I. WINTER WHEAT FERTILIZER NITROGEN USE EFFICIENCY IN GRAIN AND FORAGE PRODUCTION SYSTEMS

II. DETECTION OF NITROGEN DEFICIENCIES IN COTTON USING SPECTRAL IRRADIANCE MEASUREMENTS AND COTTON RESPONSE TO TOPDRESS APPLICATIONS

By

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Winter Wheat Fertilizer Nitrogen Use Efficiency in Grain and Forage Production Systems

Abstract

Nitrogen use efficiency (NUE) is known to be less than fifty percent in winter wheat grain production systems. This study was conducted to determine potential differences in NUE when winter wheat (Triticum aestivum L.) is grown strictly for forage or grain. The effects of different nitrogen rates on plant N concentrations at different growth stages and on grain yield were investigated in two existing long-term winter wheat experiments near Stillwater (experiment 222) and Lahoma (experiment 502), Oklahoma. At both locations in all years, total N uptake was greater when wheat forage was harvested twice (Feekes 7 and flowering) compared to total N uptake when wheat was grown only for grain. Percent N content immediately following flowering was much lower compared to percent N in the forage harvested prior to flowering, indicating relatively large losses of N over a short period of time. Averaged over locations and years, at the 90 kg N ha $^{-1}$ rate, wheat produced for only forage had much higher NUE (77%) when compared with grain production systems (31%). While gaseous N loss was not measured in this trial, the higher NUE values found in the forage only production systems were attributed to harvesting prior to anthesis and prior to the time when plant N losses are known to be greater.

Introduction

Nitrogen use efficiency is defined as units of N harvested per unit of N applied. Two principal components of NUE are efficiency of uptake and efficiency of N utilization to produce grain or forage (Moll et al., 1982). Nitrogen use efficiency is important when discussing fertilizer applications and plant growth. Nitrogen use efficiency depends on the nitrification rate of the soil, the form of N applied, the growth stage of the plant and weather, etc. Farmers desire to apply N at the ideal time and using the fertilization method that will optimize efficiency. Environmentally, it is important to know how much fertilizer is used by the plant and how much is lost. Scientifically, it is important to understand the processes and storage methods for N and other nutrients.

Nitrogen content varies with the growth stage of the plant (Wuest and Cassman, 1992). Gaseous plant N loss has been found to be significant from flowering to physiological maturity (Harper et al. 1987). Recent work has found that the total N content of the grain and straw components is not equal to total N content of plants at flowering (Harper et al. 1987). Fertilizer N use efficiency as reflected in grain yield of winter wheat has also been shown to change with time and rate of application (Ellen and Spiertz, 1980). Nitrogen use efficiency varies with different genotypes of winter wheat with estimated N loss from flowering to physiological maturity ranging from 4 to 28 kg N ha^{-1} (Kanampiu et al., 1997). Increased N rates have resulted in increased N concentrations in leaves of tall fescue and switchgrass (Staley et al., 1991). Work with winter wheat has shown that high N concentrations in plants at flowering are associated with increased plant N loss (Parton and Morgan, 1988). Many authors have noted that grain yield and N content of cereal grain crops increase significantly with applied N (Simonis, 1987; Raun and Johnson, 1995). However, the higher N rates generally result in decreased NUE values. Olson and Swallow (1984) found that half of the N applied over a five year period remained in the 0 - 0.10 m layer of the soil profile, suggesting loss from aboveground plant mass and not from leaching.

Harper et al. (1987) found that much of the loss of fertilizer N is due to gaseous loss from plants at senescence. At flowering, N is translocated to the grain causing gaseous N losses to increase and efficiency to decrease (Harper et al., 1987). O'Deen (1989) detected volatile ammonia emissions from winter wheat and attributed the source of ammonia to the decomposition of protein during translocation from the leaf to the seed. Research has indicated that NUE decreases at grain fill in cereals, mostly due to gaseous N loss (Bruno et al., 1987).

Nitrogen is essential for plant growth and is known to be present in proteins, nucleic acids and chlorophyll. Plant roots assimilate N mostly as ammonium and nitrate. Adequate N nutrition is required for full development of tillers and leaves and also enables the plant to operate at peak photosynthetic capacity. Nitrogen is the nutrient most susceptible to loss, and recovery of N is usually less than half of that applied (Boswell et al., 1985). Whitehead (1995) found that N concentration in the plant tends to decrease as plants age, mostly due to the increase in cell wall material and decrease in cytoplasm. Similar studies by Harper et al. (1987) noted decreased N concentrations in winter wheat with time during the growing season.

In the south central United States, producers often use winter wheat as a forage crop for cattle as well as grain. The period of winter growth and the relatively high N content of winter wheat make it a good forage crop for ruminant grazing. However, it should be noted that the NUE of livestock production is generally much lower (usually less the 20%) due to inefficiency of conversion and harvest (Van der Ploeg et al., 1989).

Whitehead (1995) suggested that forage production systems are more efficient users of N than grain production systems because harvest before maturity prevents loss of volatile ammonia. Many research sources are available discussing NUE in either forage or grain production systems, but there is little information comparing forage-only versus grain-only production systems for the same crop. The objective of this experiment was to determine potential differences in NUE when winter wheat is grown strictly for forage or for grain.

