RELATIONSHIP BETWEEN PLANT NITROGEN AND NDVI OF COTTON ON THE TEXAS HIGH PLAINS

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ABSTRACT

Nitrogen (N) fertilizer is an important nutrient in cotton production, and if the optimal amount is not applied then it could lead to a reduction in lint yield (Hutmacher et al. 2004). A more efficient application of N fertilizer due to specifics 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 evaluate the interaction of N rate, irrigation level, and cotton cultivar on plant health and cotton productivity by increasing NUE. The project will determine the relationships between end of season N uptake and normalized difference vegetative index (NDVI) to lint yield. Urea-ammonium nitrate (32-0-0) was applied pre-plant and after emergence by knife-injection at three rates of 15, 75 and 135 lb N ac^{-1} under two irrigation levels and two cultivars. Lint yield was greater when the N rate of 75 lb ac^{-1} was applied with either irrigation level, cultivar, and experimental years. 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 N application.

INTRODUCTION

Nitrogen is required in the largest amount by most all plants (Marschner, 2012). Plant available N in soil is limited and can be lost easily due to environmental conditions (IPNI, 2012). Pre-plant soil nitrate-N (NO_3^--N) levels are used to determine N fertilizer recommendations. However, due to N losses within the growing season leaf analysis can be used to determine the need for in-season N applications (Sabbe and Zelinski, 1990; Zhang et al., 1998). Normalized difference vegetative index (NDVI) is a tool that can be used to manage water, N, crop development and to predict yield at peak bloom (Li et al., 2001; Bronson et al., 2003; Zhou and Yin 2014). To detect N deficiencies within the plant, NDVI is calculated 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. (2007) reported a strong correlation between NDVI readings and leaf N, plant biomass and yield. However, NDVI readings have also been reported to not respond to changes in cotton leaf N (Li et al., 2001; Bronson et al., 2003, 2005). The main objective of this research was to evaluate the interaction of N rate, irrigation level, and cultivars on plant health and cotton productivity with the overall goal of optimizing cotton production by maximizing NUE.

MATERIALS AND METHODS

A field experiment was conducted in 2019 and 2020 at the Texas A&M AgriLife Research experiment station in Lubbock, Tx. There were three main treatment effects, N fertilizer rate, irrigation level and cotton cultivar. Treatment combinations were replicated four times (48 total plots). Plots were four rows (40 inch spacing) by 25 ft in length. The field was arranged in a split split-plot design with the whole plot being irrigation level, and within the irrigation levels, there were subplot treatments for cultivar. 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 (DP 1820 B3XF and DP 1823 NR B2XF) was planted on 7 June 2019 at 50,000 seed acre^{-1} and 4 June 2020 at 50,820 seed acre^{-1}. The irrigation levels were a low evapotranspiration (ET) replacement rate of 30% and a high ET rate of 70%. Urea-ammonium nitrate (UAN; 32-0-0) was applied prior to planting (pre), 3 weeks following emergence (PE) and at pinhead square (PHS) at different rates which included:

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

Soil cores were collected and composited by zone prior to pre-plant fertilizer application on 8 May 2019 and 30 March 2020 at 0-6”, 6-12” and 12-24” soil depths. Samples were sent to the Texas A&M AgriLife Extension Soil, Water and Forage Testing Laboratory. Soil macronutrients were extracted using Mehlich 3 (Mehlich, 1978; Mehlich, 1984) and micronutrients were extracted using diethylenetriaminepentaacetic acid (DTPA) (Lindsay and Norvell, 1978). NDVI data was collected using the Holland Scientific GeoScoutX data logger and the Holland Scientific Crop Circle sensor ACS-211 (2019) and ACS 435 (2020 & 2021). Data was collected about every two weeks, which totaled 11 sampling dates in 2019, and in 2020 there were 15 sampling dates. The ACS-211 measures at 670 nanometers (nm) and 780 nm wavelengths, and the output is five samples sec^{-1}. The ACS-435 measures at 670 nm, 730 nm, and 780 nm. The sensors were mounted 40 inches above the plant canopy of the tallest plants in the 135-0-0 treatment and high irrigation level of rows two and three. The ACS-211 has a field of view of 40° by 8°, while the ACS-435 has a field of view of 40^{o} by 10^{o}.

