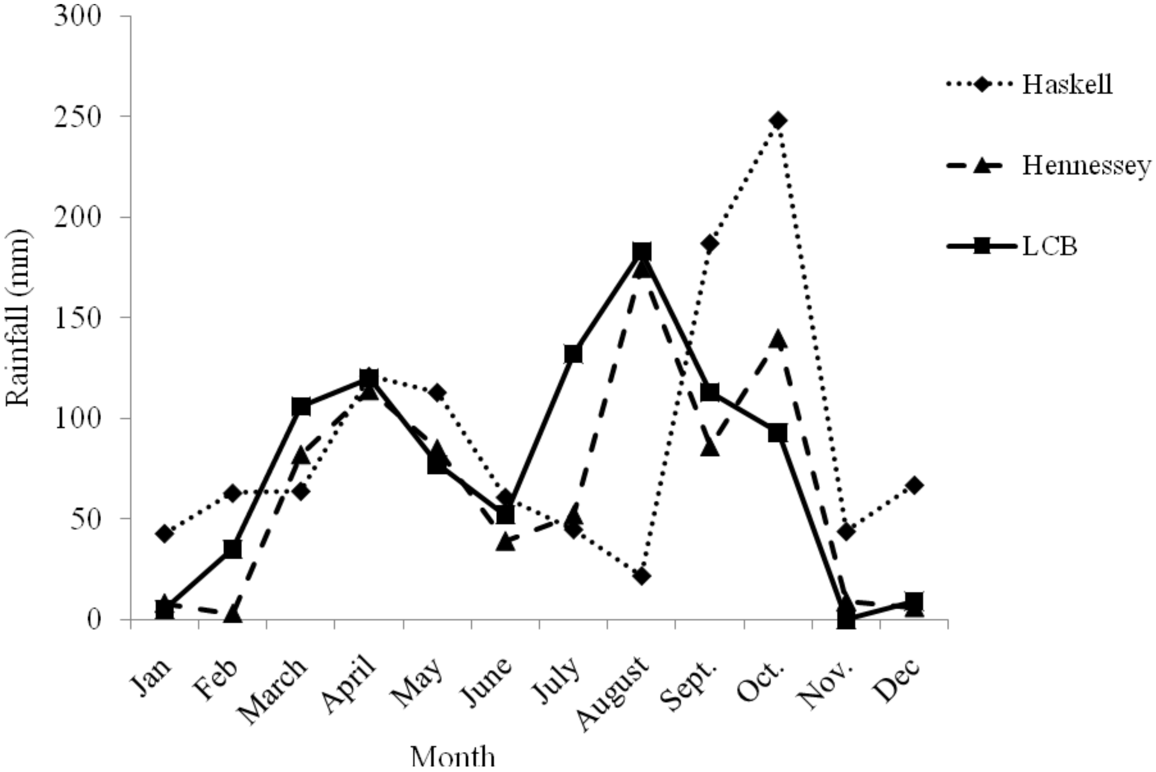

Figure 2. Rainfall distribution at Haskell. Lahoma, Hennessey, Lake Carl Blackwell (LCB) and Efaw, 2009

