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Use of Spectral Radiance for Correcting Nitrogen Deficiencies and Estimating Soil Test Variability in an Established Bermudagrass Pasture

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ABSTRACT

The use of variable rate technology has become increasingly popular for applying plant nutrient elements. The most widely used method for determining variable fertilizer rates is presently based on soil testing and yield mapping. Three field studies (Burneyville 1995, Burneyville 1996, and Ardmore 1996) were initiated in established Midland bermudagrass [*Cynodon dacrylon* (L) *Pers.*] pastures to determine the relationship between spectral radiance at specific wavelengths with forage nitrogen (N) removal and biomass, and to determine field variability of soil test parameters. Variable N (applied to 1.5 x 2.4 m subplots within 2.4 x 45.7 m main plots), fixed N and check treatments were evaluated at each location. Spectral radiance readings were taken in the red (671±6 nm), green (570±6 nm), and near infrared (NIR) (780±6 nm) wavelengths. The normalized difference vegetation index (NDVI) was calculated as NIR-red/NIR+red. Variable N rates were applied based on NDVI. The highest fixed variable N rate was set at 224, 336, and 672 kg N ha^{-1} for

Burneyville, 1995, 1996, and Ardmore, 1996, respectively. At Burneyville, soil samples were collected in all variable rate plots (1.5 x 2.4 m) and analyzed for various soil test characteristics. NDVI, red, green, and NIR spectral radiance readings were correlated with bermudagrass forage N removal and yield. Correlation of forage yield and N removal with red, NIR, and NDVI were best with maximum forage production, however, when forage production levels were low correlation decreased dramatically for the red wavelength compared with NIR and NDVI. Forage yield and forage N removal in variable rate treatments increased when compared to the check while being equal to the half-fixed and fixed rates where higher N rates were applied. Also, variability about the mean in variable rate plots was significantly lower than half-fixed and fixed rates which supports adjusting N rates based on indirect NDVI measurements. Variable N rate plots reduced fertilizer inputs by 60% and produced the same yield as fixed rate plots, while fixed and half-fixed rates did not increase N content in the forage over that of the variable rate treatment. Soil sample data collected from small consecutive plots (<4 m^2) was extremely variable indicating that intense sampling would be needed if variable fertilizer application were to be based on soil test results.

INTRODUCTION

The use of sensor-based variable fertilizer application has not been extensively studied. Spectral radiance has been previously used to detect weed versus bare soil and NIR instruments have been used to detect protein content and digestibility in forages. The use of precision farming for applying plant nutrient elements is becoming increasingly popular although the most widely used method to adjust nutrient application continues to be soil testing. Kincheloe (1994) noted that wide yield variations occur in fields which have continually received the same inputs and where much of the variability is due to soil type. Wibawa et al. (1993) indicated that a 15-m sampling grid was a better estimator of field variability compared to a 76-m sampling grid. Grain yield increased from the reduced grid size, but the intense sampling resulted in a lower net return because of the high sampling and testing costs. Han et al. (1994) calculated the minimum cell size by subdividing a field into small enough regions that soil properties within regions were uniform thus keeping application rates constant. They estimated that the minimum cell size for soil nitrate (NO_3) concentration was 20 m x 20 m. Cahn et al. (1994) analyzed spatial variability of soil properties and nutrient concentrations for site-specific crop management and concluded that reducing sampling intervals from 50 to 1 m would reduce variability of soil water content, soil organic carbon (C), nitrate-nitrogen (NO_3-N), phosphate-phosphorus (PO_4-P), and potassium (K) estimates by 74, 95, 25, 64, and 58%, respectively. Vansichen and De Baerdemaeker (1993) reported that 67% of the variability in corn silage yield was explained by soil sampling variables. Wollenhaupt et al. (1994) estimated mapping accuracy by dividing a field into cells of 97 m^2 and taking a composite soil sample from each cell. They also looked at a second field and divided it into cells of size 32 m^2 and took samples using a grid-point method in which soil samples were taken on grid intersections. This work showed that the 97 m^2 cells were not acceptable for variable rate fertilizer application and if used would result in some misapplication, while the 32 m grid-point samples increased mapping accuracy by 38%. Chancellor and Goronea (1994) found that application of N in wheat based on spatial variability of <1 m intervals increased N-use efficiency 12% over spatial variability greater than 1 m.