A Case International Harvester 1400 cotton stripper was used in mechanical harvest of the cotton in 2019. The stripper was not fitted with a bur extractor, thus bur cotton and not seed cotton was collected at harvest in 2019. A John Deere cotton stripper was used in 2020. The center two rows were harvested at the end of the season on 16 Nov 2019 and 11 Nov 2020. Bur cotton sample weights were collected in the field in 2019 and seed cotton weights were collected in 2020. Following harvest samples of bur cotton and seed cotton from each plot were ginned at the Texas A&M AgriLife Research and Extension Center gin in Lubbock, TX.

Plant samples were collected to determine N uptake prior to harvest by sampling the whole cotton plant at first open boll (Bronson et al., 2018). A 50-cm segment of plants from two rows were cut at ground level. The whole plants are then separated into leaves, bolls, and stems. The plant parts were then dried at 65°C and weighed before grinding on a Thomas Wiley universal mill. The bolls were then separated into seed cotton and burrs. The seed cotton is weighed and then ginned using a small custombuilt tabletop ten saw box gin (Dennis manufacturing, Athens, TX). After ginning, the lint and seed were weighed separately, and the seed was acid delinted and then ground. Once the leaves, stems, burrs and seed have been ground to pass a 2-mm mesh sieve, they were shipped to Waters Agricultural Labs in Camilla, Georgia, and N was determined using a high temperature combustion process and was reported on a dry plant basis (Nelson & Sommers, 1973). Nitrogen uptake was calculated by multiplying N concentration by biomass. Internal NUE (iNUE) was calculated by dividing lint yield by total N uptake to determine optimal N fertilization and reduced N export from over-fertilization (Bronson, 2021). Agronomic N use efficiency (ANUE) was calculated to determine the efficiencies with N fertilizer applied at different rates and time periods compared to the pre-season N fertilizer rate.

$$\text{ANUE}=\frac{Y-\text{ Y}_0}{F}$$

where Y is the yield of harvested portion of the crop with applied nutrient, Y_0 is the yield in the control (PP) and F is the amount of N applied (Snyder & Bruulsema, 2007). Recovery N use efficiency (RNUE) was calculated to determine crop uptake of the applied N.

$$\text{RNUE}=\frac{U-U_0}{F}$$

where U is the total N uptake in aboveground crop biomass with applied N, U_0 is the total N uptake in aboveground crop biomass in the control (PP) and F is the amount of N applied (Snyder & Bruulsema, 2007).

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 was calculated using two irrigation treatments in a split split-plot design with four replications (PROC GLIMMIX) at $\alpha < 0.05$. Means of treatment effects were compared within sample using Fisher's least significant difference (LSD) at $\alpha < 0.05$. Pearson's simple linear regression (PROC REG) was used to evaluate the relationship between lint yield and NDVI at $\alpha < 0.05$. Main effects of N rate, irrigation level, and cultivar on cotton lint yield were analyzed. The effect of N fertilizer treatment on NDVI and yield were analyzed within irrigation and cultivar due to significance of these factors.

RESULTS AND DISCUSSION

Soil results in 2019 indicated an average pH of 7.8 across all depths. Phosphorus ranged from high (59 ppm) at the shallowest depth (0-6") to very low (6 ppm) at the deepest depth (12-24"), while K ranged from very high (456 ppm) to high (282 ppm). Calcium (>750 ppm), Mg (>150 ppm), and S (>13 ppm) were high, and Na (<98 ppm) was very low according to the rating system of the Texas A&M AgriLife Extension Soil, Forage and Water testing lab (Table 1). Soil NO_3^--N ranged from 14 ppm at the shallowest depth (0-6") to 21 ppm at the deepest depth of 12-24" (Table 1). Soil results in 2020 indicated an average pH of 7.6 across all depths. Phosphorus ranged from moderate (43 ppm) at the shallowest depth (0-6") to very low (5 ppm) at the deepest depth (12-24"), while K ranged from very high (385 ppm) at the shallowest depth to high (236 ppm) at the deepest depth (12-24"). Calcium (>750 ppm), Mg (>150 ppm) and S (>13 ppm) were high, and Na (<98 ppm) was very low according to the rating system of the Texas A&M AgriLife Extension Soil, Forage and Water testing lab

(Table 1). Nitrate-N ranged from 23 ppm at the shallowest depth (0-6”) to 48 ppm at the deepest depth of 12-24”. The nutrients NO_3^--N, P and K decreased deeper into the soil profile, while Ca and Na increased deeper into the soil profile for both years.

