BERMUDAGRASS FORAGE YIELD RESPONSE TO HIGH RATES OF APPLIED UREA AND AMMONIUM NITRATE AND THE USE OF SPECTRAL RADIANCE FOR ESTIMATING NITROGEN DEFICIENCIES AND SOIL VARIABILITY

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CHAPTER I

BERMUDAGRASS FORAGE YIELD RESPONSE TO HIGH RATES OF APPLIED UREA AND AMMONIUM NITRATE

ABSTRACT

Extensive research has not been performed to study the effect of high rates (up to 1344 kg N ha^{-1}) of applied N on bermudagrass forage production and total N, and nitrate content. Two field studies were initiated to evaluate the effects of rate, timing, and source of N on bermudagrass forage production, total N, nitrate concentration, and fertilizer recovery. Nitrogen was applied at rates of 112, 224, 448, 672 and 1344 kg N ha^{-1} using ammonium nitrate (AN) and urea (UR), applied in early-spring (March) and late-summer (August). Forage yields were maximized at 1344 kg N ha^{-1} applied in early-spring as AN, and total production from four harvests exceeded 19 Mg ha^{-1} (8 ton/acre). Early-spring applied N tended to result in higher yields, nitrogen removal, and percent fertilizer recovery as compared to late-summer applied N. Ammonia volatilization from UR was expected, and N recovery was highest for AN fertilizer, especially when N was applied in late-summer.

Although estimated fertilizer recovery levels were greatest at the lowest N rates (112 and 224 kg N ha^{-1} in the early-spring and late-summer, respectively) forage production and N removal were doubled when applying much higher N rates (>672 kg N ha^{-1}) at the N responsive Ardmore site. Nitrate concentration in the forage was significant only immediately following fertilization, with nitrate concentration increasing with N rate. Even under the high N fertilization rates evaluated, forage nitrate levels never approached toxic amounts for animal consumption.

INTRODUCTION

High rates of applied N (> 600 kg N ha^{-1}) have not been thoroughly evaluated in bermudagrass forage production systems. Mathias et al. (1978) found that bermudagrass yields and N concentration increased while percent recovery decreased with increasing N up to 448 kg N ha^{-1}. Morris and Celecia (1962) found increased N removal in bermudagrass when N was applied in the spring compared to fall application. Prine and Burton (1956) found that increasing the annual N rate from 0 to 1008 kg N ha^{-1}, increased yield and percent protein, but decreased N recovery. Mathias et al. (1973) found increasing dry matter yield with increasing N rate up to 672 kg ha^{-1} yr^{-1}, but percent N recovery was highest at 224 kg N ha^{-1}. Fisher and Caldwell (1959) found that Coastal bermudagrass produced 0.6 Mg ha^{-1} and 8 % protein with no fertilization and 2.9 Mg ha^{-1} and 13 % protein at an N rate of 1120 kg ha^{-1}. Hanson et al. (1978)

concluded that increasing applied N on perennial grasses resulted in increased fertilizer N recovery at rates up to 448 kg N ha^{-1} for all times of application (split compared to early-spring) and that a split application resulted in the highest percent recovery. Work by Staley et al. (1991) on tall fescue and switchgrass noted that increasing applied N increased N concentration and they also reported 47 % fertilizer N recovery at a 180 kg ha^{-1} N rate. Power (1980) reported that the amount of fertilizer N in plant tops, roots and soil inorganic N was linearly correlated with the amount of fertilizer N applied. Bermudagrass forage yields and total N were positively correlated with increased N applied, up to 224 kg N ha^{-1}, and the highest N concentration occurred with the highest yields, indicating that N removal was not diluted at high yields (Wiedenfeld, 1988). Work by Burton et al. (1963) found that increased N rates up to 1008 kg ha^{-1} significantly increased total dry matter production up to 15.2 Mg ha^{-1} and 18.5 % crude protein. In a rye-wheat-ryegrass forage production system, nitrogen use efficiency was >60 % for all rates of N up to 224 kg ha^{-1} (Altom et al., 1996). Eichhorn (1989) found that maximized forage yields occurred at 448 kg N ha^{-1} while N removal and crude protein concentration continued to increase at N rates up to 672 kg N ha^{-1}. Percent fertilizer recovery decreased as N rates increased from 224 to 672 kg N ha^{-1}.

The major factors that affect nitrate accumulation in forages were investigated by Crawford et al. (1961). Stage of growth, level of N fertilization, plant part and light intensity all influenced nitrate-N concentration. Factors that did not affect nitrate-N concentration were variety, time, source and placement of N fertilizer. Hojjati et al. (1972) concluded that high nitrates in bermudagrass forage occurred only with high total N content, but high total N did not always result in high nitrate content. Although increasing N fertilizer rates increased nitrate concentration in the tissue, N rates as high as 2240 kg N ha^{-1} did not result in bermudagrass forage nitrate accumulation levels that would be toxic to animals (Worker and Peterson 1962). Murphy and Smith (1967) found that increased nitrate-N concentration in sudangrass above the toxic level (0.7 %) was a direct result of increased N fertilization up to 896 kg N ha^{-1}, while advancing plant maturity was indirectly related. Accumulation of nitrate-N in forage crops was directly related to N rate and decreased with advancing plant maturity (Murphy and Smith.1967). Work by Lovelace et al. (1968) indicated that nitrate accumulation in 'NK-37' was twice that of Coastal bermudagrass and that soil texture had a greater influence on tissue nitrate levels than did fertilizer nitrogen rates. Wright and Davison (1964) indicated that forages with over 0.34 to 0.45 % nitrate-N are considered toxic to cattle, and when fed should be mixed with safer feeds lower in nitrate-N. In an Oklahoma study, bermudagrass yields and N removal were generally lower for urea compared to urea-ammonium-nitrate (UAN), while N use efficiency was higher for UAN than urea (Westerman et al., 1983). Brejda et al. (1995) concluded from a comparison of urea, ammonium nitrate and ammonium sulfate that forage yield and percent protein was greater for ammonium nitrate as compared to other sources and that each resulted in a linear increase in yield with N rate up to 235 kg N ha^{-1}. Nitrogen rate had a greater influence on dry matter production than did N source. Anderson and Kundel (1983) found that bermudagrass fertilized with urea compared to ammonium nitrate and urea-ammonium nitrate resulted in higher yields, with no differences in N removal. Nitrogen recovery and bermudagrass forage yield were less for liquid fertilizer as compared to solid ammonium nitrate (Walker et al., 1979).

The objectives of this study were to evaluate the effects of application timing and N source on bermudagrass forage production, and N use efficiency and to determine the seasonal relationship between total forage N and tissue nitrate.

