OPTIMIZING IRRIGATION AND FERTILIZER MANAGEMENT IN COTTON TO INCREASE NITROGEN USE EFFICIENCY

A.R. Bumguardner, K.L. Lewis, G.L. Ritchie, K.F. Bronson, and M.M. Maeda
Texas A&M AgriLife Research, Lubbock, TX
amee.bumguardner@ag.tamu.edu (806)746-6101

ABSTRACT

Nitrogen (N) fertilizer is an important nutrient in cotton production, and if the optimal amount is not applied yield penalty may occur (Hutmacher et al. 2004). A more efficient application of N fertilizer based on plant N requirements, soil texture, and N availability can increase cotton yield and N-use efficiency (NUE). The main objective of this research was to determine the relationship between cotton lint yield and normalized difference vegetation index (NDVI) across multiple irrigation levels, varieties and N fertilizer rates. Urea-ammonium nitrate was applied pre-plant and after emergence by knife-injection at three rates (15, 75 and 135 lb N ac^{-1}) under two irrigation levels (30 and 70% ET), and multiple varieties. Under the low irrigation level in 2018, lint yield of DP 1820 had no statistical response to N application, however, 75-0-0 was greater than all other treatments. Under the low irrigation level in 2019, lint yield of DP 1823 had no statistical response to N application, however, for all other treatments there was a positive response to N application. There was a moderate to poor linear relationship between NDVI and lint yield at different growth stages. The weak relationship may have been due to poor environmental conditions. Further research into NDVI may prove to be beneficial for improved N management.

INTRODUCTION

Nitrogen is required in the largest amount by most plants (Marschner, 2012). Plant available N in soil is limited and can be lost easily depending on environmental conditions (IPNI, n.d.). Pre-plant soil nitrate (NO_3^--N) test levels are often used to determine N fertilizer requirements, however, due to soil N losses within the growing season leaf samples can be used to determine the need for in-season N applications (Sabbe and Zelinski, 1990; Zhang et al., 1998). Normalized difference vegetation index (NDVI) is a tool that can be used to manage water, N, crop development and to predict yield at peak bloom, and may be a non-destructive means to estimate in-season N status of cotton (Li et al., 2001; Bronson et al., 2003; Zhou and Yin 2014). In order to detect N deficiencies within the plant, NDVI is determined via remote sensing equipment by estimating chlorophyll content within the leaves (Thomas and Gausman, 1977; Chappelle et al., 1992; Blackmer et al, 1994). Bronson et al. (2014) reported a strong correlation between NDVI readings and leaf N, plant biomass and yield. However, NDVI readings have also been reported unresponsive to changes in cotton leaf N (Li et al., 2001; Bronson et al., 2003, 2005). The main objective of this research was to determine the relationship between cotton lint yield and NDVI across multiple irrigation levels, varieties, and N fertilizer rates with the overall goal of optimizing cotton production by maximizing NUE.

MATERIALS AND METHODS

A field experiment was conducted in 2018 and 2019 at the Texas A&M AgriLife Research experiment station in Lubbock, TX. There were three main treatment effects, N fertilizer rate, irrigation levels and cotton variety. Treatments were replicated four times. Plots were four rows wide (40 inch spacing) by 50 ft in length in 2018 and four rows wide (40 inch spacing) and 24 ft in length in 2019. The field was arranged in a split-plot design with the whole plot being irrigation level and the subplot treatment was variety. The soil series is an Acuff loam (fine-loamy, mixed, superactive, thermic aridic paleustolls), which is described as a very deep, well drained, moderately permeable soil (USDA, 2017). Cotton varieties DP 1820 B3XF and DP 1823 NR B2XF were planted on 29 May 2018 at 52,775 seed acre^{-1} and 7 June 2019 at 50,000 seed acre^{-1}. The irrigation was applied as sub-surface drip at two levels, a low evapotranspiration (ET) replacement rate of 30% and a high ET rate of 70%. Urea-ammonium nitrate (UAN; 32-0-0) was applied pre-plant, 3 weeks following emergence, and at pinhead square. Different rates included:

1) 15 lb acre^{-1} N applied pre (15-0-0);
2) 15 lb acre^{-1} N pre + 30 lb acre^{-1} N early + 30 lb acre^{-1} N late (75-0-0); and,
3) 15 lb acre^{-1} N pre + 60 lb acre^{-1} N early + 60 lb acre^{-1} N late (135-0-0).