Table 1. Soil characterization of samples collected at three depths (0-6, 6-12 and 12-24 inches) prior to fertilizer application in 2019 and 2021.

Year	Depth	pH	EC	NO_3^--N	P	K	Ca	Mg	S	Na
	inch	--	umhos cm^{-1}			ppm				
	0-6	7.6	171	14	59	456	1996	694	21	22
2019	6-12	7.9	134	11	24	299	1948	815	24	40
	12-24	7.9	207	21	6	282	4878	861	41	78
	0-6	7.6	223	23	43	385	1986	664	23	26
2020	6-12	7.7	239	27	12	251	1953	714	26	42
	12-24	7.6	395	48	5	236	4586	733	45	87

Lint yield differences within cultivar and irrigation level were determined in 2019 and 2020. Under the 70% ET irrigation level in 2019, lint yield of DP 1820 with the 75-0-0 treatment was greater than the 135-0-0 treatment, while lint yield of DP 1823 with the 135-0-0 treatment was greater than the 15-0-0 treatment (Fig. 1A). With the 30% ET irrigation level in 2019, lint yield of DP 1820 with the 75-0-0 and 135-0-0 treatments was greater than the 15-0-0 treatment (Fig. 1B). With the 70% ET irrigation level in 2020, lint yield of DP 1820 with the treatments of 15-0-0 and 75-0-0 was greater than the 135-0-0 treatment, while with DP 1823 the 75-0-0 and 135-0-0 treatments were greater than the 15-0-0 treatment (Fig. 2A). Under the 30% ET irrigation level in 2020, lint yield of DP 1820 with the treatments of 15-0-0 and 135-0-0 were greater than the 75-0-0 treatment (Fig. 2B). A possible reason that the highest split application treatment of 135-0-0 was not consistently greater than the 75-0-0 treatment may be due to high levels of N in the irrigation water.

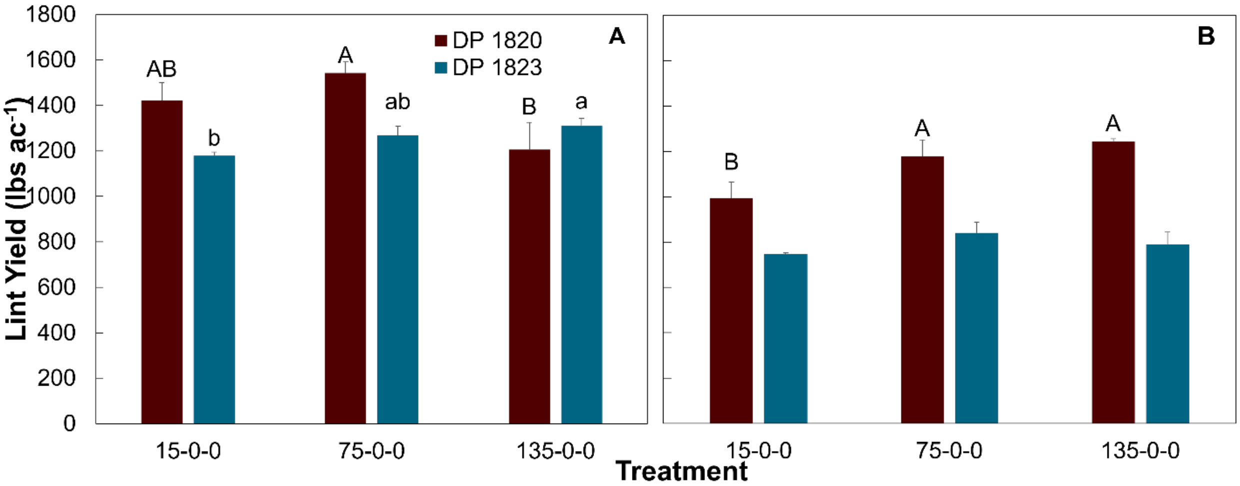

Figure 1. Cotton lint yield determined in 2019 (A) under the 70% ET irrigation level and (B) under the 30% ET irrigation level. Uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at $P<0.05$ by Fisher's protected LSD. The vertical bars represent standard error of the mean.