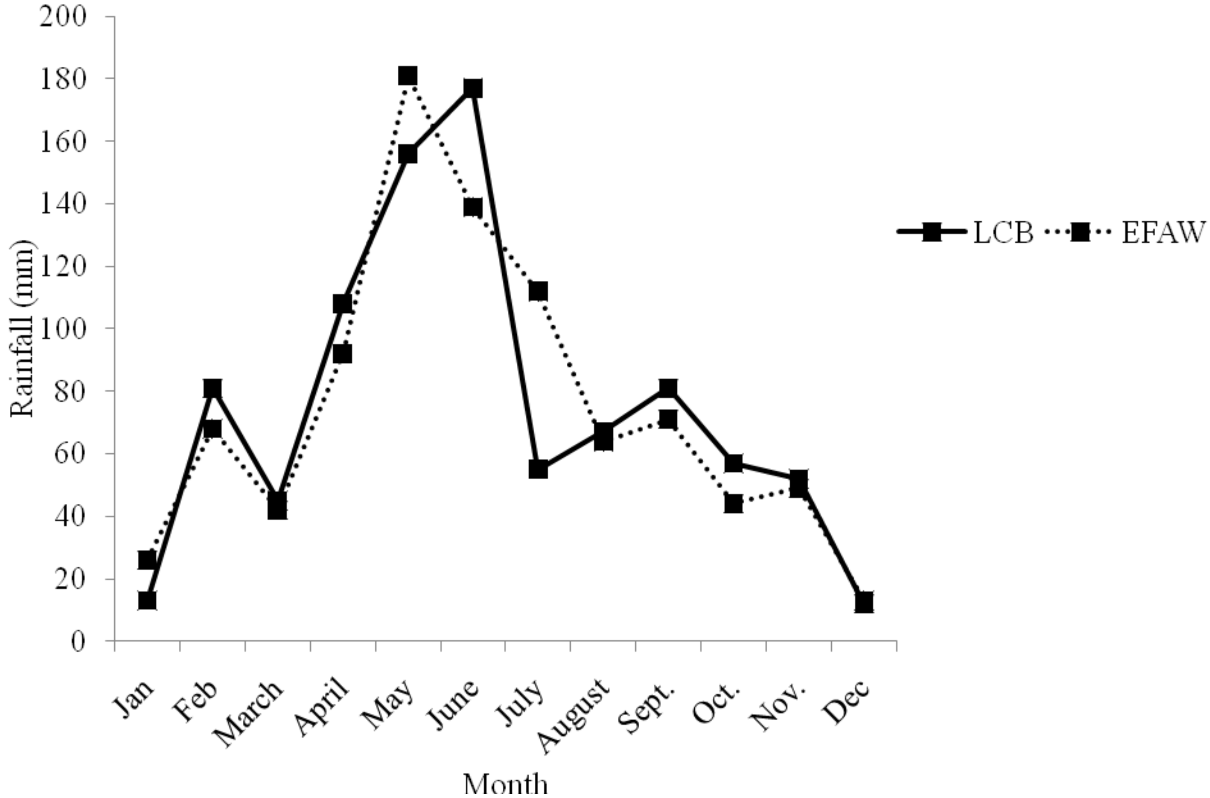

Figure 3. Rainfall distribution at Haskell. Lahoma, Hennessey, Lake Carl Blackwell (LCB) and Efaw, 2010

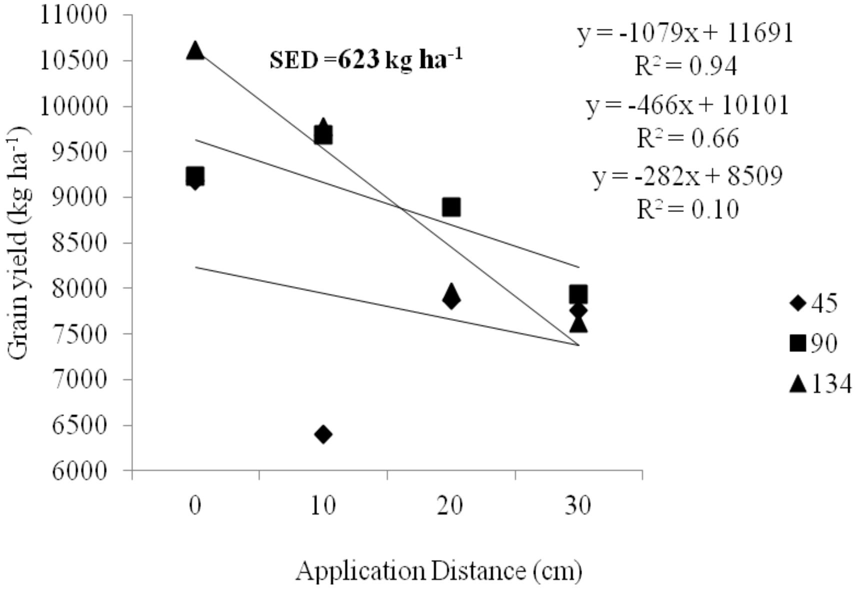

Figure 4. Grain yield as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0,10, 20 and 30 cm, away from the maize row, Lake Carl Blackwell, OK, 2008.