MATERIALS AND METHODS

Two field experiments were established at Ardmore and Burneyville OK. Both sites were established Midland bermudagrass pastures. Initial soil test characteristics and soil classification are reported in Table 1. The experimental design was a randomized complete block with three replications at both locations. Plots were 4.8 m X 7.6 m at Ardmore and 2.4 m X 7.6 m at Burneyville. Nitrogen treatments were applied as either ammonium nitrate (AN) or urea (UR) in August (late-summer cycle) or

March (early-spring cycle). Nitrogen rates for the late-summer cycle were 224, 448, 672 and 1344 kg N ha^{-1}, while early-spring cycle rates were 112, 672 and 1344 kg N ha^{-1}. Nitrogen treatments applied in late-summer and early-spring were analyzed independently. Therefore, the late-summer cycle represented all harvests after N fertilization in August but prior to the August fertilization for the following year. Early-spring cycles included all harvests after March N fertilization but prior to March N fertilization the following year. Since interest was in the total cycle production and total N removal, analysis of variance was performed on the sum of late-summer and/or early-spring harvests, by year. Single-degree-of-freedom non-orthogonal contrasts were used to determine treatment differences. Fertilization dates are reported in Table 2. Phosphorus and potassium were broadcast applied to the entire experimental area (both locations) at 48.9 kg P ha^{-1} as triple superphosphate and 186 kg K ha^{-1} as potassium chloride in early March 1993 and again in late May 1995. In order to eliminate the effects of low soil pH, lime was applied at a rate of 6.7 Mg ha^{-1} in late May 1995 to each location. 'Weedmaster' [2, 4-D (dimethylamine salt) + dicamba 3, 6-(dichloro)-2-(methoxybenzioc acid)] 48.1 % active ingredient was applied to all plots at a rate of 0.47 liters ha^{-1}, in early March of each year.

Forage yield was collected throughout the growing season and harvest dates are reported in Table 2 for each location. Forage yield was determined by harvesting a 0.96 m x 7.6 m area from each plot using a self propelled John Deere 256 rotary mower at a height of 0.1 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. Total N was determined on all forage samples using dry combustion (Schepers et al., 1989). Forage nitrate was determined by extracting 0.2 g forage samples with 20 ml of 0.01 M $CaSO_4$, shaken for 30 minutes, filtered, and analyzed by Cd reduction using an automated flow injection analysis system (Lachat, 1989). Nitrogen removal was estimated by multiplying total N analysis and dry forage biomass. The difference method was used to estimate fertilizer recovery, by year using total production (N removal in check plot subtracted from N removal in fertilized plots and divided by the rate applied).

RESULTS AND DISCUSSION

Results of analysis of variance and single-degree-of-freedom-contrasts by cycle for total forage yield, N removal and fertilizer recovery are reported in Tables 3-6. A significant linear and/or quadratic response to applied N was observed for forage yield and N removal in the late-summer and early-spring cycles for both N sources at both locations.

Ardmore (late-summer) Total forage yield was maximized at the 672 kg N ha^{-1} rate for AN, however, yields continued to increase at the high N rate (1344 kg N ha^{-1}) when UR was applied (late-summer, 1993-1994, Table

3). Forage N removal continued to increase at the high N rates for both N sources (Table 3). For the late-summer cycle of 1994-1995, forage yields peaked at the 448 kg N ha^{-1} rate for both AN and UR, while increases in N removal continued to take place at the 672 kg N ha^{-1} rate (Table 3). Continued N removal at N rates in excess of that required for maximum yield was consistent with work in wheat by Wuest and Cassman, (1992), and Rasmussen and Rohde, (1991). Similar to previous work by Westerman et al. (1983) and Brejdi et al. (1995), AN produced significantly higher yields when applied in late-summer as compared to UR (AN vs UR over N rate contrast). Increased production from AN could possibly be attributed to the immediate availability of NO_3 and NH_4 as compared to UR. Also, ammonia volatilization from urea was expected to be significant considering the daily high temperatures (38.3 and 31.0°C in 1993-1994 and 1994-1995, respectively), at the time of application, lack of incorporation and presence of surface residues high in urease. At this site no rainfall was received until ten days after fertilizers were applied in both years. In the ten days following fertilization average surface air temperatures were 30.7 and 26.7°C in 1993-1994 and 1994-1995, respectively, which enhanced the potential for ammonia volatilization as shown by Ernst and Massey, (1960). Total production levels were lower for the 1994-1995 period when compared to 1993-1994 (Tables 3 and 4) which was largely due to decreased rainfall (551mm vs 937mm, respectively). However, forage yield and N removed for AN continued to be significantly greater than UR (AN vs UR over N rates, Table 3).

Ardmore (early-spring) Total early-spring forage production was maximized (19.8 Mg ha $^{-1}$) at the highest N rate in 1994 (Table 4). Total N removed exceeded 600 kg N ha^{-1} for this same year. Some tissue salt-burn was observed in the high N rate plots soon after fertilization which delayed N response. Unlike data from late-summer applied production cycles, no differences were found in forage yield between N sources (Tables 3 and 4). However, N removal was significantly higher for AN when compared to UR in both 1994 and 1995 (Table 4). The lack of differences between N sources in total forage production suggests that ammonia volatilization losses from UR were not a factor for early-spring applied N. However, N removal was significantly higher for AN compared to UR at the high N rate in both years (Table 4). It is possible that immediate availability and preferential assimilation of nitrate by bermudagrass from AN could have increased N removal when compared to UR. Alternatively biuret toxicities from UR may have decreased growth and thus N removal.

Burneyville (late-summer) Only one complete cycle of late-summer applied N data was obtained at this site. A significant response to applied N was observed for forage yield and N removed from both N sources (Table 5). Total forage yield was maximized at the 448 kg N ha^{-1} rate for both N sources when N was applied in late-summer at this site (Table 5).

Similar to results at Ardmore, forage N removal showed slight increases at N rates in excess of that required for maximum yields (Table 5). It was important to note that forage yields were high for the first harvest following fertilization and all subsequent harvests were roughly half that obtained in late-September of 1994 (Appendix Table 5). Total N removed at this site was much less than that removed at Ardmore in the same year (1994-95, Tables 3 and 5) and under similar climatic conditions. Differing results were in part due to one less harvest obtained at Burneyville over the same time period. Unlike late-summer cycle results at Ardmore, 1994-1995, no significant differences were observed between AN and UR sources. This could be due to rainfall (.25 mm) received at Burneyville soon after fertilization (within 8 hours).

Burneyville (early-spring) In both 1994 and 1995, applied N increased forage yield and N removed for both N sources (Table 6). In general, yields peaked at the low N rate (112 kg N ha^{-1}) while significant increases in N removed were noted at the higher 672 kg N ha^{-1} rate (both 1994 and 1995). Similar to results from early-spring applied N at Ardmore, no differences were found between N sources for total forage yield or N removed in either 1994 or 1995. Unlike Ardmore, the yield increases relative to the check (no N applied) were generally small at this site (2-4 Mg ha^{-1}). Organic carbon and total N in the surface 0-15 cm were roughly two times greater at Burneyville compared to Ardmore (Table 1). Because of this, less response to applied N was expected at this site. Using OSU soil test recommendations, P and K were roughly 80 % sufficient at Burneyville and 100 % at Ardmore. Because of this, preplant P and K fertilization rates may not have been adequate at Burneyville, which could be reflected in the lower production levels. However, the check plot yields at Ardmore were less than half that found at Burneyville for both late-summer and early-spring cycles. Because yield levels at Burneyville never approached that found at Ardmore (very similar climatic conditions), some other nutrient or growth factor may have been controlling response.