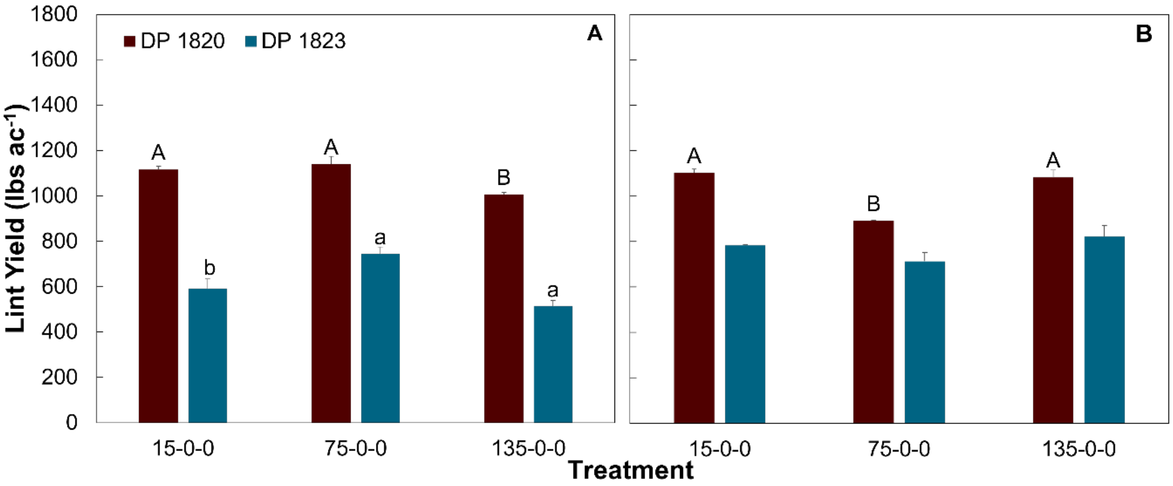

Figure 2. Cotton lint yield determined in 2020 (A) under the 70% ET irrigation level and (B) under the 30% ET irrigation level. Uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at $P<0.05$ by Fisher's protected LSD. The vertical bars represent standard error of the mean.

Nitrogen uptake was significant in 2020 (Fig. 3). With the 70% ET irrigation level, the 15-0-0 and 75-0-0 treatments were greater than the 135-0-0 treatment for DP 1823. With the 30% ET irrigation level the 135-0-0 treatment was greater than the 15-0-0 and 75-0-0 treatments with the DP 1820 cultivar. The 15-0-0 and 75-0-0 treatments were less than the 135-0-0 treatment within the 30% ET irrigation level and the DP 1823 cultivar. The results within the 70% ET irrigation level were opposite the 30% ET irrigation level.

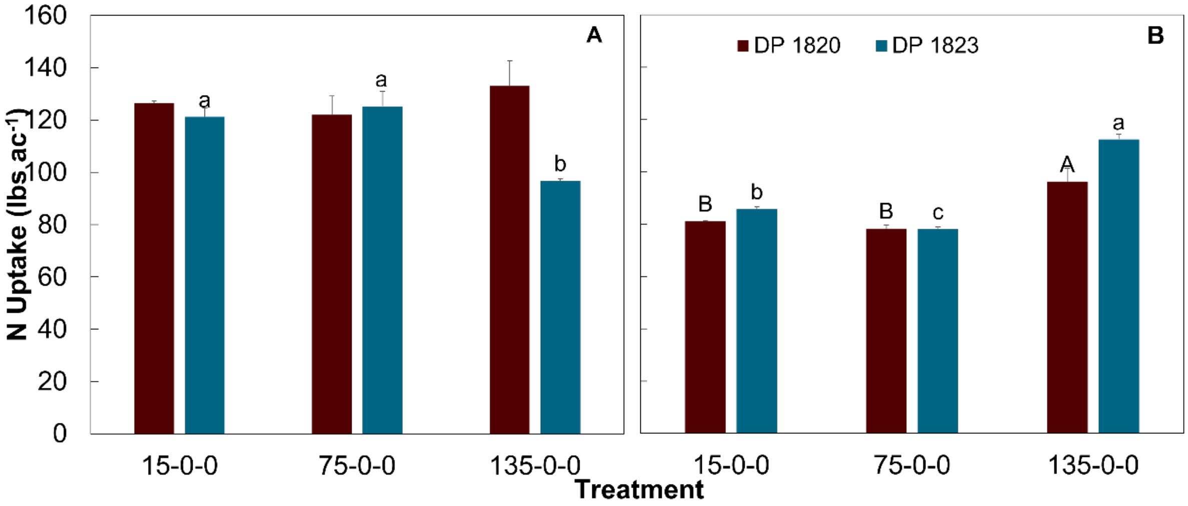

Figure 3. Nitrogen uptake in 2020 under the 70% ET (A) and 30% ET (B) irrigation levels. Uppercase letters within DP 1820 and lowercase letters within DP 1823 are not different at $\alpha<0.05$ by Fisher's protected LSD. The vertical bars represent standard error of the mean.