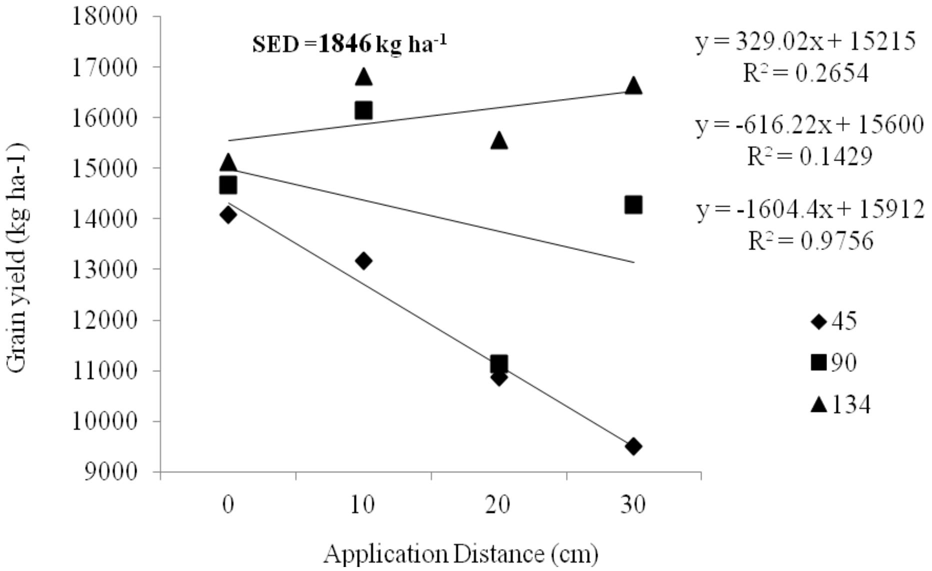

Figure 5. Grain yield as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20, and 30 cm, away from the maize row, Lake Carl Blackwell, OK, 2009.

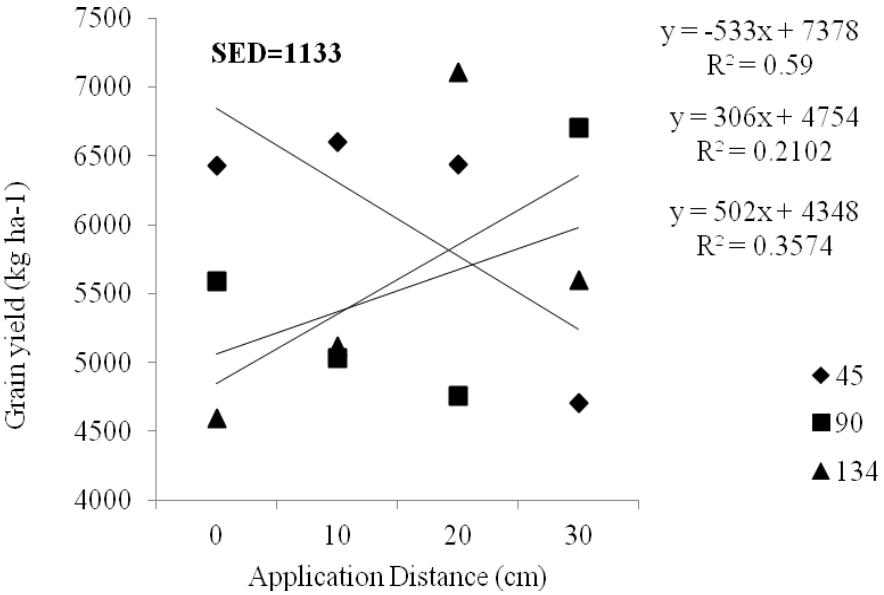

Figure 6. Grain yield as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Haskell, OK, 2009.