Soil cores were collected and composited by each zone of the drip field, that was divided into eight rows, prior to pre-plant fertilizer application on 5 May 2018 and 8 May 2019 at 0-6 inch, 6-12 inch and 12-24 inch soil depths. Samples were sent to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory. Soil macro and micro- nutrients were extracted using Mehlich 3. The NDVI data was collected using a GeoScoutX data logger and the Crop Circle sensor ACS-211 (Holland Scientific, city, state). There were five sampling dates in 2018, and eleven in 2019. The ACS-211 measures the 670 nanometers (nm) and 780 nm wavelengths and the output is five measurements sec^{-1}. The sensors were mounted to a cart 40 inches above the plant canopy of the tallest plants in the 135-0-0 treatment and high irrigation level and measurements collected from rows two and three. The ACS-211 has a field of view of 40° by 8°.

A Case International Harvester 1400 cotton stripper was used to mechanically harvest the cotton. The harvester was not fitted with a bur extractor, thus bur cotton was collected at harvest. The two center rows were harvested to determine yield at the end of the season on 15 Nov 2018 and 16 Nov 2019. Sample weights were collected in the field. Following harvest samples from each plot were ginned at the Texas A&M AgriLife Research and Extension Center in Lubbock, TX.

For analysis of the NDVI data, ArcGIS 10.5.1 was used. Statistical analysis for all measurements were performed using SAS version 9.4 software (SAS Institute Inc., Cary, North Carolina). Analysis of variance for all parameters were calculated using two irrigation treatments in a split plot design with four replications using PROC GLIMMIX at $\alpha < 0.05$. Means of treatment effects were compared using Fisher's least significant difference (LSD) at $\alpha < 0.05$. Pearson's simple linear regression was used to evaluate the relationship between lint yield and NDVI at $\alpha < 0.05$ using PROC REG. Main effects of N rate, irrigation level, and variety on cotton lint yield were analyzed. The effect of N fertilizer treatment on NDVI and yield were analyzed within irrigation and variety due to significance of these factors.

RESULTS AND DISCUSSION

Soil results in 2018 indicated pH to be alkaline. The nutrients K, Ca, Mg, and S levels were high, while P was low, and Na was very low level according to current Texas A&M

AgriLife Extension Soil, Forage and Water testing lab critical values (Table 1). Soil nitrate-N (NO_3^--N) in 2018 ranged from 5 to 9 ppm for 12-24 and 0-6-inch sampling depths, respectively (Table 1). Soil results in 2019 indicated a neutral pH. The nutrient P level was moderate, K was very high, Ca, Mg, and S were high, and Na was very low (Table 2). Soil NO_3^--N ranged from 14 ppm at the shallowest depth to 21 ppm at the deepest sampling depth (Table 2).

Table 1. Characteristics of soil samples collected at three depths (0-6, 6-12 and 12-24 inches) prior to fertilizer application in 2018.

Soil Depth	pH	EC	NO_3-N	P	K	Ca	Mg	S	Na
inch		umhos cm^{-1}	mg kg^{-1}						
0-6	8.0	241	9	23	281	2098	756	14	35
6-12	8.1	183	5	6	228	3010	901	17	51
12-24	8.1	293	5	6	239	6621	864	22	76

Table 2. Characteristics of soil samples collected at three depths (0-6, 6-12 and 12-24 inches) prior to fertilizer application in 2019.