Recovery NUE was significant in 2020 within the 30% ET irrigation level with the 135-0-0 treatment being greater than the 75-0-0 treatment with DP 1823 (Table 2). Agronomic NUE was significant in 2019 with DP 1820 within the 70% ET irrigation level being greater with the 75-0-0 treatment than the 135-0-0 treatment. In 2020, DP 1823 was greater with the 75-0-0 treatment and the 70% ET irrigation level. With the 30% ET irrigation level, the 135-0-0 treatment was greater than the 75-0-0 treatment with both cultivars (Table 2). Internal NUE was 13.96 lb lint lb N^{-1} for the 135-0-0 treatment in 2019 with the 70% ET irrigation level and the cultivar DP 1823, however it was most likely deficient in N due to it being greater than 11.4 lb lint lb N^{-1} according to Bronson (2021). The 15-0-0 treatment was less than the 75-0-0 and 135-0-0 treatments with the 30% ET irrigation level and the cultivar DP 1820. The cultivar DP 1820 under the 70% ET irrigation level had an optimal iNUE across all treatments. In 2020, the 15-0-0 treatment had the greatest N uptake (13.6 lb lint lb N^{-1}), which was deficient in N, while the 75-0-0 and 135-0-0 treatments had an optimal iNUE according to Bronson (2021) (Table 2). However, N was mostly taken up in excess according to our results. When plant N uptake was the greatest, iNUE was the lowest, which resulted in excess N uptake due to it being less than 10.5 lb lint lb N^{-1} (Rochester, 2011; Bronson, 2021) (Figure 3 & Table 2).

Table 2. Nitrogen use efficiencies in 2019 and 2020 with DP 1820 and DP 1823. Letters within irrigation levels are not different at α<0.05 by Fisher's protected LSD.

			RNUE		iNUE		ANUE	
Irrigation	**Cultivar**	**N**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
		(kg ha^{-1})	(lb N lb N $applied^{-1}$)		(lb lint lb N^{-1})			
70% ET	DP 1820	15	---	---	9.757	8.824	---	---
		75	0.002	-0.060	10.708	9.480	1.566 A	0.334
		135	-0.174	0.048	9.780	7.700	-1.317 B	-0.808
	DP1823	15	---	---	11.824	4.859 B	---	---
		75	-0.314	0.053	13.282	5.983 A	1.151	2.053 A
		135	-0.283	-0.182	13.958	5.304 AB	0.952	-0.575 B
30% ET	DP 1820	15	---	---	5.908 B	13.613 A	---	---
		75	-0.038	-0.038	8.300 A	11.411 B	2.391	-2.816 B
		135	-0.042	0.113	9.533 A	11.317 B	1.806	-0.153 A
	DP1823	15	---	---	8.161	9.142 A	---	---
		75	0.120	-0.102 B	8.436	9.144 A	1.511	-0.934 B
		135	0.060	0.198 A	7.991	7.311 B	0.462	0.286 A

A relatively poor relationship was observed between NDVI and lint yield for both 2019 and 2020. Under the 70% ET 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 greater relationship at squaring (42 DAP; R^2=0.606) (Table 3). With the 30% ET irrigation level in 2019 NDVI had a greater relationship with lint yield at the flowering/open bolls growth stage (69 DAP; R^2=0.569) with the cultivar DP 1820, while DP 1823 had a greater relationship at squaring (42 DAP; R^2=0.281) (Table 3). With the 70% ET irrigation level in 2020 NDVI had a greater relationship with lint yield at the boll development growth stage (92 DAP; R^2=0.389) with the cultivar DP 1820, while DP 1823 had a greater relationship at boll development growth stage (99 DAP; R^2=0.297). The cultivar DP 1820 had a better relationship with NDVI and lint yield during the flowering growth stage of both years, while DP 1823 had a greater relationship during the squaring growth stage in 2019 and in 2020 it was higher during boll filling, but not significant. The poor relationships between NDVI and lint yield may be due to the limited range in lint yield across N treatments. The environmental conditions in 2019 may have affected the interaction between NDVI and lint yield. Similar results to Bronson et al. (2003 & 2005) were determined in which NDVI had a moderate to poor correlation to lint yield.