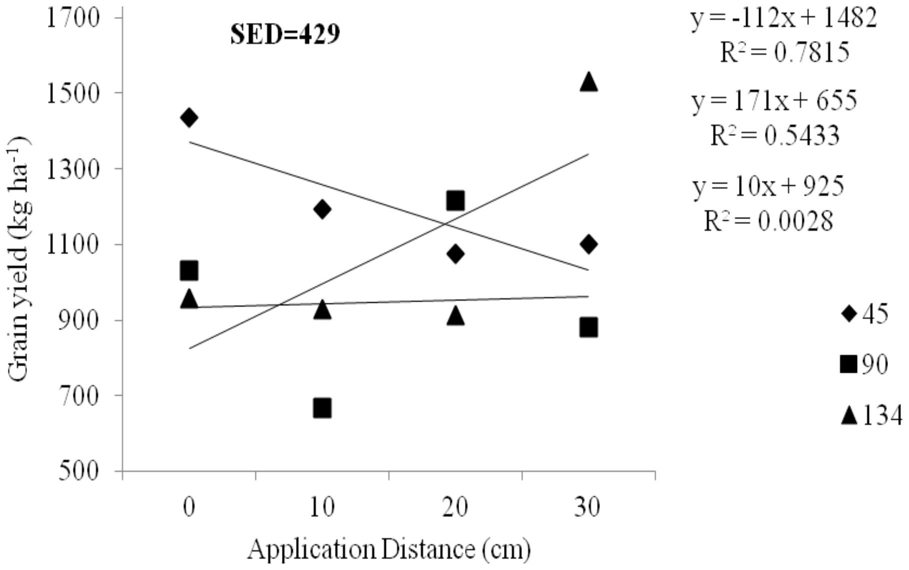

Figure 7. Grain yield as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Hennessey, OK, 2009.

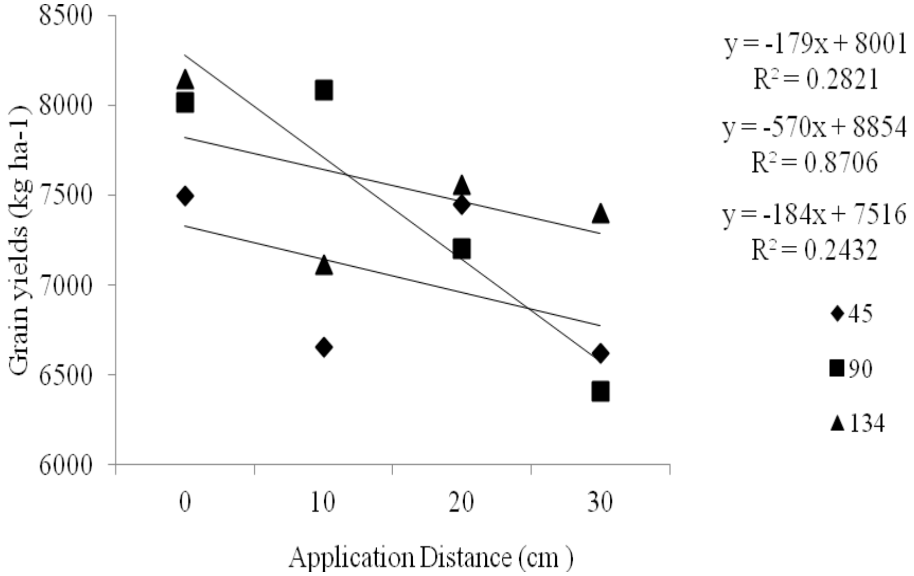

Figure 8. Grain yield as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Efaw, OK, 2010.