Materials and Methods

Experimental sites were selected as sub-plots in two existing long-term winter wheat experiments near Stillwater (experiment 222) and Lahoma (experiment 502), Oklahoma, where N rates have been applied annually since 1969 and 1970, respectively. Both experiments employed randomized complete block experimental designs with four replications. Plots were 6.1 x 18.3 and 4.9 x 18.3 m at 222 and 502, respectively. At both sites, N has been applied preplant and incorporated utilizing a conventional tillage system. Nitrogen rates were 0, 45, 90, and 134 kg N ha^{-1} yr^{-1} at Stillwater and 0, 22, 45, 67, 90, and 112 kg N ha^{-1} yr^{-1} at Lahoma. Ammonium nitrate (34-0-0) was applied broadcast and incorporated preplant at both sites. Phosphorus and potassium as triple superphosphate (0-46-0) and potassium chloride (0-0-62) were applied with the N each year at rates of 29 and 20 kg P ha^{-1} and 38 and 56 kg K ha^{-1} at Stillwater and Lahoma, respectively. Initial soil test data taken from the check plots is shown in Table 1. In all years, forage sub-plots (1.44-2.08 m^2) were hand harvested at Feekes growth stages six and again from the same area at Feekes ten (Large, 1954). Grain was harvested from sub-plots, adjacent to forage sub-plots, with a combine from a 3.66 m^2 area. Forage and grain samples were dried and ground to pass a 140 mesh sieve (100 μm) and analyzed for total N content using a Carlo-Erba NA 1500 automated dry combustion analyzer (Schepers et al., 1989). Total N uptake in the forage was determined by multiplying N content and dry matter yield for both harvests taken from the same area. Grain N uptake was determined by multiplying dry matter grain yield and grain total N. Nitrogen use efficiency was determined as N uptake in N treated plots minus N uptake from the check (0-kg N applied) divided by the applied N rate. Fertilizer applications, planting and harvest dates are reported in Table 2.

Results

Analyses of variance and associated means for total forage yield and N uptake, grain yield, and grain N uptake are reported in Tables 3-8 for Stillwater and Lahoma for 1996, 1997, and 1998. A significant grain yield and grain N uptake response to N fertilization was found for the grain production system at both sites. Similarly, forage and forage N uptake responded to applied N at both sites (Tables 3-8). It was interesting to note that dry matter production levels were nearly double for forage-only when compared to the grain production system at both sites. Although less pronounced, forage N uptake or removal was nearly double in the forage-only system when compared to grain-only at both locations (Tables 3-8).

As a result of increased dry matter production and N removal, NUE's were much greater for the forage-only systems at both sites when compared to grain-only systems (Tables 3-8). As per the work of Francis (1993), gaseous plant N losses are known to be greatest between flowering and maturity. The two forage harvests employed here

(March, Feekes 6 and May, Feekes 10) were both prior to flowering. Regrowth, including secondary tillers, following the March harvest did produce plants with heads by May, however, flowering was not achieved. Only limited growth was observed in the forage-only plots following the May harvest. By harvesting the plant for forage before grain fill, potential losses were avoided, thus increasing NUE. At both locations, grain-only production systems had estimated NUE's less than 60 percent in all years excluding the low N rate. The values for the lowest N rate are not discussed because the applied rate is well below those recommended for acceptable yields. With forage-only production systems, NUE's were much greater, exceeding 80% at Lahoma. Although NUE's were expected to decrease with increasing N rates for grain production, this effect was not consistent, excluding the high N rates where depressed NUE's were found. Figures 1 and 2 represent 3-yr. average NUE values at Stillwater and Lahoma, respectively. Three-year NUE average values were included because the purpose of this study was to evaluate the long-term differences between forage and grain production systems. In 1997, forage yields were well above normal, exceeding 10 Mg ha^{-1} at both sites at the highest N rates. Forage production conditions were ideal with a mild wet winter and cool spring. Increased production at the high N rates was a result of depressed yields in both 1995 and 1996 due to poor growing conditions, leaving significant residual N in an environment where nitrate leaching is not expected (Raun and Johnson, 1995). When environmental conditions favored higher yields than the current fertilizer application could support, N was possibly mineralized from the soil organic pool and made available to growing plants. While the 1998 crop year was also conducive to superior forage production, we did not see yields as high as those achieved in 1997, because the reserve of mineralizable N was depleted in 1997.

Conclusions

Expected decreases in NUE's with increasing applied N rates for the grain only production system were not observed in this study. Averaged over locations and years, NUE values for forage production systems were substantially higher than those for grain only production systems. At 90 kg N ha^{-1}, a commonly applied preplant rate in this region, wheat produced for forage only had much higher NUE's (77%) when compared with grain production systems (31%). This is largely due to continuous pre-anthesis harvesting, prior to the onset of gaseous plant N loss. This work suggests that NUE's can be increased using a forage production system, but that these systems will be heavily dependent upon an inefficient animal component. The human requirement for grain will necessitate future improvements in NUE that consider holistic management strategies.

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Table 1. Surface soil (0-15cm) chemical characteristics and classification at Stillwater (experiment 222) and Lahoma, (experiment 502) OK in check plots, 1995.

Location	pH[a]	NH_4-N	NO_3-N	P[b]	K[b]	Total N[c]	Organic C[c]
		--------------mg kg^{-1}---------------				-------g kg^{-1}-----	
Stillwater	5.7	4.64	2.3	33	159	0.9	10.6
Classification: Kirkland silt loam (fine-mixed, thermic Udertic Paleustoll)							
Lahoma	5.6	5.60	4.0	77	467	0.9	11.0
Classification: Grant silt loam (fine-silty, mixed, thermic Udic Argiustoll)							

[a]pH: 1:1 soil:water
[b]P and K: Mehlich III
[c]Organic C and Total N: dry combustion

Table 2. Planting and harvest dates for Stillwater (experiment 222) and Lahoma (experiment 502) NUE expts.