Recent work by Stone et al. (1995) has demonstrated that total plant N can be estimated by using spectral radiance measurements in the red (671 nm) and NIR (780 nm) wavelengths. A plant-nitrogen-spectral-index (inverse of NDVI) was used to calculate the amount of fertilizer N required to correct in-season winter wheat N deficiencies. Blackmer et al. (1994) stated that light reflectance near 550 nm was best to separate N treatment differences and could be used to detect N deficiencies in corn. Work by Bowman (1989) measured leaf spectral reflectance of cotton in the near-infrared spectra (810, 1,665, and 2,210 nm) as it related to relative leaf water content, total water potential and turgor pressure. Hagger et al. (1984) used a hand-held meter which measured relative intensity of reflected light at 650 and 750 nm on various legumes and grasses, and indicated that the meter could be used to discriminate between white clover and N-deficient grasses. Green leaf dry matter and infrared/red ratios indicated that reflectance measurements could be used to estimate leaf dry matter or leaf area measurements in spring and winter wheat (Aase and Tanaka, 1984). Everitt et al. (1985) studied the relationship of plant leaf N content and leaf reflectance from 500 to 750 nm and concluded that buffelgrass which received no fertilizer N resulted in higher reflectance readings. Kleman and Fagerlund (1987) found that an infrared/red ratio was strongly correlated with biomass 200 days after planting barley. Walburg et al. (1982) measured spectral differences across N treatments in corn and found that N treatments had an effect across the entire wavelength interval measured (0.4 to 2.4 μm). Readings in the red reflectance increased from N-deprived canopies, while the near infrared reflectance decreased, with a near infrared/red ratio differing more than a single wavelength.

The objectives of this work were to determine the relationship between spectral radiance at specific wavelengths with total bermudagrass forage N and biomass and to quantify soil test variability in small plots.

MATERIALS AND METHODS

For all experiments, forage spectral radiance measurements were obtained using an integrated sensor and signal processing system. Photodiode detectors included interference filters for red (671±6 nm), NIR (780±6 nm), and green (550±6 nm) with a spectral band width of 0.46 m and 0.075 m long. Using sensor measurements obtained for NIR and red uncalibrated voltage readings, NDVI was calculated

TABLE 1. Initial surface (0-15 cm) soil test characteristics and soil classification, Ardmore and Burneyville, OK, 1995 and 1996.

Location	pH	Total N	Org. C	NH_4-N	NO_3-N	P	K
		g kg^{-1}		mg kg^{-1}			
1995							
Burneyville	5.7	0.8	9.5	7.8	2.2	23	184
Classification : Minco fine sandy loam (coarse-silty, mixed thermic Udic Haplustoll)							
1996							
Ardmore	5.4	0.6	9.6	15.8	1.8	9	141
Classification: Wilson silt loam (fine, montmorillonitic, thermic Vertic Ochraqualfs)							
Burneyville	5.4	0.8	9.1	8.7	1.2	30	149
Classification: Minco fine sandy loam (coarse-silty, mixed thermic Udic Haplustoll)							

pH-1:1 soil:water, total N and organic C-dry combustion, NH_4-N and NO_3-N-2M KCl extract, P and K-Mehlich III extraction.

based on work by Stone et al. (1996), Perry and Lautenschlager (1984), and Sancan et al. (1993). Spectral radiance readings were obtained at the start of the experiment and before each subsequent forage harvest. The sensor components were mounted on the front of a John Deere Model 318 lawn and garden tractor traveling at a speed of 3 km hr^{-1}. Approximately 10 readings were taken per second, with a range of 75-100 readings from each 2.4 x 1.5 m plot. Red, NIR, and green were determined from each plot by averaging the collected readings. All sensor readings were taken in the same direction (south) for all experiments. Variable N rates were applied based on a linear NDVI-N rate scale in which readings with the highest NDVI value (highest total forage N) received the lowest fertilizer N rate, and the lowest NDVI value (lowest total forage N) receiving the highest fertilizer N rate, dependent on the location and year. All variable N rates were broadcast by hand as ammonium nitrate (NH_4NO_3) to each subplot.

All forage samples (prior to and after fertilization) were collected using a self-propelled John Deere 256 rotary mower at a height of 0.09 m. Plot weights were recorded and sub-sampled for moisture and chemical analysis. Sub-samples were dried for 120 hr in a forced-air oven at 70°C and ground to pass a 100-mesh screen. Bermudagrass forage and soil samples were analyzed for total N and organic carbons (C) (soil only), by dry combustion, (Schepers et al., 1989), and total P (only prefertilization at Burneyville 1995) using the vanadomolybdate method without the use of sulfuric acid (H_2SO_4) in the digest (Barton, 1942; Bolin and Stamberg, 1944). Soil samples were additionally analyzed for pH (1:1 soil:water), ammonium-nitrogen (NH_4-N) and NO_3-N [2M potassium chloride (KCl) extractant, LACHAT, 1989], and extractable K and P [Mehlich III extractant (Mehlich, 1984)].