Fertilizer Recovery Fertilizer recoveries were generally higher for AN compared to UR over N rates at both locations and cycles, although this was only consistently seen at N rates $\leq$ 224 kg N ha^{-1} (Tables 3-6). Fertilizer recoveries decreased with increased N rate for all cycles, application times, sources and years. Higher percent fertilizer recovery for AN as compared to UR was observed for all late-summer and early-spring cycles at both locations excluding early-spring cycle at Ardmore, 1995. Estimated fertilizer recovery exceeded 85 % for AN applied at 112 kg N ha^{-1} in early-spring at both locations in 1994 and 1995 (Tables 4 and 6). At N rates > 112 kg N ha^{-1} fertilizer recovery decreased dramatically in early-spring cycles (Tables 4 and 6). Unfortunately the 112 kg N ha^{-1} rate was not included in the late-summer cycles thus restricting comparisons at this rate. Although estimated fertilizer recovery levels were greatest at the lowest N rates (112 and 224 kg N ha^{-1} in the early-spring and late-summer, respectively) forage production and N removal were doubled when applying much higher N rates (>672 kg N ha^{-1}) at the N responsive Ardmore site. Fertilizer N uptake increased with increasing N applied in all post fertilization harvests (especially the final harvest 345 days after the late-summer fertilization) Figure 1. This could indicate that substantial immobilization had taken place soon after fertilization. This is plausible since over 142, 225, 276, and 361 kg N ha-1 was available from the 224, 448, 672, and 1344 kg N ha-1 rates, respectively in the four harvests after fertilization. The first harvest was 35 days after fertilizers were applied. Assuming that the balance was leached, 37, 50, 59, and 74 % of the total N applied would have been lost via this process at the 224, 448, 672 and 1344 kg N ha-1 rates, respectively. By the fourth harvest (following 347 days where N could have been potentially leached) fertilizer N removed was near 10 % of the total N applied for all rates (Table 7).

Total N Total N concentration increased with increased N rate for all cycles and both locations, time of application and sources. Total N was higher for AN compared to UR (Figures 2-5). For the late-summer applications at both locations, total N remained relatively constant until 250 days after fertilization, after which it decreased with time (Figures 2 and 4). Early-spring total N in 1994 generally decreased up to 150 days, and then increased for the higher N rates (Figures 3 and 5).

Nitrate Bermudagrass tissue nitrate increased significantly as a result of applying N. However, this was only observed immediately following fertilization (Figures 6-9). Increased availability of nitrate from AN resulted in an increase in tissue nitrate for all cycles at Ardmore as compared to UR (Figures 6 and 7). Similar to N removal and fertilizer recovery at the higher rates of N at Burneyville, higher nitrate levels were found for UR treatments compared to AN (Figures 8 and 9). At all fertilization rates, sources and dates, forage nitrate levels were not found to be toxic (<0.7%) for cattle consumption (Worker and Peterson, 1962 and Murphy and Smith, 1967 Wright and Davison, 1964).

Conclusions

Forage production was maximized at the 672 kg N ha^{-1} rate in the late-summer cycles, with increased N removal at higher N rates. In 1994, 1344 kg N ha^{-1} as AN applied in early-spring at Ardmore, resulted in a yield of 19.8 Mg ha^{-1} and total N removed exceeded 600 kg N ha^{-1}. Nitrogen removal increased at N rates in excess of that required for maximum yield, while fertilizer recoveries decreased. Nitrogen applied at 112 kg N ha^{-1} in early-spring resulted in fertilizer recoveries in excess of 90 %, while 1344 kg N ha^{-1} resulted in < 20 % recovery. Ammonium nitrate application resulted in increased yields, N removal and fertilizer recovery greater than UR at Ardmore, but not at Burneyville. Increased forage yields and N removed for AN compared to UR was possibly due to increased ammonia volatilization from UR at Ardmore. At Burneyville, rainfall immediately following fertilization may have helped to decrease ammonia volatilization losses. Although estimated fertilizer recovery levels were greatest at the lowest N rates (112 and 224 kg N ha^{-1} in the early-spring and late-summer, respectively) forage production and N removal were doubled when applying much higher N rates (>672 kg N ha^{-1}) at the N responsive Ardmore site.

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Table 1. Initial surface (0-15 cm) soil test characteristics and soil classification at Ardmore and Burneyville, OK.

Location	pH	BI	Total N	Org. C	NH_4-N	NO_3-N	P	K
			-------- g kg^{-1} --------		--------------- mg kg^{-1} ---------------			
Ardmore	5.2	6.33	0.69	9.9	10.9	1.8	59	247
Classification: Wilson silt loam (fine, montmorillonitic, thermic Vertic Ochraqualfs)								
Burneyville	5.6	6.79	1.48	20.8	7.6	1.9	26	179
Classification: Minco fine sandy loam (coarse-silty, mixed thermic Udic Haplustoll)								

pH - 1:1 soil:water, BI - Buffer Index, Total N and Organic C - dry combustion, NH_4-N and NO_3-N - 2M KCl extract, P and K - Melich III extraction.

Table 2. Harvest and fertilization dates, by cycle and climatic conditions at the time of fertilization, Ardmore and Burneyville, OK.

Ardmore Fertilization	Ardmore Harvest	Burneyville Fertilization	Burneyville Harvest
	1993-1994 Late-summer		
8-27-93	10-3-93	-	-
	5-26-94		-
	6-29-94		-
	8-9-94		-
	1994-1995 Late-summer		
8-9-94	9-26-94	8-9-94	9-27-94
	3-22-95		5-23-95
	5-23-95		6-27-95
	6-28-95		8-10-95
	8-11-95		
	1994 Early-spring		
3-31-94	5-26-94	3-31-94	5-26-94
	6-28-94		6-29-94
	8-9-94		8-9-94
	9-26-94		9-27-94
	1995 Early-spring		
3-22-95	5-23-95	3-22-95	5-23-95
	6-28-95		6-27-95
	8-11-95		8-10-95
			9-28-95

	Temperature °C		Total Rainfall, mm		
	Daily High	Average surface	0-24 hr	24-48 hr	48-72 hr
Ardmore		Late-summer			
1993-1994	38.3	30.7	0	0	0
1994-1995	31.0	26.7	0	0	0
		Early-spring			
1994	19.9	10.2	0	0	4.8
1995	28.9	20.8	0	0	0
Burneyville		Late-summer			
1994-1995	33.2	26.0	.25	0	0
		Early-spring			
1994	22.3	12.4	0	0	2.5
1995	30.1	20.8	0	0	4.3

Average surface and daily high temperatures, and total rainfall were obtained from Mesonet stations located at Ardmore and Burneyville, respectively, for 24 hour time periods.

Table 3. Analysis of variance, treatment means and single-degree-of-freedom-contrasts for forage yield, N removal and percent fertilizer recovery, late-summer applied N, Ardmore, OK, 1993-1994 and 1994-1995.