Procedure	1996	1997	1998
	----year----		
Stillwater 222			
Fertilization	Oct 9	Sept 5	Oct 2
Planting	Oct 10	Oct 3	Oct 3
Forage harvest 1	Mar 1	Jan 6	Feb 18
Forage harvest 2	May 7	May 13	May 12
Grain harvest	June 11	June 19	June 10
Lahoma 502			
Fertilization	Aug 31	Sept 4	Sept 10
Planting	Oct 10	Oct 3	Oct 17
Forage harvest 1	Mar 5	Jan 3	Mar 25
Forage harvest 2	May 6	May 6	May 11
Grain harvest	June 21	June 13	June 12

Table 3. Analysis of variance and means for total dry matter forage yield (sum of harvests in March and May) grain yield, N uptake, and nitrogen use efficiency (NUE) Stillwater, OK, 1996

		Forage			Grain		
		Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]
Source of variation	df	mean squares					
Replication	3	0.690	164	192	0.037	38	3
N rate	3	1.956*	1995*	332	0.329*	628*	403
Residual error	9	0.612	396	192	0.059	108	109
SED		0.553	14.0	9.7	0.171	7.3	6.9
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	%	Mg ha^{-1}	kg ha^{-1}	%
0		2.719	49.58	-	1.007	28.95	-
44		2.841	59.01	21	1.274	35.61	15
90		3.553	83.12	37	1.382	48.49	22
134		4.228	98.52	36	1.701	56.79	21

* Significant at the 0.05 probability level
**Significant at the 0.01 probability level
[@] df for NUE, N rate = 2
SED- Standard error of the difference between two equally replicated means

Table 4. Analysis of variance and means for total dry matter forage yield (sum of harvests in March and May) grain yield, N uptake, and nitrogen use efficiency (NUE) Stillwater, OK, 1997

		Forage			Grain		
		Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]
Source of variation	df	mean squares					
Replication	3	1.10	336	1113	.0364	235	3
N rate	3	19.1*	3667**	4016	1.011*	725*	403
Residual error	9	0.79	793	1046	0.126	79	109
SED		1.21	20.0	22.9	0.251	6.3	6.9
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	%	Mg ha^{-1}	kg ha^{-1}	%
0		3.334	49.88	-	0.872	20	-
44		5.077	76.05	58	0.859	21	17
90		7.460	103.75	60	1.069	29	19
134		9.668	143.12	69	1.920	50	21

* Significant at the 0.05 probability level
**Significant at the 0.01 probability level
[@] df for NUE N rate = 2
SED- Standard error of the difference between two equally replicated means

Table 5. Analysis of variance and means for total dry matter forage yield (sum of harvests in March and May) grain yield, N uptake, and nitrogen use efficiency (NUE) Stillwater, OK, 1998

		Forage			Grain		
		Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE$^{@}$	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE$^{@}$
Source of variation	df	mean squares					
Replication	3	1920.4**	377**	744	1.876	103	163*
N rate	3	6265.5**	2766**	1709	1012**	324**	319**
Residual error	9	187.23	41.20	261	109	32.42	40.75
SED		0.306	4.54	11.42	0.233	4.03	4.51
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	%	Mg ha^{-1}	kg ha^{-1}	%
0		1.886	23.21	-	1.153	22	-
44		2.768	41.20	40	1.434	31	20
90		3.276	50.96	31	1.808	38	18
134		4.868	80.76	47	2.316	43	15

* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
$^{@}$df for NUE N rate = 2
SED- Standard error of the difference between two equally replicated means

Table 6. Analysis of variance and means for total dry matter forage yield (sum of harvests in March and May) grain yield, N uptake, and nitrogen use efficiency (NUE) Lahoma, OK, 1996

		Forage			Grain		
		Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]
Source of variation	df	mean squares					
Replication	3	1.300	1394	2.580	324	660*	1341*
N rate	5	3.197*	4844*	5.708	1510**	1140**	2850**
Residual error	13	0.520	568	4.033	184	156	387
SED		0.509	16.8	1.16	0.247	7.2	11.4
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	%	Mg ha^{-1}	kg ha^{-1}	%
0		2.89	57.98	_	1.48	33	-
22		3.04	75.90	24	1.96	51	81
45		3.49	87.32	65	2.22	58	55
67		4.29	113.32	80	2.17	54	32
90		5.24	149.90	102	2.87	74	46
112		4.91	133.93	68	3.17	80	42

* Significant at the 0.05 probability level
**Significant at the 0.01 probability level
[@]df for NUE N rate = 4
SED- Standard error of the difference between two equally replicated means

Table 7. Analysis of variance and means for total dry matter forage yield (sum of harvests in March and May) grain yield, N uptake, and nitrogen use efficiency (NUE) Lahoma, OK, 1997

		Forage			Grain		
		Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE[@]
Source of variation	df	mean squares					
Replication	3	17412**	2541**	6744*	663	426	879
N rate	5	32914**	17434**	19830**	4265**	2361*	3049
Residual error	13	2012	344	1675	462	201	811
SED		0.82	10.7	23.6	0.39	8.2	16.5
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	%	Mg ha^{-1}	kg ha^{-1}	%
0		3.94	69	-	1.47	35	-
22		7.92	115	208	2.23	54	83
45		8.37	123	121	2.30	55	45
67		9.17	146	114	3.05	73	56
90		10.99	206	153	3.58	81	51
112		12.20	143	162	4.32	104	62

* Significant at the 0.05 probability level
**Significant at the 0.01 probability level
[@]df for NUE N rate = 4
SED- Standard error of the difference between two equally replicated means

Table 8. Analysis of variance and means for total dry matter forage yield (sum of harvests in March and May) grain yield, N uptake, and nitrogen use efficiency (NUE) Lahoma, OK, 1998

		Forage			Grain		
		Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE$^{@}$	Yield Mg ha^{-1}	N uptake kg ha^{-1}	NUE$^{@}$
Source of variation	df	mean squares					
Replication	3	858.3	1308	6155	250.8**	506.2	1979
N rate	5	5536.2**	5171**	4064	3415.4**	2640**	4183
Residual error	13	567.1	461	3134	44.0	314.8	1086
SED		0.435	12.4	32.3	0.121	10.24	19.02
N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	%	Mg ha^{-1}	kg ha^{-1}	%
0		4.06	86	-	2.112	49.37	-
22		4.45	102	70	2.284	50.00	17
45		4.86	112	57	3.719	88.74	78
67		5.79	139	79	3.665	87.15	56
90		6.65	160	82	3.426	83.08	37
112		6.89	180	83	4.542	117.10	60