Burneyville 1995

One field experiment was established in the summer of 1995 on a Minco fine sandy loam at Burneyville, OK. Initial soil test characteristics are reported in Table 1. Whole plot treatments (2.4 x 45.7 m) consisted of check (no-N), fixed (242 kg N ha^{-1}) and a variable rate (N rate dependent on NDVI readings) applied to 30 subplots (2.4 x 1.5 m) within whole plots. The experimental design was a split-plot randomized complete block with three replications. A proportion of the third replication was infested with crabgrass and was not included in the forage yield results. Fertilizer treatments were applied after sensor readings were taken and forage was removed, with the variable rate application ranging from 0 to 224 kg N ha^{-1} (agronomic rate determined based on yield goal for the region). A blanket application of P as triple superphosphate (0-45-0) and K as potassium chloride (KCl) was applied (at the time of N fertilization) at rates of 48.9 kg ha^{-1} of P and 186 kg ha^{-1} of K, respectively. Surface soil samples (0-15 cm) were taken from all subplots within variable rate plots prior to fertilization to evaluate soil heterogeneity.

Ardmore and Burneyville 1996

Two added field experiments were established at Ardmore and Burneyville to determine the use of spectral radiance reading for estimating N deficiencies in bermudagrass pastures. The Burneyville 1996 site was 200 m away from the Burneyville 1995 experiment. Soil test values and classification are reported in Table 1. The experimental design was a split-plot randomized design with two replications. Whole plot treatments (3.1 x 45.7 m) consisted of a check (0 kg N ha^{-1}), fixed (600 and 300 kg N ha^{-1}) Ardmore and Burneyville, respectively), half-fixed (half the fixed rate at each site, respectively) and variable rate (N rate dependent on NDVI readings). Whole plots were subdivided into 30 subplots (3.1 x 1.5 m). Fertilizer treatments were applied after sensor readings were taken, when the bermudagrass was approximately 0.1 m tall, with the variable N rate ranging from 0 to 600 kg N ha^{-1} and 0 to 300 kg N ha^{-1} at Ardmore and Burneyville, respectively. The top fixed rate (600 and 300 kg N ha^{-1} at Ardmore and Burneyville) was chosen based on yield maximums observed over time in companion studies at the same sites (data not reported). A blanket application of P and K was applied as was done in 1995, but in early April at these two sites. Spectral radiance readings were taken prior to fertilization and before each subsequent harvest following fertilization for all treatments.

RESULTS AND DISCUSSION

Prefertilization Forage Yield

Prior to any fertilization, a contour map of NDVI readings was developed from mean values generated from every plot (2.4 x 1.5 m) from the entire experimental

TABLE 2. Simple correlation coefficients and significance levels for forage production, total N, N removal, NDVI, red, NIR, and green spectral radiance readings, Ardmore and Burneyville, OK, 1995 and 1996.

	Forage Yield kg ha^{-1}	Total N g kg^{-1}	N Removal kg ha^{-1}
		R	
1995			
Burneyville Prefertilization (n=53)			
Red	-0.74 **	0.09	-0.73 **
NIR	0.55 **	0.14	0.63 **
NDVI	0.60 **	0.09	0.66 **
1996			
Ardmore Prefertilization (n=60)			
Red	-0.57 **	-0.16	-0.61 **
Green	-0.47 **	-0.25	-0.51 **
NIR	0.12	-0.16	0.11
NDVI	0.51 **	0.11	0.54 **
Post Fertilization			
Ardmore First Harvest (n=240)			
Red	-0.12	0.16	-0.01
Green	0.35 **	0.13 *	0.39 **
NIR	0.50 **	0.10	0.50 **
NDVI	0.59 **	0.11	0.46 **
Ardmore Second Harvest (n=240)			
Red	-0.48 **	-0.78 **	-0.62 **
Green	0.64 **	-0.13 *	0.49 **
NIR	0.88 **	0.32 **	0.83 **
NDVI	0.76 **	0.71 **	0.83 **
Burneyville Prefertilization (n=60)			
Red	-0.75 **	0.08	-0.55 **
Green	-0.67 **	0.20	-0.42 **
NIR	-0.03	0.10	0.02
NDVI	0.72 **	0.02	0.56 **
Post Fertilization			
Burneyville First Harvest (n=240)			
Red	-0.58 **	-0.44 **	-0.60 **
Green	-0.06	-0.02	-0.06
NIR	0.50 **	0.55 **	0.58 **
NDVI	0.74 **	0.68 **	0.80 **
Burneyville Second Harvest (n=240)			
Red	0.02	0.18	0.06
Green	0.43 **	0.50 **	0.49 **
NIR	0.57 **	0.57 **	0.64 **
NDVI	0.62 **	0.50 **	0.63 **