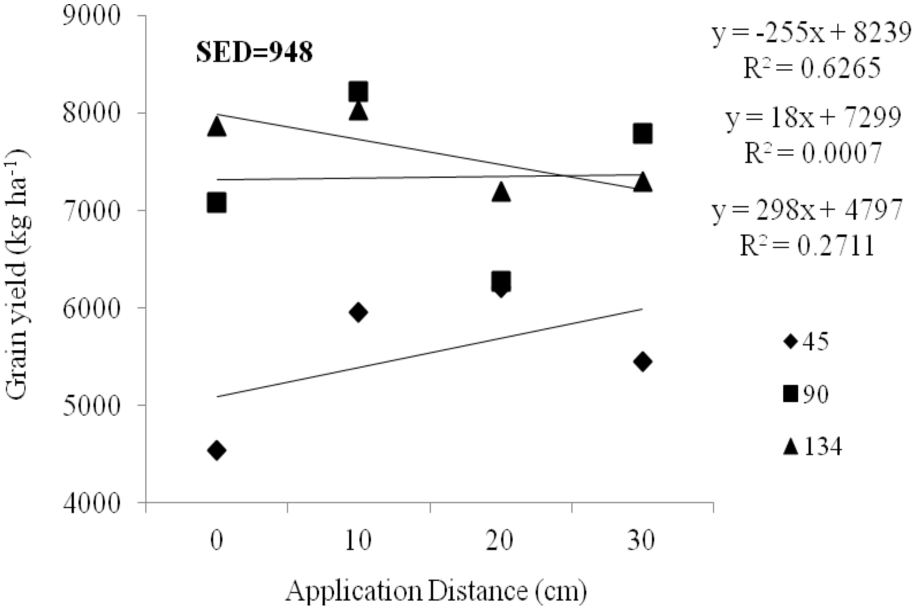

Figure 9. Grain yield as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Lake Carl Blackwell, OK, 2010.

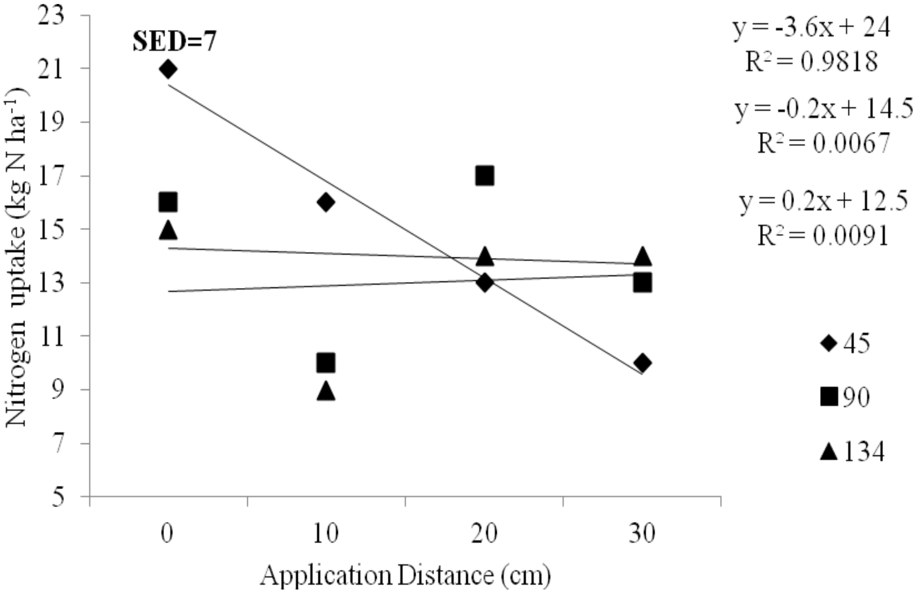

Figure 10. Grain N uptake as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Hennessey, OK, 2009.