* Significant at the 0.05 probability level
** Significant at the 0.01 probability level
@! df for NUE N rate = 4
SED- Standard error of the difference between two equally replicated means

Table 8. Analysis of variance and means for total dry matter forage yield (sum of harvests in March and May) grain yield, N uptake, and nitrogen use efficiency (NUE) Lahoma, OK, 1998

		Forage			Grain		
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Source of variation	df	mean squares					
Replication	3	858.3	1308	6155	250.8**	506.2	1979
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N rate, kg ha^{-1}		Mg ha^{-1}	kg ha^{-1}	%	Mg ha^{-1}	kg ha^{-1}	%
0		4.06	86	-	2.112	49.37	-
22		4.45	102	70	2.284	50.00	17
45		4.86	112	57	3.719	88.74	78
67		5.79	139	79	3.665	87.15	56
90		6.65	160	82	3.426	83.08	37
112		6.89	180	83	4.542	117.10	60

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@! df for NUE N rate = 4

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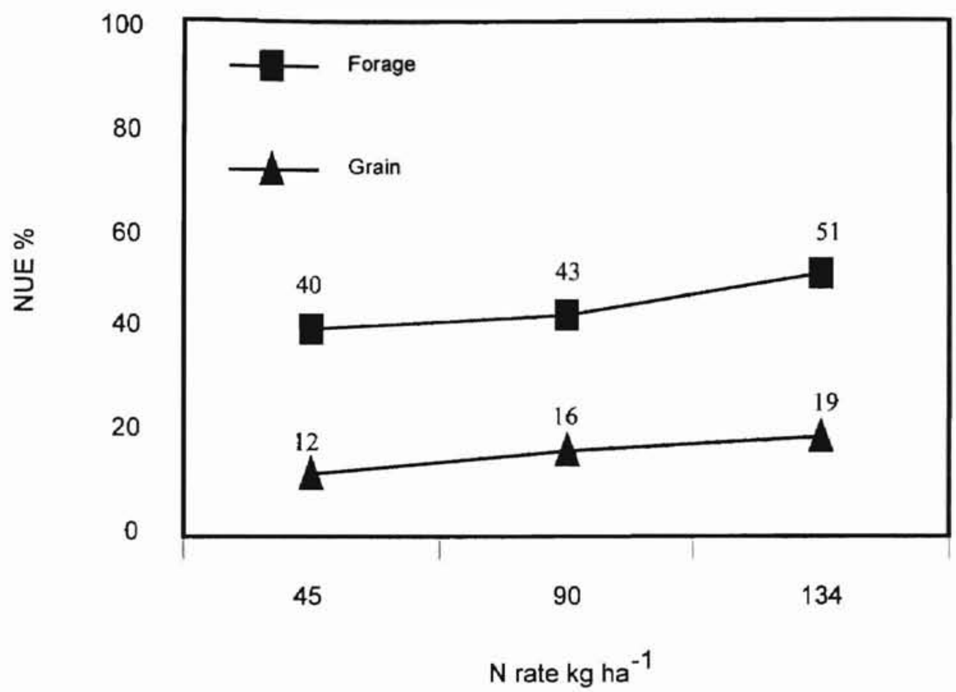

Figure 1. Average NUE values for forage and grain production systems, Stillwater OK, (experiment 222)

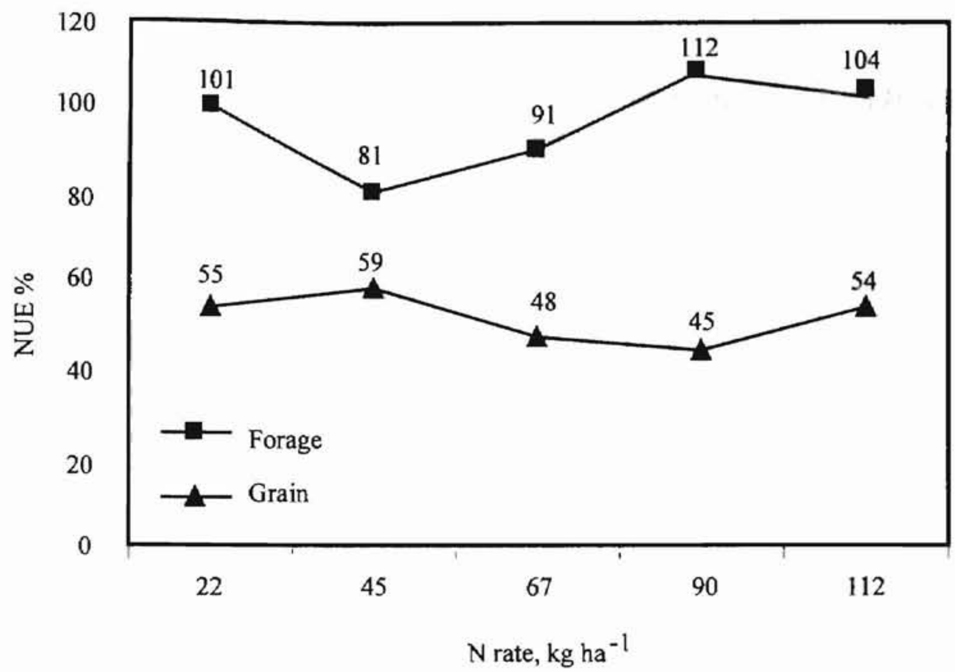

Figure 2. Average NUE values for forage and grain production systems, Lahoma, OK, (experiment 502)

Detection of Nitrogen Deficiencies in Cotton Using Spectral Irradiance and Cotton Response to Topdress Applications

Abstract

Upland cotton (Gossypium hirsutum L.) requires adequate, but not excessive N to produce optimum yields and still reach maturity at a reasonable date. This optimum rate of N is strongly dependent on yield potential and environmental conditions. The ideal situation is to keep N from limiting plant growth while avoiding excessive N applications. In-season N applications are popular because they allow the producer to adjust fertilizer inputs based on how the crop is maturing. This study was conducted to evaluate spectral radiance in cotton canopies and discern which wavelengths detect N deficiencies, and to evaluate the effect of foliar applied N on cotton lint yield based on spectral radiance measurements. The effects of differing N rates and timing were evaluated using a spectrometer. Normalized difference vegetative index (NDVI) from spectral radiance measurements collected mid bloom was highly correlated with preplant N rate and cotton petiole N concentration. Reliable prediction of the N status in cotton using NDVI was also indicated by the variable N rate treated plots as N rates were reduced compared to fixed rates with no decrease in yield.