Soil Depth	pH	EC	NO_3-N	P	K	Ca	Mg	S	Na
inch		umhos cm^{-1}	mg kg^{-1}						
0-6	7.6	171	14	59	456	1996	694	21	22
6-12	7.9	134	11	24	299	1948	815	24	40
12-24	7.9	207	21	6	282	4878	861	41	78

Lint yield within variety and irrigation level was significant in 2018 and 2019. Under the high irrigation level in 2018, lint yield of DP 1820 and DP 1823 with the split application treatment (75-0-0) was greater than the pre-plant fertilizer treatment (15-0-0) (Fig. 1A). Under the low irrigation level in 2018, lint yield of DP 1823 with the split application treatment (75-0-0) was greater than the 15-0-0 and 135-0-0 treatments (Fig. 1B). Under the high irrigation level in 2019, lint yield of DP 1820 with the split application treatment (75-0-0) was greater than the 135-0-0 treatment, while lint yield of DP 1823 with the split application treatment (135-0-0) was greater than the pre-plant treatment (15-0-0) (Fig. 2A). Under the low irrigation level in 2019, lint yield of DP 1820 with the split application treatments (75-0-0 and 135-0-0) was greater than the 15-0-0 treatment (Fig. 2B). The lack of yield response to the highest split application treatment (135-0-0) when compared to the 75-0-0 treatment may be due to high levels of N in irrigation water.

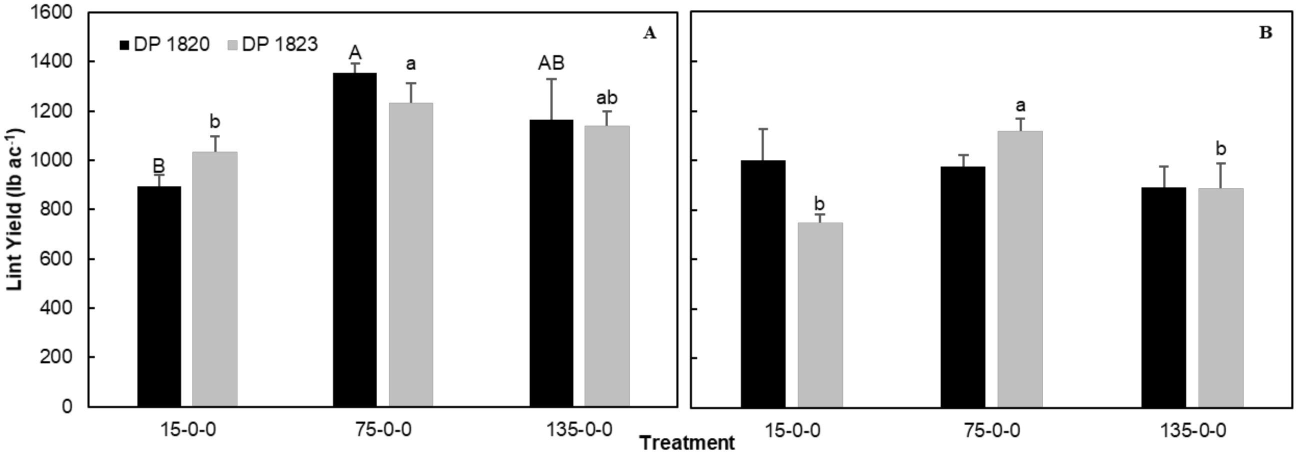

Figure 1. Cotton lint yield in 2018 under the high (70% ET, A) and low (30% ET, B) irrigation levels. The same uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at P<0.05. The vertical bars represent standard error of the mean.