**, *Significant at the 0.01 and 0.05 probability levels, respectively.

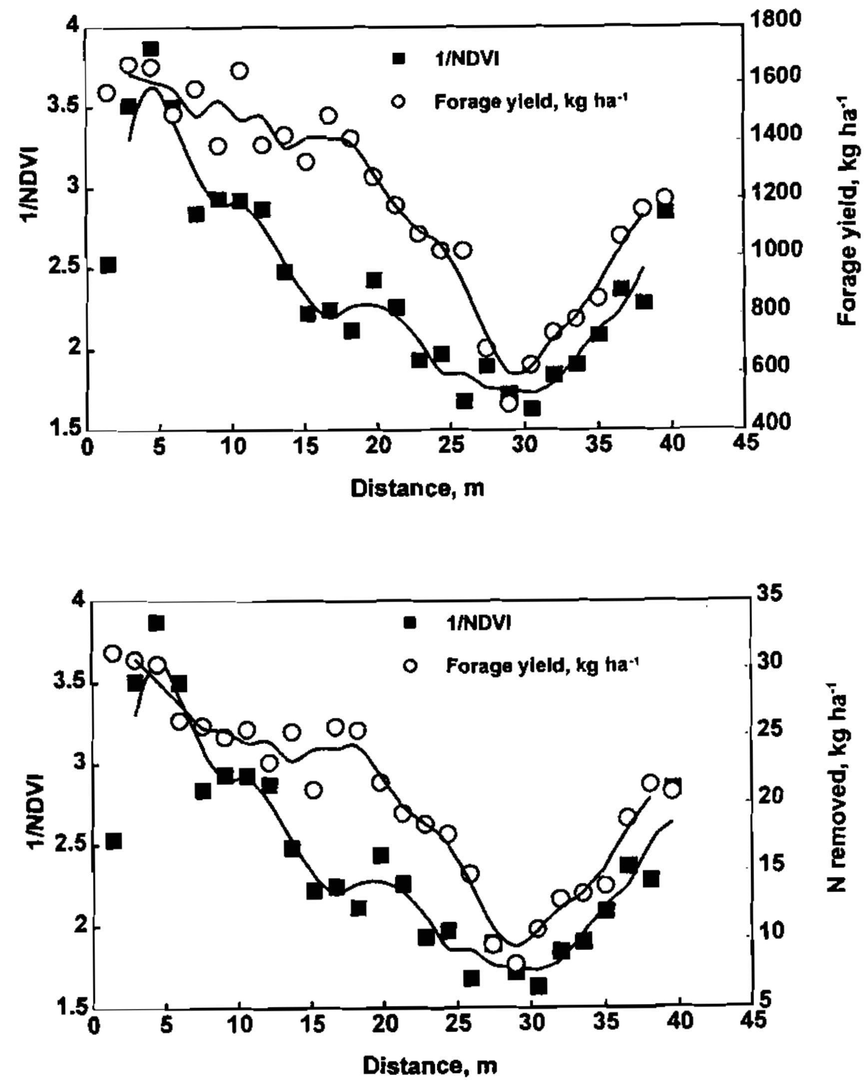

FIGURE 1. Variability in bermudagrass forage yield, N removal, and the inverse of NDVI, and weighed average trendlines, replication 2, Burneyville, OK, 1995.

TABLE 3. Post fertilization treatment means, total N and N removal by harvest, Ardmore and Burneyville, OK, 1996.