Introduction

Upland cotton (Gossypium hirsutum L.) requires adequate, but not excessive N to produce optimum yields. Optimum rates of N are strongly dependent on environmental yield potentials. Plentiful N can lead to larger plants with the potential to produce more cotton. Excessive N stimulates excessive plant growth to the detriment of yield and earliness (Boquet et al., 1994). The ideal situation is to keep N from limiting plant growth while avoiding excessive N applications. Many producers apply most of the required N before planting and then make additional N applications when environmental conditions favor high yields. Modern, high-yielding varieties grow and fruit faster than older varieties and therefore, require larger amounts of nutrients in a shorter time. These characteristics make in-season nutrient application even more critical. In some cases, even when soil tests indicate sufficient plant nutrients, deficiency symptoms appear. This suggests that plant uptake mechanisms may not immediately meet plant requirements. Attempts have been made to correct in-season deficiencies with foliar fertilizer applications in hopes that the fertilizer would be more readily available to the plant.

One common method of supplementing N is with foliar applied liquid UAN. Foliar application of N has been shown to increase cotton yields when N was deficient (Miley and Bonner, 1985). The problem with foliar application is determining the point in the growth pattern of the plant that will provide maximum response.

Modern testing procedures often use the plant itself as an indicator of nutrient need (Gardner and Tucker, 1967). One school of thought follows the idea that the petiole from the most recently mature leaf is the best indicator of plant N status (Gardner and Tucker, 1967). This plant part is often used as the benchmark for the rest of the plant. Petiole N content has been used for many years to determine N status in the plant (Baker et al., 1972). These results have varied between regions and years, often owing to the difficulty of determining the most recently mature leaf of the plant and variable environmental conditions. Total N values for leaves are more stable, but are less sensitive to N status of the plant (Cope, 1984). Leaf characteristics such as age and surface wax are some of the factors that affect plant response to foliar-applied N (Bondada et al., 1994).

Soil analysis for N content is a common method for determining N application rates. The amount of N detected in soils has been correlated with the amount of N taken up by the plant. The major drawback to this method is that soil sampling and analysis involve money and time, time the producer does not have when attempting to correct in-season deficiencies. The ideal time for N application during the growing season has a narrow window (Ebelhar and Welch, 1996). The perennial growth habit of the cotton plant forces producers to wait until the plant has produced several leaves to use plant samples to determine N status of the plant. Producers must also apply nitrogen during blooming or earlier to avoid excess vegetative growth.

Spectral properties of the leaf canopy can provide alternative measures for detecting nutrient status (Raun et al., 1996). This technology offers the ability to detect N deficiencies and apply fertilizer at the same time, eliminating the need for more time consuming, in-season testing methods and reduces the number of trips made across the field. Fields are not totally uniform and plants vary in N uptake due to environmental factors. Some seeds may germinate sooner than others depending on the quality of the seed and the temperature of the soil. Soil temperature also changes within specific areas of the field.

The most important thing to remember about in-season testing is that the deficiency must be detected before severe deficiency stress occurs. If the problem is detected early enough, minimal loss of yield will result. Thus, in-season testing offers the ability to tailor N applications with crop status at the time of sensing, while also having a plant indicator (biomass) as an index of yield potential. Combined with planting density, time of planting and environmental data, indirect in-season measurements could assist in refining N fertilization strategies.

Sensor based applications rely on in-season application of a liquid or granular N source. Foliar N applications have been reported to provide yield increases when N is limiting (Miley and Bonner, 1985). Foliar applications make the applied N available to the plant for use in the critical early square to early boll growth stages. Foliar applications have also been observed to increase root development of seedling cotton (Chiles,1989). The effectiveness of this treatment is contingent on growth stage and leaf morphology of the plant. While there are many different views on the feasibility of foliar N applications, most of the research indicates that foliar applications are productive if N is deficient. When combined with sensor-based deficiency detection, this method should improve yield and increase producer profits. The objectives of this study were: 1) to evaluate spectral irradiance from cotton leaf canopies and discern which wavelengths detect N deficiency; and 2) evaluate the effect of foliar applied N on cotton lint yield based on spectral irradiance measurements.

Materials and Methods

One experimental site was chosen at Altus, Oklahoma (Tables 1and 2). A randomized complete block experimental design with three replications was employed. Plot size was 4.06 x 18.3 m. Pre-plant nitrogen rates were 0, 22, 45, 67, and 90, kg ha^{-1}. Ammonium nitrate (34-0-0) was the N source used for all pre-plant treatments. Phosphorus as triple superphosphate (0-46-0) and potassium as potassium chloride (0-0-