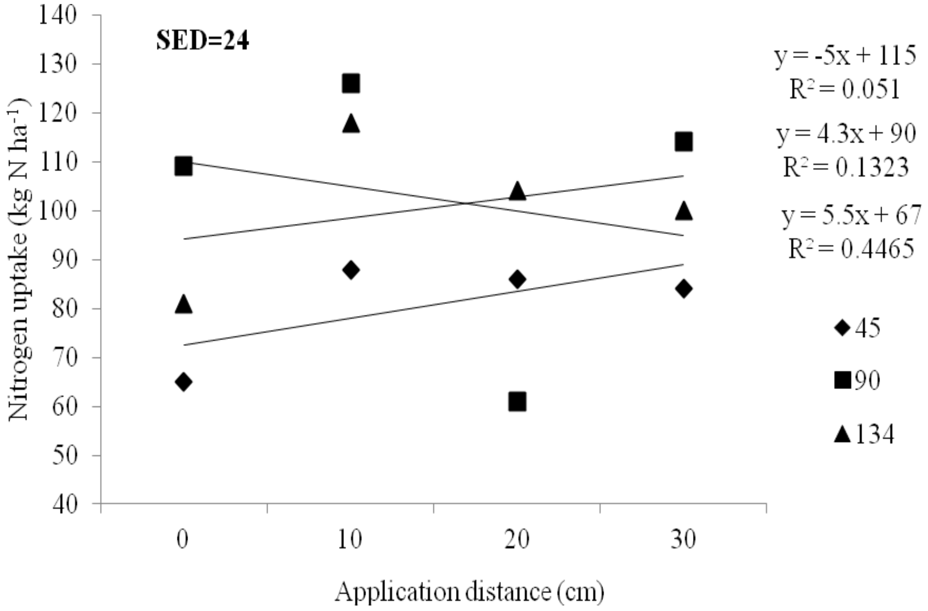

Figure 11. Grain N uptake as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Lake Carl Blackwell, OK, 2009.

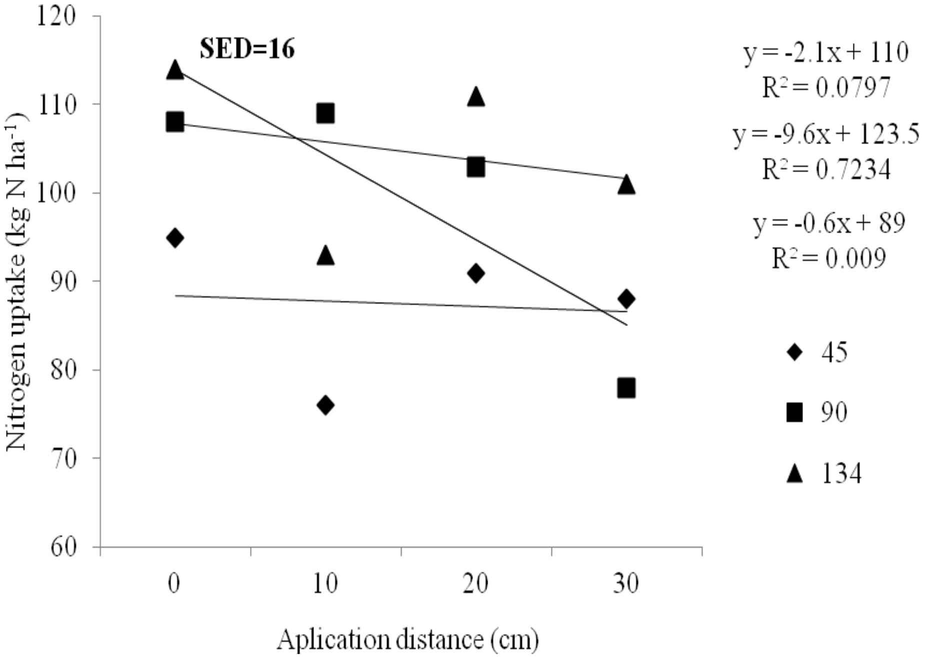

Figure 12. Grain N uptake as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Efaw, OK, 2010.