Source		df	Forage yield, Mg ha^{-1} 1993-1994	Forage yield, Mg ha^{-1} 1994-1995	df	N removal, kg ha^{-1} 1993-1994	N removal, kg ha^{-1} 1994-1995	df	Fertilizer recovery, % 1993-1994	Fertilizer recovery, % 1994-1995
			Mean Squares							
Rep		2	0.2	0.2	2	689.3	311.8	2	88.5	752.8 **
Trt		9	36.4 **	43.1 **	9	42707.6 **	49372.3 **	7	726.4 **	1415.7 **
Contrast										
AN linear		1	177.0 **	190.8 **	1	231288.2 **	234938.8 **	1	2102.9 **	4101.2 **
AN quadratic		1	15.4 **	53.8 **	1	5848.7 *	44166.0 **	1	0.7	31.7
UR linear		1	88.3 **	87.2 **	1	96216.8 **	80013.9 **	1	794.4 **	1255.4 **
UR quadratic		1	0.1	10.3 *	1	0.1	9941.5 *	1	96.2	34.0
AN vs UR (over N rate)		1	48.5 **	79.1 **	1	60996.2 **	108873.6 **	1	2072.5 **	4447.8 **
Error		18	1.0	1.7	18	709.9	906.4	13	50.6	80.9
SED			0.8	1.1		21.7	24.6		5.8	7.3
N Rate	Source		Treatment Means							
0	-		4.66	4.09		80.7	72.7		-	-
0	-		4.72	4.70		87.8	86.4		-	-
224	AN		9.58	7.34		226.2	254.1		63.4	74.9
448	AN		11.69	12.88		308.9	357.5		50.1	60.5
672	AN		13.75	13.52		360.3	395.2		41.1	46.0
1344	AN		14.51	13.91		445.7	402.0		26.9	23.5
224	UR		7.94	6.85		175.8	178.7		40.9	41.2
448	UR		8.75	9.87		203.8	246.5		26.7	35.7
672	UR		9.21	10.45		226.8	271.8		21.2	27.6
1344	UR		12.45	11.58		331.4	311.3		18.4	16.7
AN (over N rates)			12.38	11.91		335.3	352.2		36.5	40.6
UR (over N rates)			9.59	9.69		234.5	252.1		22.4	25.7

**, * - significant at the 0.01 and 0.05 probability levels, respectively, SED - standard error of the difference between two equally replicated means, df - degree of freedom, AN - ammonium nitrate, UR - urea.

Table 4. Analysis of variance, treatment means and single-degree-of-freedom-contrasts for forage yield, N removal and percent fertilizer recovery, early-spring applied N, Ardmore, OK, 1994 and 1995.

			Forage yield, Mg ha^{-1}			N removal, kg ha^{-1}			Fertilizer recovery, %	
Source		df	1994	1995	df	1994	1995	df	1994	1995
			Mean Squares							
Rep		2	1.6	1.1	2	1728.1	804.1	2	322.8	499.8
Trt		7	140.4 **	19.2 **	7	166690.4 **	27750.8 **	5	1493.5 **	498.2
Contrast										
AN linear		1	536.1 **	70.8 **	1	642282.3 **	117361.7 **	1	1259.9 *	251.9
AN quadratic		1	3.5	4.3 *	1	34.4	2020.5	1	3045.3 **	1033.1 *
UR linear		1	386.0 **	59.9 **	1	412889.2 **	58219.4 **	1	34.9	296.3
UR quadratic		1	16.4 *	2.1	1	3324.6	569.3	1	1847.3 **	547.8
AN vs UR (over N rate)		1	6.1	1.5	1	25398.8 *	11963.4 **	1	1280.0 *	361.9
Error		14	2.7	0.6	14	3211.6	634.2	10	174.2	195.4
SED			1.4	0.6		46.3	20.6		10.8	11.4
N Rate	Source		Treatment Means							
0	-		4.29	2.83		77.7	49.8		-	-
0	-		4.62	3.45		89.9	62.4		-	-
112	AN		9.16	5.16		192.1	108.0		96.8	46.3
672	AN		17.80	8.89		511.1	280.7		63.6	33.4
1344	AN		19.84	8.83		614.4	287.1		39.5	17.2
112	UR		8.92	4.66		163.2	96.3		71.0	35.9
672	UR		17.80	8.20		504.9	203.0		62.7	21.9
1344	UR		17.29	8.33		481.6	221.9		29.6	12.3
AN (over N rate)			15.60	7.63		439.2	225.3		52.9	25.2
UR (over N rate)			14.67	7.06		383.2	173.7		49.6	17.5

**, * - significant at the 0.01 and 0.05 probability levels, respectively, SED - standard error of the difference between two equally replicated means, df - degree of freedom, AN - ammonium nitrate, UR - urea.

Table 5. Analysis of variance, treatment means and single-degree-of-freedom-contrasts for forage yield, N removal and percent fertilizer recovery, late-summer applied N, Burneyville, OK, 1994-1995.

Source		df	Forage yield, Mg ha^{-1} 1994-1995	df	N removal, kg ha^{-1} 1994-1995	df	Fertilizer recovery, % 1994-1995
			----Mean Squares----				
Rep		2	1.9	2	790.3	2	41.7
Trt		9	13.3 **	9	14515.1 **	7	357.9 **
Contrast							
AN linear		1	30.6 **	1	42006.4 **	1	1908.8 **
AN quadratic		1	3.9	1	4897.7 *	1	35.8
UR linear		1	55.5 **	1	60265.1 **	1	209.6 *
UR quadratic		1	0.2	1	360.2	1	75.8
AN vs UR (over N rate)		1	0.1	1	1101.8	1	236.5 *
Error		17	1.2	17	836.1	13	43.5
SED			0.9		23.6		5.4
N Rate	Source		----Treatment Means----				
0	-		7.67		120.0		-
0	-		6.38		92.5		-
224	AN		10.03		212.5		47.4
448	AN		11.45		252.2		32.6
672	AN		11.06		249.5		21.3
1344	AN		12.20		288.1		13.5
224	UR		9.28		161.8		24.8
448	UR		10.77		229.5		27.5
672	UR		11.68		251.3		21.6
1344	UR		13.27		299.4		14.4
AN (over N rate)			11.19		250.6		21.5
UR (over N rate)			11.25		235.5		19.2

**, * - significant at the 0.01 and 0.05 probability levels, respectively, SED - standard error of the difference between two equally replicated means, df - degree of freedom, AN - ammonium nitrate, UR - urea.

Table 6. Analysis of variance, treatment means and single-degree-of-freedom-contrasts for forage yield, N removal and percent fertilizer recovery, early-spring applied N, Burneyville, OK, 1994 and 1995.