62) were applied at rates of 80 kg P ha^{-1} and 80 kg K ha^{-1} to the area. Paymaster HS-26 seed was planted on May 14, 1997 at a rate of 19.3 kg ha^{-1}. Dates for irrigations and pesticide applications are listed in Table 1. Soil classification and characteristics are listed in Table 2. Spectral data was collected within each plot using a PSD-1000 portable dual spectrometer manufactured by Ocean Optics Inc., from two overlapping bandwidths, 300-850 nm and 650-1100 nm. The PSD-1000 is connected to a portable computer through a PCMCIA slot using a PCM-DAS16D/12 A/D converter manufactured by Computer Boards, Inc. The fiber optic spectrometer has spectral resolution as low as 1nm, however, all spectral readings were partitioned into 10 nm bandwidths (75 spectral bands per reading). Six spectral readings (350-1100 nm) were taken from three $1m^2$ areas within each plot at bloom and 10 days post-bloom and averaged for each 10 nm bandwidth. In addition to the 75 spectral bands collected from each reading, the spectral indices normalized difference vegetative index (NDVI) microwave polarization difference index (MPDI, Becker and Choudhury, 1988), water band index (WBI, Penuelas et al., 1993), and normalized total pigment to chlorophyll a ratio index (NPCI, Penuelas et al., 1993), were calculated for all spectral radiance readings. The 75, 10 nm bandwidths for each growth stage where data was recorded and indices computed were evaluated for simple correlation with petiole NO_3-N, total N, and N use efficiency components adapted from Moll et al. (1982). Specific wavelengths where no correlation was found were evaluated as divisors, for their potential use within indices whereby illumination deviations can be removed from spectral indices. These indices were again analyzed in the AOV model for their use in detecting main effects and main effect interactions. Spectral radiance readings were taken from each plot at bloom and ten days

post-bloom. At these same time periods, petiole samples were taken from the first mature leaf from sixteen plants in the center two rows. Petiole samples were dried and ground to pass a 140 mesh sieve (100μm) and analyzed for total N using a Carlo-Erba NA 1500 dry combustion analyzer (Schepers et al., 1989) and for NO_3-N using cadmium reduction (Lachat, 1985). In-season applications of 0 and 45 kg ha^{-1} as a fixed rate, and a variable rate of N were applied as UAN (28% N) at mid bloom. Variable rates were determined by analyzing petioles for total N content and comparing it with the sensor readings but on a much finer grid (1 x 2 m). The index NDVI was used as the basis for topdress N applications. The values for this index were correlated with the N concentrations determined from the tissue samples to determine plant N status and fertilizer need. The plot with the lowest NDVI values received the highest rate of N (45 kg ha^{-1}) and the plots with the highest values received no added N.

Results

Spectrometer readings showed peaks at 527 and 770 nm for the cotton crop (Figure 1). No one index was consistently shown to have the highest correlation with petiole N content. The index NDVI (I_{780nm}-I_{671nm}/ I_{780nm}+I_{671nm}, where I represents the spectrometer reading) paralleled preplant N rate over time and was therefore used as a measure of crop N status (Figures 2,3, and 4). The NDVI readings were correlated with actual plant N measures and the N status of the plant was evaluated by the use of spectral irradiance (Figures 3 and 4). With this correlation established, we then used the NDVI readings to determine the N status of the plant on site, and liquid UAN applied as needed based on these spectral readings using the equation, N rate applied = -0.0089(NDVI) + 0.3565. NDVI indices gave a good prediction of the amount of N the plant would require for the remainder of the growing season based on final lint yields (Figure 3). Cotton lint yields increased with increasing N applied either preplant or in-season, with lower yields seen in plots with in-season only treatments (Table 3). The observed effects of increased yield with N rate were linear (Table 3). Yields at the three highest variable rates were greater than those for the in-season fixed applications with less fertilizer applied, up to 30 kg at the highest rate. We also found a general trend toward increasing yields with increasing N rates for the variable rate treated plots and average lint yields for the same pre-plant N rates were higher for the variable applied treatments. In-season variable treatments allowed us to use a lower pre-plant rate and then adjust the amount of N based on NDVI. The 67 kg ha^{-1} pre-plant rate produced 918 kg, with the in-season addition of 26 kg ha^{-1} of N (based on NDVI values) yields of that treatment were brought up to the maximum yield which was also achieved with the 90 kg ha^{-1} pre-plant rate(Table 3). This information would allow producers to begin the growing season with less N and adjust applications according to crop status. Production per unit of N values (kg lint kg N $applied^{-1}$) are shown in Table 3. Highest efficiencies were obtained with the lowest rates of applied N. Variable treated plots showed increased efficiencies when compared to the in-season fixed applications. These results show yields for the variable plot were similar to or greater than the in-season fixed treatments with less total fertilizer applied. This indicates that variable applied N based on NDVI readings could result in less total input cost for the producer. This work will be continued for the 1998 crop year.

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Table 1. Dates and information regarding Altus Variable Rate Cotton Expt., 1997

Irrigations:	
July 14	
July 28	
Herbicide applications:	
March 26	Treflan 4EC(PPI) at 2.0 pts. product/ac
May 14	Caparol 4L (Pre) at 3.2 pts. product/ac
July 3	Staple (Post) at 1.2 oz product/ac
Fungicide application:	
May 14	Start 15 G Brand Fungicide (In furrow) at 2.0 lb. product/ac
Insecticide applications:	
May 14	Temik 15 G (In furrow) at 0.5 lb. Ai/ac
June 21	Vydate C-LV (Post) at 4.25 oz. product/ac
June 28	Vydate C-LV (Post) at 4.25 oz. product/ac
July 4	Vydate C-LV (Post) at 4.25 oz. product/ac
August 9	Vydate C-LV + Larvin 3.2 at 4.40 + 5.12 oz. product/ac
August 15	Vydate C-LV + Larvin 3.2 at 4.40 + 5.12 oz. product/ac
August 23	Karate + Furadan 4F at 0.03lb. Ai/ac + 8.0 oz. product/ac
August 30	Vydate C-LV at 4.37 oz. product/ac
September 10	Malathion ULV at 10.0 oz. product/ac
September 18	Malathion ULV at 10.0 oz. product/ac
September 26	Malathion ULV at 10.0 oz. product/ac
Harvest aid applications:	
September 30	Prep + Folex 6 EC at 1.3 pts. product/ac + 1.0 pt. product/ac
Harvest date:	
October 31, 1997	

Table 2. Initial surface soil (0-15cm) chemical characteristics and classification at Altus, OK.