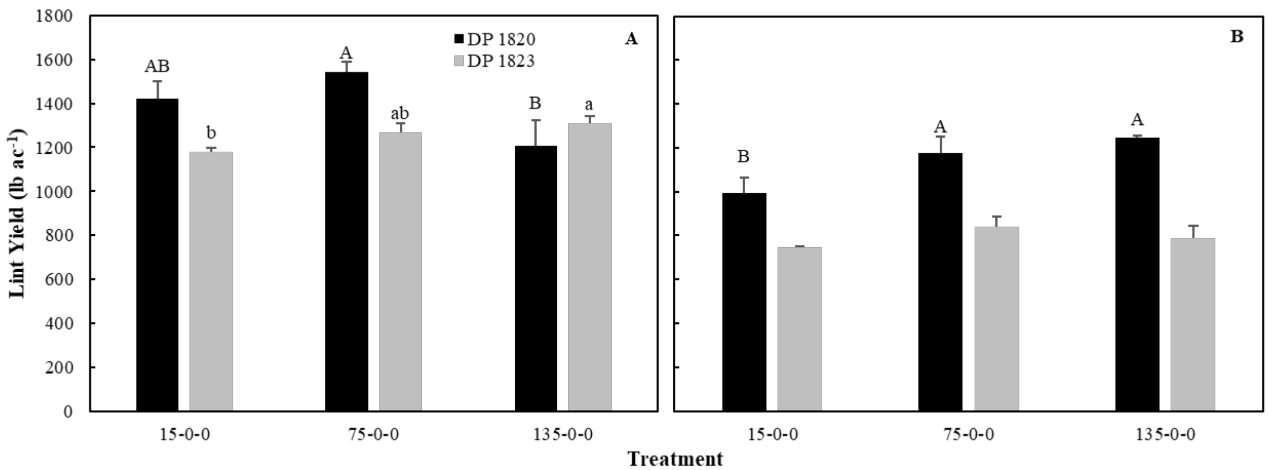

Figure 2. Cotton lint yield in 2019 under the high (70% ET, A) and low (30% ET, B) irrigation levels. The same uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at P<0.05. The vertical bars represent standard error of the mean.

A relatively poor relationship was observed between NDVI and lint yield for both 2018 and 2019. Under the high irrigation level in 2018 NDVI had a stronger relationship with lint yield 51 days after planting (DAP) (R^2=0.791) at squaring/first flower for variety DP 1820, while DP 1823 had a stronger relationship at flowering/boll development stage (91 DAP; R^2=0.486) (Table 3). Under the high irrigation level in 2019 NDVI had a greater relationship with lint yield at the flowering growth stage (56 DAP; R^2=0.616), while DP 1823 had a stronger relationship at squaring (42 DAP; R^2=0.606) (Table 4). Under the low irrigation level in 2018 a greater relationship between NDVI and lint yield was observed at the squaring/first flowering growth stage (51 DAP; R^2=0.292) for DP 1820, while DP 1823 showed a stronger relationship at the open boll stage (126 DAP; R^2=0.380) (Table 3). Under the low irrigation in 2019 NDVI had a stronger relationship with lint yield at the flowering/open boll stage (69 DAP; R^2=0.569) for DP 1820, while DP 1823 had a stronger relationship at squaring (42 DAP; R^2=0.281) (Table 4). The lack of a strong relationship between NDVI and lint yield may be due to the limited range in lint yield across N treatments. Hail damage to the test plots in 2019 is also acknowledged here as a possible confounding effect. Moderate to poor correlation between NDVI and cotton yield have also been reported by Bronson et al. (2005) and Raper et al. (2013).

Table 3. Regression R^2 and p-values for normalized difference vegetation index (NDVI) vs lint yield in 2018.

		DP 1820		DP 1823	
DAP	Irrigation	R^2	p-value	R^2	p-value
51	High	0.791	0.000	0.200	0.145
	Low	0.292	0.070	0.289	0.071
65	High	0.007	0.798	0.177	0.174
	Low	0.260	0.091	0.306	0.062
77	High	0.464	0.015	0.179	0.171
	Low	0.006	0.813	0.009	0.769
91	High	0.006	0.818	0.486	0.012
	Low	0.019	0.669	0.297	0.067
126	High	0.231	0.114	0.178	0.172
	Low	0.030	0.589	0.380	0.033

† DAP, Days after Planting

Table 4. Regression R^2 and p-values for normalized difference vegetation index (NDVI) vs lint yield in 2019.