	Harvest #1			Harvest #2		
	Forage Yield kg ha^{-1}	Total N g kg^{-1}	N Removal kg ha^{-1}	Forage Yield kg ha^{-1}	Total N g kg^{-1}	N Removal kg ha^{-1}
Ardmore 1996						
Check	443	2.97	13.2	641	1.73	11.1
Variable	1233	2.94	36.3	1412	2.78	39.1
½ Fixed	1521	2.89	43.7	1779	2.71	47.3
Fixed	1437	3.66	52.4	1638	2.90	46.6
SED	406	0.73	14.3	378	0.28	9.4
Burneyville, 1996						
Check	1522	1.48	22.5	1013	1.64	16.7
Variable	2122	2.44	51.3	1749	2.73	47.6
½ Fixed	1735	2.32	40.5	1321	2.48	32.8
Fixed	2438	2.49	61.4	1527	2.90	44.7
SED	504	0.21	11.7	325	0.38	8.7

SED-standard error of the difference between two equally replicated means.

area to determine the variable fertilizer rates. Simple correlation coefficients for forage yield, total N, N removal, NDVI, red, green, and NIR combinations are reported in Table 2. Red green and NDVI readings were significantly correlated with forage yield and N removal, while the NIR spectral radiance readings were not correlated at either location in the 1996 sampling year. The lack of correlation could have been due to the low N availability (low total N content in the forage), also illustrated by the lack of correlation of total N with any of the spectral radiance readings. Results from forage harvest and NDVI data collected from consecutive (2.4 x 1.5 m) plots is reported in Figure 1. It is important to note that forage yields ranged from 400 to 1,800 kg ha^{-1} over a 40-m distance. Similarly, N removal ranged from 5 to 35 kg ha^{-1}, roughly a seven-fold difference. This large variability was not expected, however, it was important to find that NDVI readings paralleled the severe variations in yield and N removal for all prefertilization readings in both years and locations.

Post Fertilization Forage Yield

Prior to each harvest, spectral radiance readings were taken for the entire experimental area. Simple correlation coefficients by harvest and location are reported in Table 2. Forage yield and N removal were correlated with NDVI at all locations. The second harvest at Ardmore 1996 and the first harvest at Burneyville 1996 had the highest forage yields. For these harvests, red, NIR, and NDVI spectral radiance readings had the highest correlation with forage yield, total N, and N

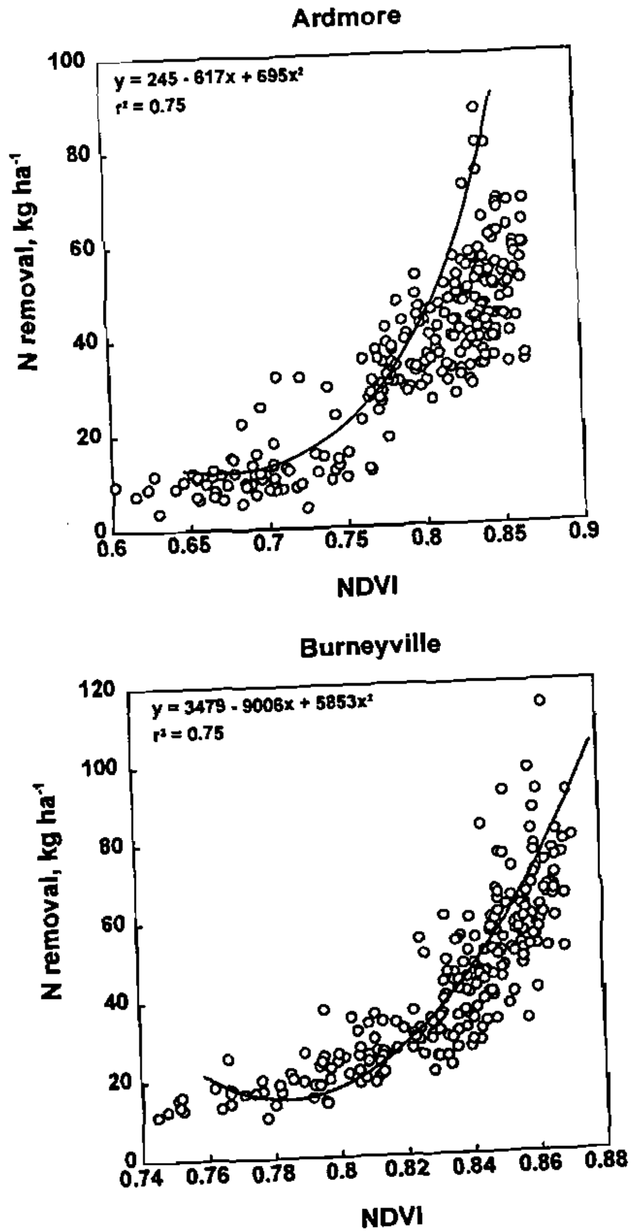

FIGURE 2. Correlation of total N removal versus NDVI spectral radiance readings, Ardmore and Burneyville, OK, 1996.