Table 3. Regression R^2 and p-values for NDVI vs lint yield in 2019.

		DP 1820		DP 1823	
DAP	**Irrigation**	**R^2**	**p-value**	**R^2**	**p-value**
26	70% ET	0.431	0.020	0.531	0.007
	30% ET	0.027	0.611	0.003	0.87
39	70% ET	0.421	0.022	0.031	0.585
	30% ET	0.007	0.793	0.126	0.257
42	70% ET	0.425	0.022	0.606	0.003
	30% ET	0.323	0.054	0.281	0.076
49	70% ET	0.028	0.602	0.042	0.522
	30% ET	0.107	0.299	0.072	0.401
56	70% ET	0.616	0.003	0.134	0.242
	30% ET	0.163	0.194	0.163	0.193
63	70% ET	0.546	0.006	0.461	0.015
	30% ET	0.048	0.492	0.193	0.153
69	70% ET	0.393	0.029	0.027	0.610
	30% ET	0.569	0.005	0.189	0.158
80	70% ET	0.265	0.087	0.004	0.840
	30% ET	0.056	0.461	0.177	0.173
88	70% ET	0.192	0.154	0.287	0.073
	30% ET	0.000	0.957	0.181	0.168
101	70% ET	0.004	0.845	0.380	0.033
	30% ET	0.113	0.285	0.255	0.094
126	70% ET	0.000	0.986	0.001	0.934
	30% ET	0.003	0.857	0.143	0.225

Table 4. Regression R^2 and p-values for NDVI vs lint yield in 2020.

		DP 1820		DP 1823	
DAP	**Irrigation**	**R^2**	**p-value**	**R^2**	**p-value**
22	70% ET	0.147	0.219	0.083	0.363
	30% ET	0.244	0.176	0.016	0.764
36	70% ET	0.185	0.163	0.02	0.664
	30% ET	0.037	0.619	0.142	0.317
57	70% ET	0.222	0.122	0.009	0.775
	30% ET	0.112	0.378	0.044	0.588
64	70% ET	0.291	0.070	0.003	0.864
	30% ET	0.041	0.600	0.129	0.342
69	70% ET	0.326	0.052	0.030	0.593
	30% ET	0.578	0.017	0.018	0.734
78	70% ET	0.268	0.085	0.021	0.653
	30% ET	0.091	0.432	0.000	1.000
84	70% ET	0.292	0.070	0.172	0.181
	30% ET	0.373	0.081	0.179	0.256
92	70% ET	0.389	0.030	0.076	0.387
	30% ET	0.184	0.249	0.149	0.305
99	70% ET	0.201	0.143	0.297	0.067
	30% ET	0.062	0.518	0.141	0.319
106	70% ET	0.317	0.057	0.047	0.497
	30% ET	0.027	0.670	0.174	0.264
111	70% ET	0.106	0.303	0.174	0.178
	30% ET	0.076	0.474	0.166	0.276
127	70% ET	0.129	0.252	0.007	0.793
	30% ET	0.065	0.509	0.282	0.141
132	70% ET	0.281	0.076	0.066	0.42
	30% ET	0.104	0.397	0.002	0.922

SUMMARY

This research was aimed at evaluating the effects of N rate, irrigation level and cotton cultivar on lint yield and NUE. With N being required in greater quantities than other nutrients in cotton development the lack of yield response to the highest treatment (135-0-0) when compared to the 75-0-0 treatment may be due to high levels of N in irrigation water or residual soil N below the deepest sampling depth. Recovery efficiency was variable. When N uptake was the greatest, iNUE was the lowest, which resulted in excess N uptake (Rochester, 2011; Bronson, 2021). 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. Similar results to Bronson et al. (2003 & 2005) were determined in which NDVI had a moderate to poor correlation to lint yield. NDVI may not be the best predictor of lint yield based on total N uptake in the Texas High Plains since there was not a consistently strong relationship between lint yield and N.

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