		DP 1820		DP 1823	
DAP	Irrigation	R^2	p-value	R^2	p-value
26	High	0.431	0.020	0.531	0.007
	Low	0.027	0.611	0.003	0.870
39	High	0.421	0.022	0.031	0.585
	Low	0.007	0.793	0.126	0.257
42	High	0.425	0.022	0.606	0.003
	Low	0.323	0.054	0.281	0.076
49	High	0.028	0.602	0.042	0.522
	Low	0.107	0.299	0.072	0.401
56	High	0.616	0.003	0.134	0.242
	Low	0.163	0.194	0.163	0.193
63	High	0.546	0.006	0.461	0.015
	Low	0.048	0.492	0.193	0.153
69	High	0.393	0.029	0.027	0.610
	Low	0.569	0.005	0.189	0.158
80	High	0.265	0.087	0.004	0.840
	Low	0.056	0.461	0.177	0.173
88	High	0.192	0.154	0.287	0.073
	Low	0.000	0.957	0.181	0.168
101	High	0.004	0.845	0.380	0.033

	Low	0.113	0.285	0.255	0.094
126	High	0.000	0.986	0.001	0.934
	Low	0.003	0.857	0.143	0.225

†DAP, Days After Planting

Future research includes expanding this dataset to examine plant N, boll counts, plant height, soil moisture, and canopy temperature in order to determine if there is a positive interaction between cotton lint yield and NDVI. The study will also include determining if there is a better relationship between red edge and lint yield compared to NDVI.

REFERENCES

Blackmer, T.M., J.S. Schepers. 1994. Techniques for monitoring crop nitrogen status in corn. Commun. Soil Sci. Plant Anal. 25:1791-1800.

Bronson, K.F., T.T. Chua, J.D. Booker, J.W. Keeling, and R.J. Lascano. 2003. In-season nitrogen status sensing in irrigated cotton: II. Leaf nitrogen and biomass. Soil Sci. Soc. Am. J. 67:1439–1448.

Bronson, K.F., J.D. booker, J.W. Keeling, R.K. Boman, T.A. Wheeler, R.J. Lascano, R.L. Nichols. 2005. Cotton canopy reflectance at landscape scale as affected by nitrogen fertilization. Agron. J. 97:654-660.

Chappelle, E.W., M.S. Kim, J.E. McMurtrey. 1992. Ratio analysis of reflectance spectra (RARS): An algorithm for the remote estimation of the concentrations of chlorophyll a, chlorphyll b, and carotenoids in soybean leaves. Remote Sens. Environ. 39,239-241.

Hutmacher, R.B., R.L. Travis, D.W. Rains, R.N. Vargas, B.A. Roberts, B.L. Weir, S.D. Wright, D.S. Munk, B.H. Marsh, M.P. Keeley, F.B. Fritschi, D.J. Munier, R.L. Nichols, R. Delgado. 2004. Response of recent Acala cotton varieties to variable nitrogen rates in the San Joaquin Valley of California. Agron. J. 96:48-62.

International Plant Nutrition Institute. N.d. Nutri-Facts: Nitrogen.

Li, H., R.J. Lascano, E.M. Barnes, J. Booker, L.T. Wilson, K.F. Bronson, E. Segarra. 2001. Multispectral reflectance of cotton related to plant growth, soil water and texture, and site elevation. Agron. J. 93:1327-1337.

Marschner, P. 2012. Mineral nutrition on higher plants. Ch. 6.

Raper, T.B., J.J. Varco, K.J. Hubbard. 2013. Canopy-based normalized difference vegetation index sensors for monitoring cotton nitrogen status. Agron. J. 105:1345-1354.

Sabbe, W.E., L.J. Zelinski. 1990. Plant analysis as an aid in fertilizing cotton. p. 469-493. In R.L. Westerman (ed.). Soil testing and plant analysis, 3rd ed.

United States Department of Agriculture. 2017. USDA Natural Resource Conservation Service: Official soil series, Amarillo series. Retrieved from https://soilseries.sc.egov.usda.gov/OSD_Docs/A/ AMARILLO.html. [23 January 2018].

Thomas, J.R., H.W. Gausman. 1977. Leaf reflectance vs leaf chlorophyll and carotenoid concentration for eight crops. Agron. J. 69:799-802.

Zhang, H., G. Johnson, B. Raun, N. Basta, J. Hattey. 1998. OSU soil test interpretations. Oklahoma Coop. Ext. Ser. Fact Sheet No. 2225.

Zhou, G., X. Yin. 2014. Relationship of cotton nitrogen and yield with normalized difference vegetation index and plant height. Nutr. Cycl. Agroecosyst. 100:147-160.