TABLE 4. Analysis of variance and single-degree-of-freedom-contrasts for forage yield, total N, and N removal for the first harvest after fertilization, Burneyville, OK, 1995.

Source	df	Forage Yield kg ha⁻¹	Total Forage N g kg⁻¹	N Removal kg ha⁻¹
		---Mean Squares---		
Rep	1	1102499	0.04	755.4
Trt	2	425725	6.62 *	1534.0
Contrast				
CK vs VR and FX	1	220537	17.01 **	3201.2 *
VR vs FX	1	792263	0.33	1123.0
Error (a)	2	784408	0.35	465.8
Sub-plot	26	112553	0.93	69.4
Trt*Sub-plot	52	51114	0.11	43.3
Error (b)	78	96904	0.07	73.7
SED		254	0.22	7.0
CV, %		30	11	31
Treatment Means	N rate, kg ha⁻¹			
Check	0	994	2.27	22.5
Variable-rate	126	949	2.80	26.4
Fixed	224	1121	2.95	32.8

SED-standard error of the difference between two equally replicated means. CV-coefficient of variation, %, CK-check, VR-variable rate, FX-fixed.

removal. Green spectral radiance readings were better correlated with forage yield when yield levels were lower [first post fertilization harvest at Ardmore and second harvest at Burneyville (Tables 2 and 3)]. Alternatively total N concentration was consistently correlated with spectral radiance measurements when yield production levels were high (Ardmore 1996, second post fertilization harvest, and Burneyville 1996, first post fertilization harvest) (Tables 2 and 3). The relationship between NDVI and total N removal at Ardmore (second post fertilization harvest) and Burneyville (first post fertilization harvest) in 1996 is reported in Figure 2. The quadratic equation at both locations significantly improved correlation over linear. This highly significant curvilinear relationship between NDVI and total N removal in bermudagrass was consistent with similar work in winter wheat (Stone et al., 1996).

Analysis of variance for forage yield, total N, and N removal is reported in Tables 4 and 5. The main effect of treatment for bermudagrass forage yield was not significant at the Burneyville 1995 and 1996 sites. Failure to observe a significant increase in yield in 1995 was due to initially low soil test P which was not corrected until after the first harvest. Forage yield and N removal were significantly affected by treatment at Ardmore (Table 5). The single-degree-of-freedom contrast for check versus variable rate and fixed rate treatments was significant for total N and N removal (Table 4) at Burneyville 1995. The 1996 sites showed significant

TABLE 5. Analysis of variance and single-degree-of-freedom-contrasts for total forage yield, total N, and total N removal following one fertilization, Ardmore and Burneyville, OK, 1996.

Source	df	Ardmore Forage yield kg ha⁻¹	Ardmore Total N g kg⁻¹	Ardmore N removal kg ha⁻¹		Burneyville Forage yield kg ha⁻¹	Burneyville Total N g kg⁻¹	Burneyville N removal kg ha⁻¹
		---Mean Squares---						
Rep	1	3498328	1.04	4343		4080200	0.02	780
Trt	3	59850223 *	11.73	66846 *		27999374	14.74 *	53002 *
Contrast								
CK vs VR, ½ FX, FX	1	166243419 **	27.24	183521 **		53995684	42.39 **	124996 *
VR vs ½ FX	1	12889391	0.17	6390		19952145	0.76	17791
VR vs FX	1	5545684	4.89	16704		262246	0.22	1901
Error (a)	3	3181050	5.37	4244		8501032	0.76	9974
Sub-plot	29	1095582 **	0.13	786 **		1162871 **	0.05	642 **
Trt*Sub-plot	87	364644	0.25 **	472		497344	0.06	463
Error (b)	116	441341	0.16	363		499983	0.06	307
SED		664	0.40	16		707	0.24	18
Trt Means	N rate, kg ha⁻¹				N rate, kg ha⁻¹			
Check	0	1085	2.18	24	0	2535	1.54	39
Variable-rate	268	2645	2.85	75	87	3871	2.56	99
½ Fixed	336	3300	2.77	90	168	3056	2.39	73
Fixed	672	3075	3.25	99	336	3965	2.64	106

SED-standard error of the difference between two equally replicated means. CK-check, VR-variable rate, ½ FX-½ fixed rate, FX-fixed rate.