Source		df	Forage yield, Mg ha^{-1} 1994	Forage yield, Mg ha^{-1} 1995	df	N removal, kg ha^{-1} 1994	N removal, kg ha^{-1} 1995	df	Fertilizer recovery, % 1994	Fertilizer recovery, % 1995
			Mean Squares							
Rep		2	3.9	4.1 *	2	2145.1	1836.7	2	94.2	127.9
Trt		7	5.8 *	9.3 **	7	17249.0 **	19071.2 **	5	2321.0 **	1706.9 **
Contrast										
AN linear		1	4.8	7.7 *	1	47978.0 **	37622.0 **	1	5917.1 **	3783.9 **
AN quadratic		1	3.4	5.0 **	1	1646.6	5442.5 **	1	3265.0 **	3112.9 **
UR linear		1	20.3 **	27.9 **	1	56562.6 **	63635.6 **	1	802.1 **	6.0
UR quadratic		1	1.1	0.1	1	406.4	529.1	1	952.4 **	116.2
AN vs UR (over N rate)		1	1.5	0.1	1	116.2	601.9	1	668.6 **	1515.6 **
Error		14	1.5	1.0	14	747.2	583.6	10	33.9	90.0
SED			1.0	0.8		22.3	19.7		4.8	7.7
N Rate	Source		Treatment Means							
0	-		11.44	7.22		182.9	122.0		-	-
0	-		10.93	5.89		165.3	94.7		-	-
112	AN		13.65	10.10		269.7	210.7		85.4	91.2
672	AN		13.70	10.09		322.4	279.4		22.1	25.5
1344	AN		13.09	9.22		349.7	257.7		13.1	11.1
112	UR		12.16	7.32		226.3	131.4		46.6	21.0
672	UR		14.90	10.55		332.2	260.2		23.5	22.7
1344	UR		14.41	10.69		352.3	296.2		13.3	14.0
AN (over N rate)			13.60	9.87		316.5	251.0		21.2	21.2
UR (over N rate)			13.82	9.52		303.6	229.3		19.3	18.0

**, * - significant at the 0.01 and 0.05 probability levels, respectively, SED - standard error of the difference between two equally replicated means, df - degree of freedom, AN - ammonium nitrate, UR - urea.

Table 7. Ammonium nitrate percent fertilizer removed by harvest, late-summer applied N, Ardmore, OK, 1993-1994.

Harvest date	Days after fertilization	224	448	672	1344
		---------------	---------------kg N ha-1	---------------	---------------
10-3-93	35	45.1	23.3	16.8	7.2
5-26-94	272	7.8	13.6	7.3	4.4
6-29-94	306	4.2	4.4	5.6	4.3
8-9-94	347	6.3	8.8	11.4	10.9

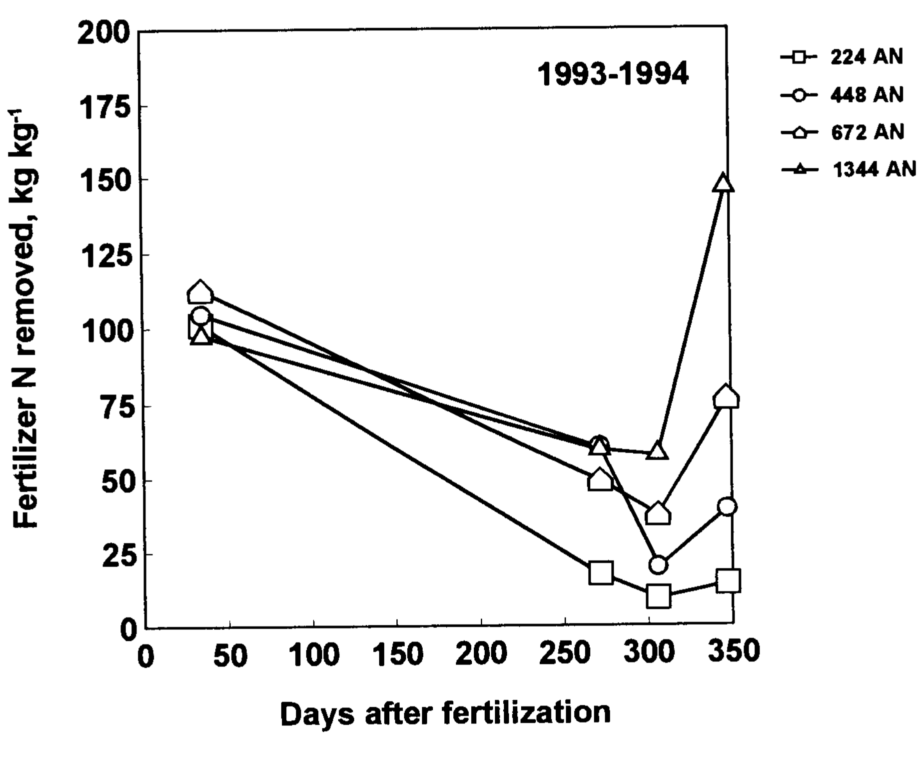
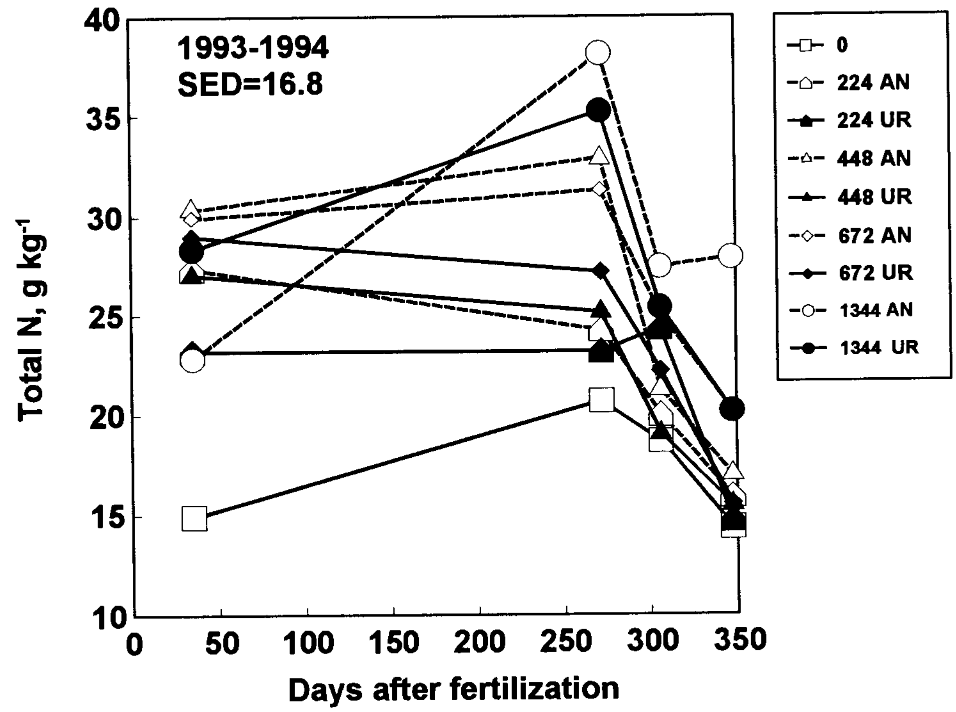


Figure 1. Fertilizer N removal over time, late-summer applied N, Ardmore, OK, 1993-1994.