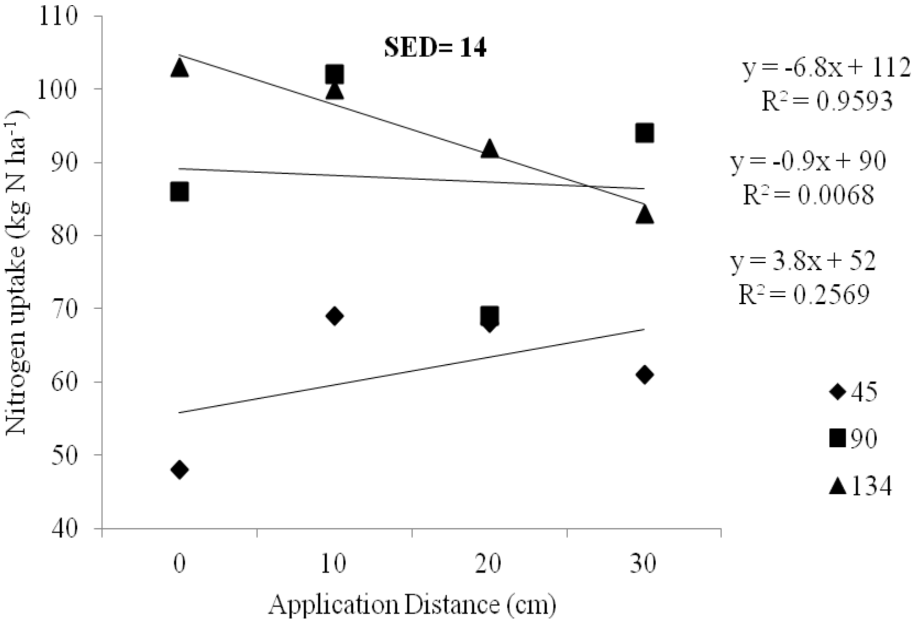

Figure 13. Grain N uptake as affected by sidedress N at 45, 90, and 134 kg N ha^{-1}, applied at 0, 10, 20 and 30 cm, away from the maize row, Lake Carl Blackwell, OK, 2010.

VITA

Emily Jeptum Rutto

Candidate for the Degree of

Doctor of Philosophy

Thesis: ABILITY OF COTTON (*Gossypium hirsutum* L.) TO RECOVER FROM EARLY SEASON NITROGEN STRESS, AND MAIZE (*Zea mays* L.) GRAIN YIELD RESPONSE TO DISTANCE NITROGEN IS PLACED AWAY FROM THE ROW

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Scope and Method of Study: For chapter one, a field experiment was conducted to evaluate cotton's ability to recover from earlier season N stress. The treatments included 4 rates of preplant (0, 33, 67 and 101 kg N ha^{-1}) and side dress (0, 33, 67, 101 and 134 kg ha^{-1}) N fertilizer applied at early pinhead square, white flower and 30 days after white flower. For chapter two, field studies were established to evaluate application of midseason (V8 to V10) variable liquid UAN (28%) at 4 rates (45, 90,134, and 224 kg N ha^{-1}) applied at different distances (0, 10, 20, 30 and 38 cm) away from the row, on maize grain yield and nitrogen use efficiency.

Findings and Conclusions: For chapter one, the results indicated that, cotton suffered N deficiency if 0 kg N ha^{-1} preplant N was applied. However, regardless of location and cropping season, cotton recovered from early season N deficiency and attained near maximum lint yield, as long as side dress N fertilizer application was done by EPHS cotton growth stage. Delaying N application to 30 DAWF 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 sidedress N recommendation for cotton at EPHS or WF growth stages. For chapter two, maize grain yields increased the closer N was applied to the row. Increased N rate led to a general decline in NUE to as low as 4%, 26%, 45%, 43% at Hennessey, Efaw, LCB (2009), and LCB (2010) respectively. Regardless of cropping season and location, the best sidedress N application distance, was between 0 and 10 cm. Application of N at distances >10cm away from the row resulted in reduced grain yield, N uptake and NUE.

ADVISER'S APPROVAL: DR. WILLIAM RAUN