**,*Significant at the 0.01 and 0.05 probability levels, respectively.

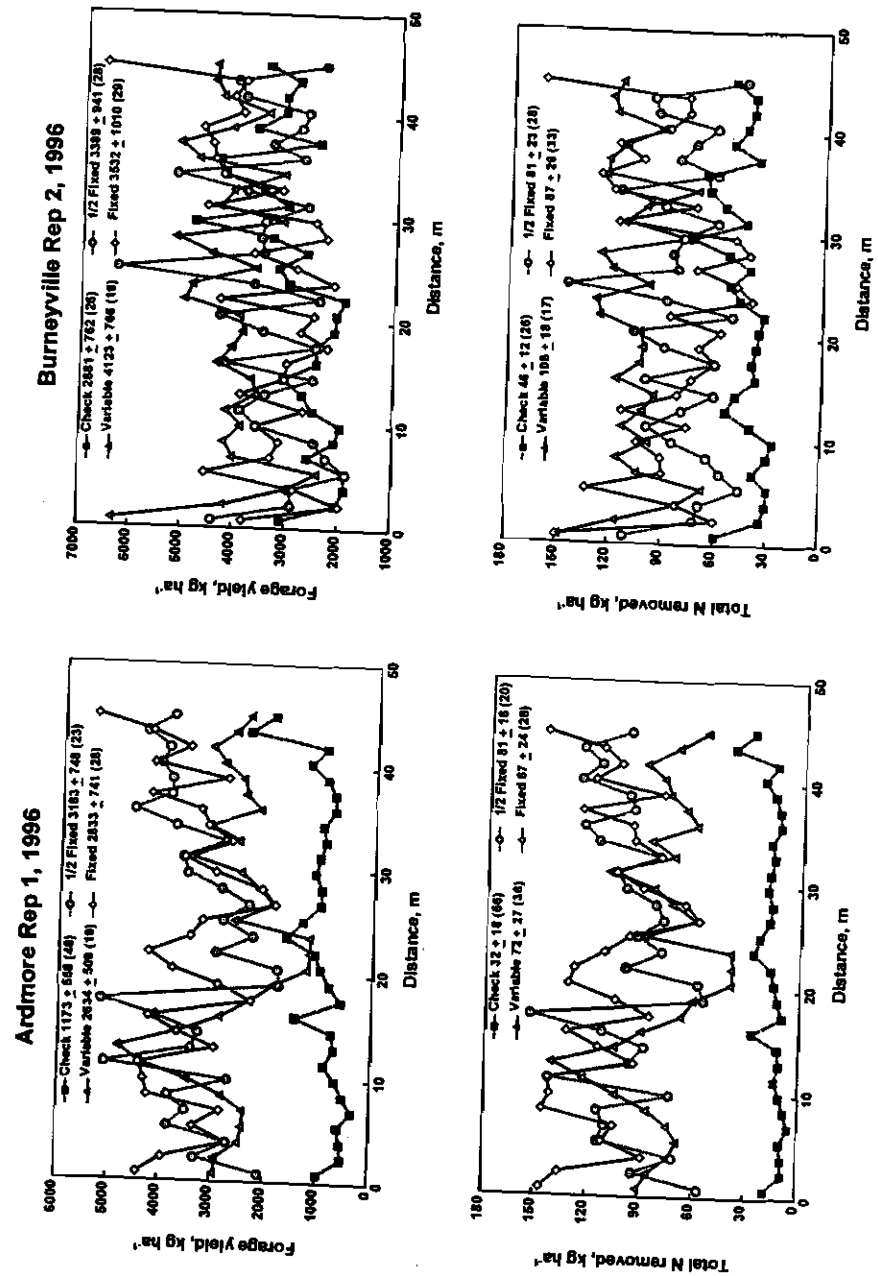

FIGURE 3. Variability of bermudagrass total forage yield and N removal from replication 1 and replication 2, first harvest following fertilization, Ardmore and Burneyville, OK, 1996 (coefficients of variation are listed in parentheses following treatment mean and standard deviations).

TABLE 6. Range, mean, and standard deviation of soil test parameters collected every 1.5 x 2.44 m, Burneyville, OK, 1995.

	pH	Total N	Org. C	Total P	NH_4-N	NO_3-N	P	K
		g kg^{-1}		mg kg^{-1}				
Min	5.1	0.4	5.4	138.8	4.6	1.2	5.7	144
Max	6.2	1.3	17.3	336.5	14.7	9.0	60.4	273
Mean	5.7	0.8	9.5	223.1	7.8	2.2	22.7	184
Std. Dev.	0.2	0.1	2.2	38.8	1.9	1.0	12.0	25

pH-1:1soil water, total N and organic C-dry combustion, NH_4-N and NO_3-N-2M KCl extract, K and P-Mehlich III extraction, total P vanadomolybdate method.