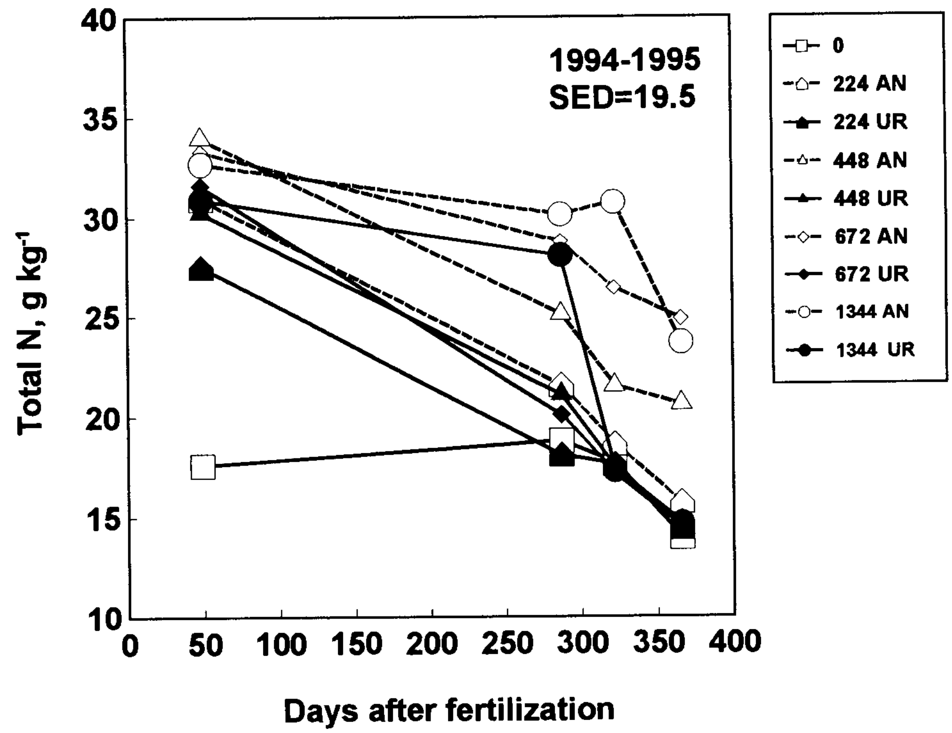


Figure 2. Bermudagrass forage N over time, late-summer applied N, Ardmore, OK, 1993-1994 and 1994-1995.

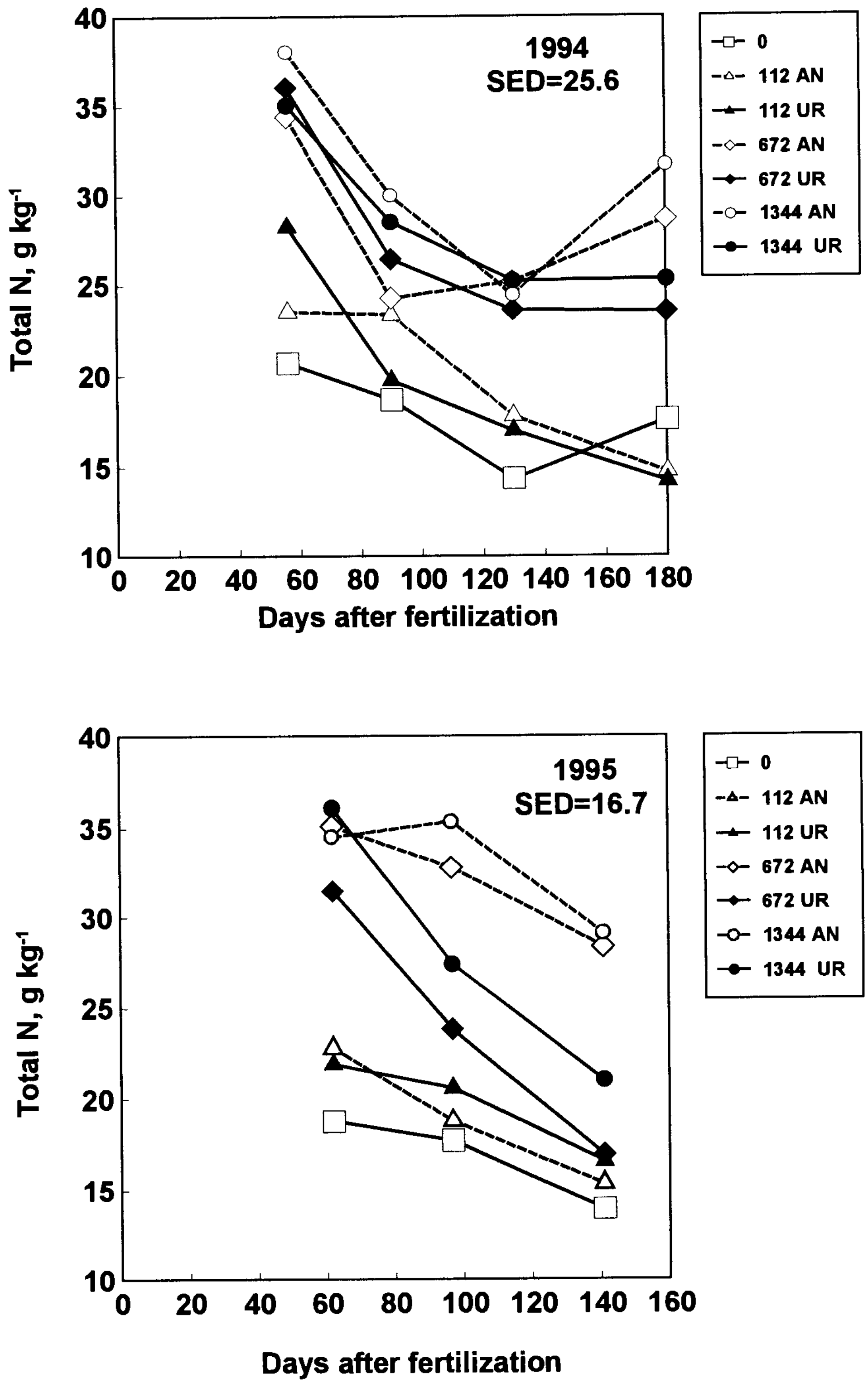


Figure 3. Bermudagrass forage N over time, early-spring applied N, Ardmore, OK, 1994 and 1995.