Location	pH[a]	NH_4-N	NO_3-N	Total N[c]	Organic C[c]
		--------mg kg^{-1}-------		------g kg^{-1}------	
Altus	8.1	5.11	4.37	0.75	8.5

Classification: Tillman-Hollister clay loam (fine-mixed, thermic Typic Paleustoll)

[a]pH: 1:1 soil:water
[c]Organic C and Total N: dry combustion

Table 3. Nitrogen rates, mean yields and analysis of variance for cotton lint yields for three N application times, Altus, 1997

Pre-plant fixed			In-season fixed			In-season variable		
N rate, kg ha^{-1}	Yield	PN	N rate, kg ha^{-1}	Yield	PN	N rate, kg ha^{-1}	Yield	PN
0	645	-	45	570	13	31	505	16
22	820	37	67	860	13	53	719	14
45	899	20	90	908	10	76	958	13
67	918	14	112	967	9	93	1168	13
90	1143	13	135	1053	8	105	1176	11

Source of variation	df	Mean Squares
Replication	2	32467.66
N Rate	14	130232.47*
Error	28	45593.92
Contrasts		
Pre-plant linear	1	360053.60*
In season linear	1	345325.74*
Variable linear	1	963429.38*
Pre-plant quadratic	1	351.60
In season quadratic	1	33894.83
Variable quadratic	1	41313.66

SED = 45.52

*Significant at the 0.05 probability level
SED- Standard error of the difference between two equally replicated means
PN- Production of lint per unit of applied N = (yield, kg ha^{-1}/total N rate applied, kg ha^{-1})

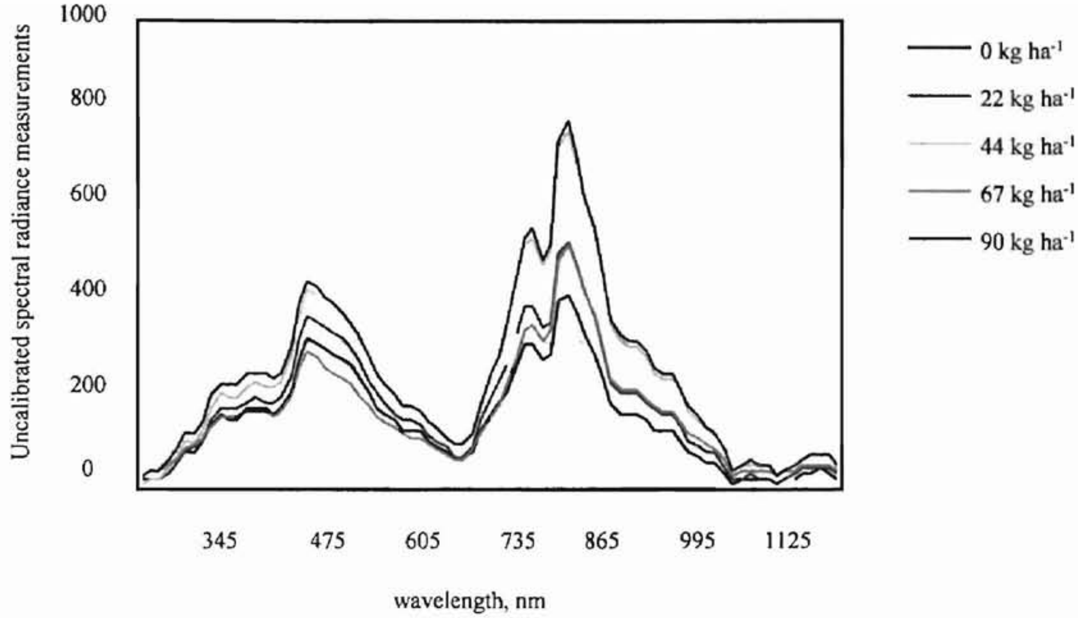

Figure 1. Spectral radiance readings collected from mid-bloom cotton as affected by N rate, July 27,1997. Altus OK

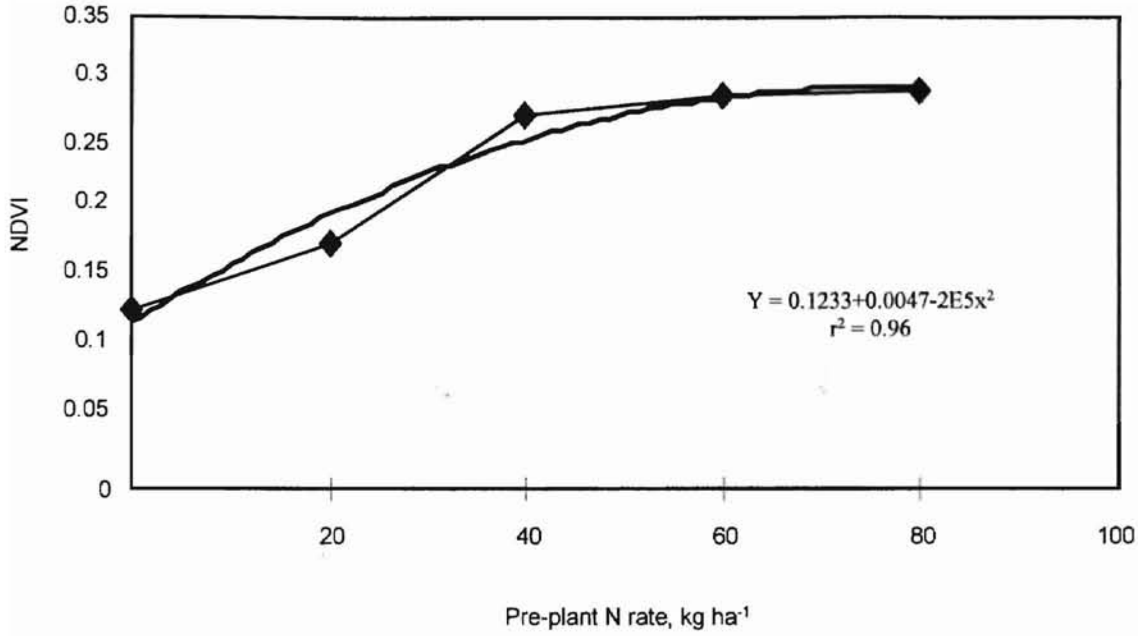

Figure 2. Relationship between NDVI readings from mid-bloom cotton and preplant N rates. July 27,1997. Altus , OK