Std. Dev.-standard deviation from the mean.

differences for the check versus variable-, half-, and fixed-rate treatment for total forage yield at Ardmore and total N at Burneyville 1996 (Table 5). Total N removal in the forage was significantly different for the above eontrast at both locations for 1996. However, no differences were detected between variable rate and half-fixed rate (VR versus half-FX) or fixed rate (VR versus FX) treatments for any of the variables measured (Table 5). At the Burneyville 1996 experiment, forage N-use efficiency was greater for the variable rate compared to the half-fixed and fixed rate treatments. Percent fertilizer recovery (N uptake treated minus N uptake check/N rate) over the check was 71% for the variable rate and 20 and 19 for the half-fixed and fixed rate, respectively. Addition of fertilizer at Ardmore increased total forage yield and total N removal compared to the check plot, with no difference detected between the variable, half-fixed, and fixed rate treatments.

Variability in the measurement of bermudagrass forage yield and N removal over 45.7 m from harvest data collected from consecutive 1.53 m intervals is illustrated in Figure 3 for Replication 1 of Ardmore and Replication 2 of Burneyville 1996. Also, reported in each figure are the treatment means over the 45.7 m (30 subplots) and the associated standard deviations. The application of variable fertilizer N had a decreased standard deviation compared to the half-fixed and fixed rate treatments for total forage yield at both locations (Figure 3). For both forage yield and forage N removal, coefficients of variation were smaller for the variable rate compared to half-fixed and fixed rate treatments (excluding forage N removal, Ardmore, Figure 3).

Soil Variability

Soil samples were taken in the variable N rate plots in 1.53 m intervals over the entire plot to quantify the actual soil variability within a 45.7 m transect. Simple statistics for each soil test are reported in Table 6. None of the soil test variables collected were correlated with total production, total N or N removal. Variability in soil test results are reported in Table 6 from samples (16 cores plot^{-1}) collected from each 1.5 x 2.44 m subplot (n=90). Soil pH ranged from 5.1 to 6.2 within this 1,350 m^2. Soil organic C had three-fold difference within the sampled area. This would represent a range in organic matter of between 1.3 to 3.4%. Similar large differences in other soil test parameters were found, especially for P. The agronomic significance of this soil variability is that it would be economically impossible to collect samples on such a fine scale and treat each area independently. This is the principle reason why indirect sensor measurements are needed to detect and subsequently treat micro-soil variability.

CONCLUSIONS

Spectral radiance readings were significantly correlated with forage yield, and N removal for all harvests and locations, indicating that sensor based variable rate technology could be used in bermudagrass forage production systems. There was a significant N treatment response to applied fertilizer for total N and total N removal for most locations. Application of N fertilizer increased total forage yield over the check at two of the three locations. Total N and total N removal was increased over the check, while the variable rate treatment was equal to the half-fixed and fixed rate. In general, the variability in both forage yield and N removal of variable rate treatments was lower than that of half-fixed rate and fixed rate treatments. This supports adjusting N rates based on indirect NDVI measurements and also because significant yield increases were found as a result of applying N. Results from soil test analysis suggested that substantial field variability is present over very short distances (<=1.53 m). The intense sampling required to account for soil variability in an entire field on this small of a scale and the costs associated with such sampling would further indicate the beneficial use of sensor-based-variable-rate-technology to adjust for nutrient element needs.

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Response of Nitrogen Use Efficient Sorghums to Nitrogen Fertilizer

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ABSTRACT

Little information is available on the response of grain sorghum [*Sorghum bicolor* (L.) Moench] genotypes differing in nitrogen (N) use efficiency (NUE) (g DM g N^{-1}) to added N fertilizer. Such knowledge is important for reducing the reliance upon fertilizer N. A dryland field experiment was conducted in 1993 and 1994 at Mead, NE evaluating the agronomic responsiveness of 13 sorghum genotypes differing in NUE to three N rates (0, 50 and 100 kg N ha^{-1}) and also to determine physiological factors that contribute to improved NUE. The experiment was conducted on a fine montmorillonitic, mesic, Typic Argiudoll soil. Total N at maturity, dry matter, and grain yield were used to calculate NUE terms. Genotype differences were found for all measured variables both years, but no N rate by genotype effects were significant. Nitrogen fertilizer enhanced plant N contents and grain yield, but decreased

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