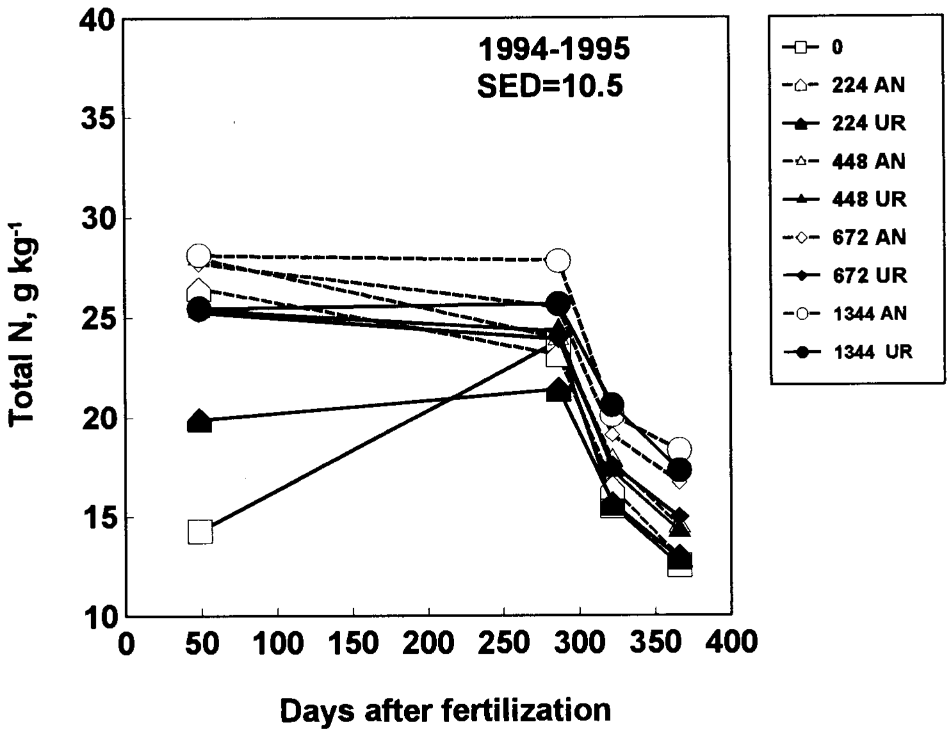
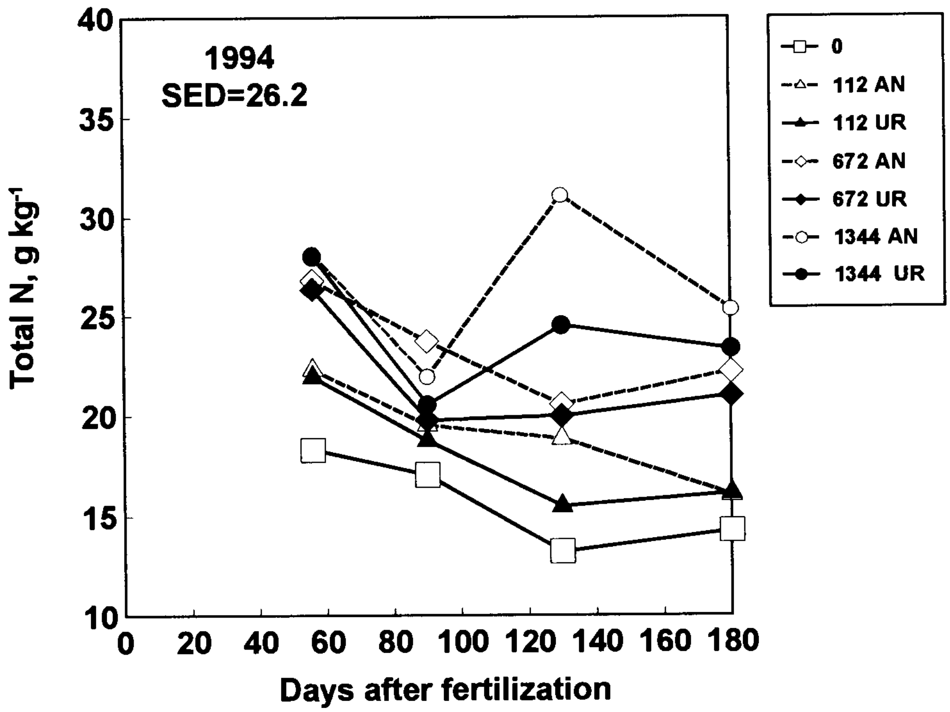


Figure 4. Bermudagrass forage N over time, late-summer applied N, Burneyville, OK, 1994-1995.



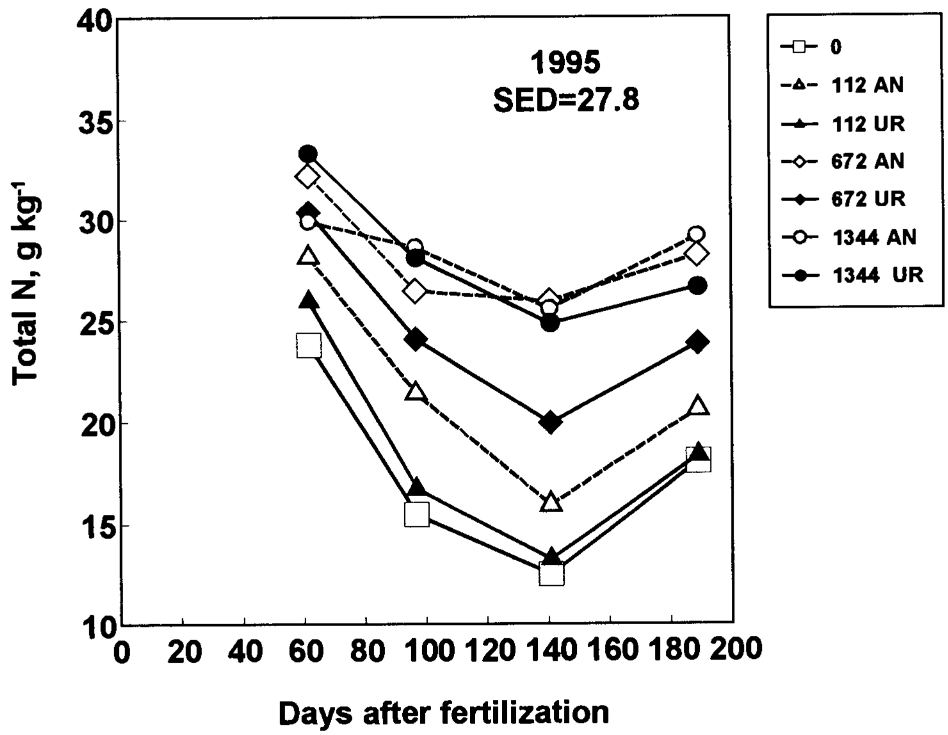
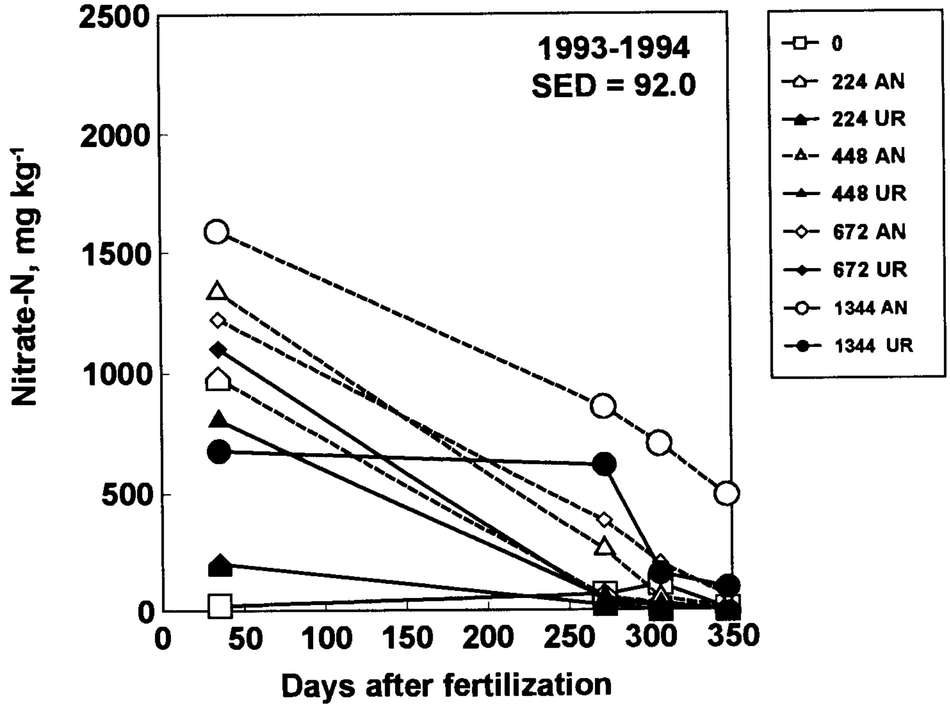


Figure 5. Bermudagrass forage N over time, early-spring applied N, Burneyville, OK, 1994 and 1995.