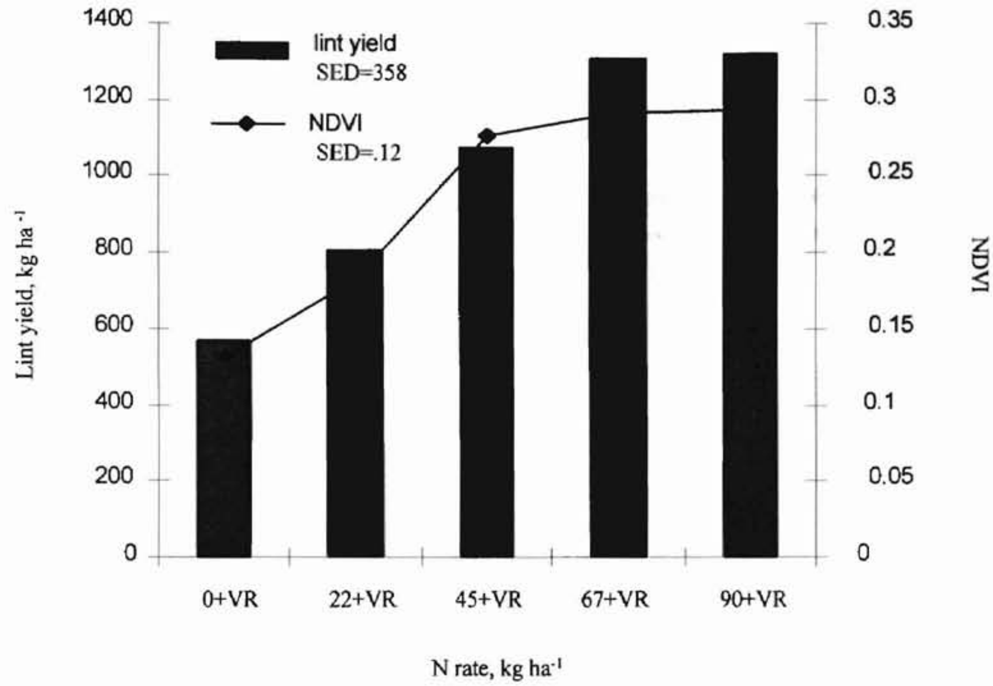

Figure 3. Relationship of lint yield and NDVI readings taken from mid-bloom cotton to N rate. July 27, 1997. Altus, OK

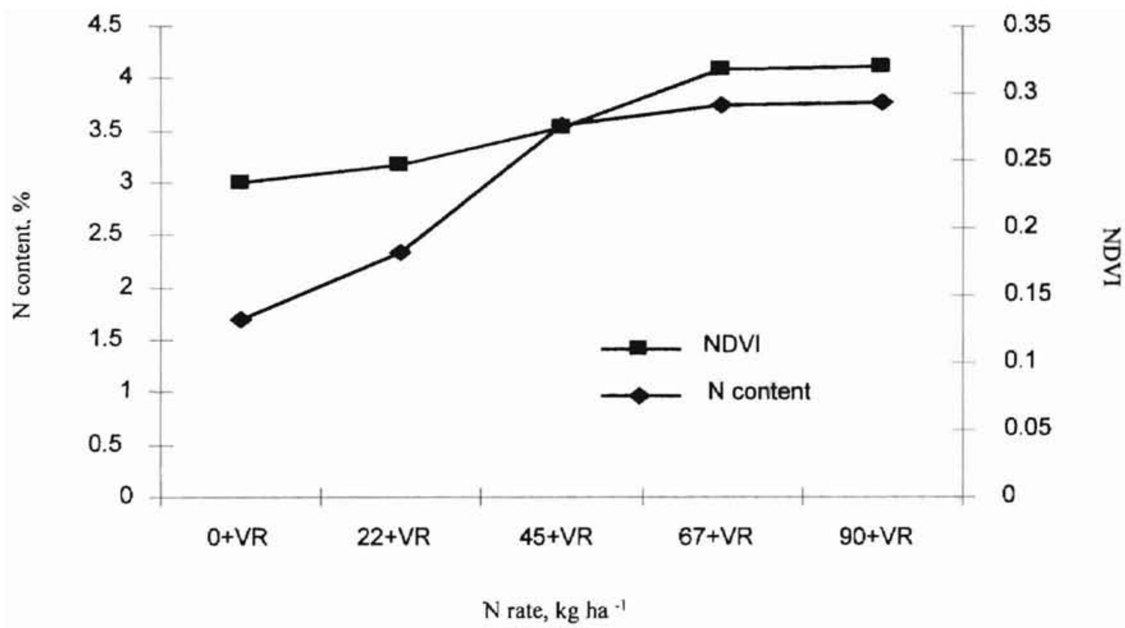

Figure 4. Relationship between NDVI values and N content from mid-bloom cotton petioles to applied N rate. July 27, 1997. Altus OK

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VITA

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Master of Science

Thesis: I. WINTER WHEAT FERTILIZER NITROGEN USE EFFICIENCY IN GRAIN AND FORAGE PRODUCTION SYSTEMS

II. DETECTION OF DEFICIENCIES IN COTTON USING SPECTRAL IRRADIANCE MEASUREMENTS AND COTTON RESPONSE TO TOPDRESS APPLICATIONS

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