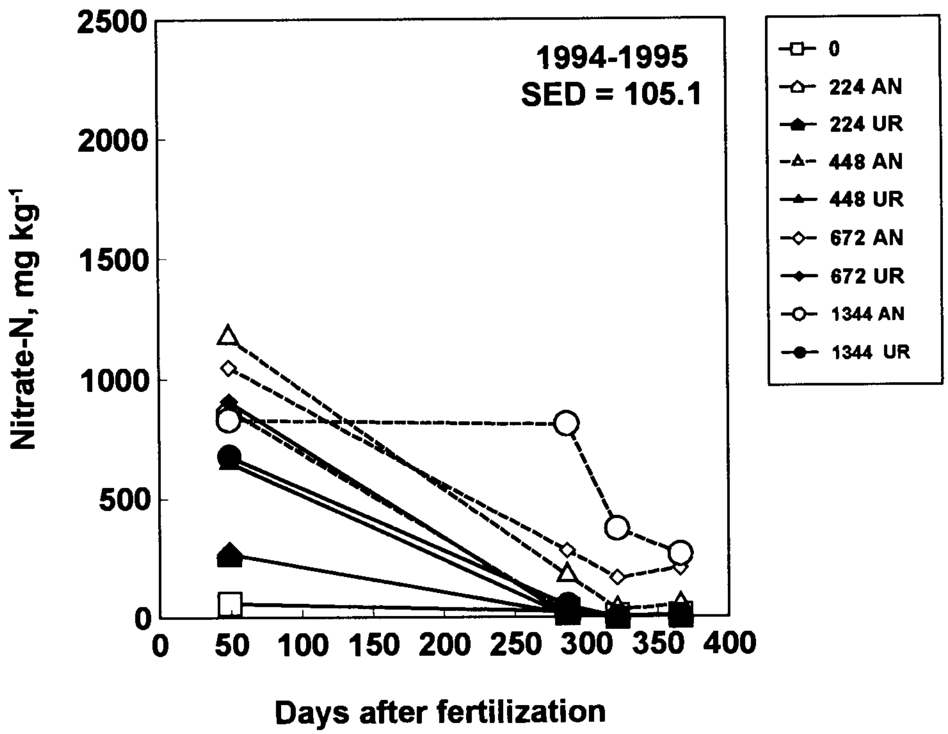


Figure 6. Bermudagrass forage nitrate-N over time, late-summer applied N, Ardmore, OK, 1993-1994 and 1994-1995.

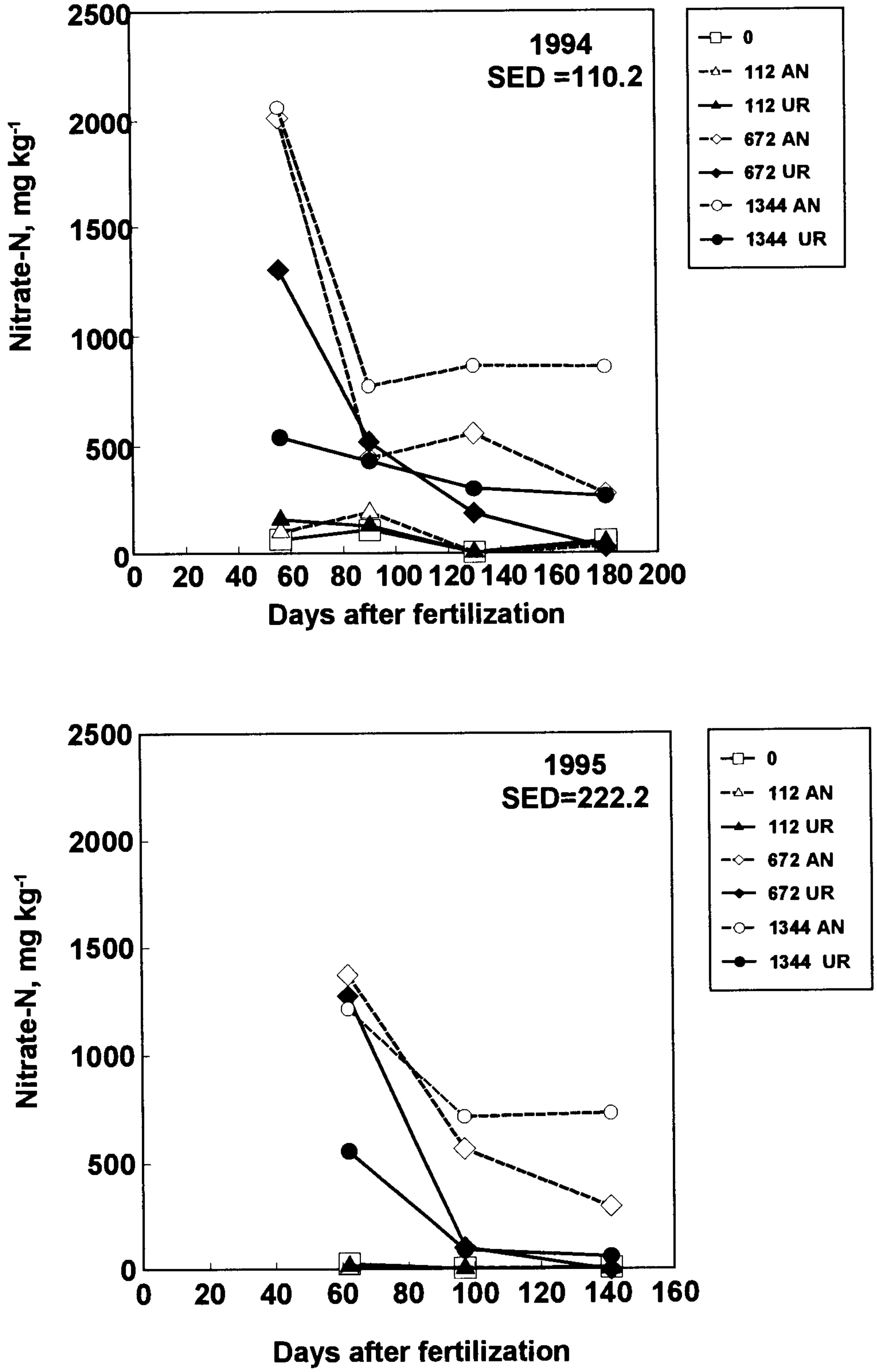


Figure 7. Bermudagrass forage nitrate-N over time, early-spring applied N, Ardmore, OK, 1994 and 1995.

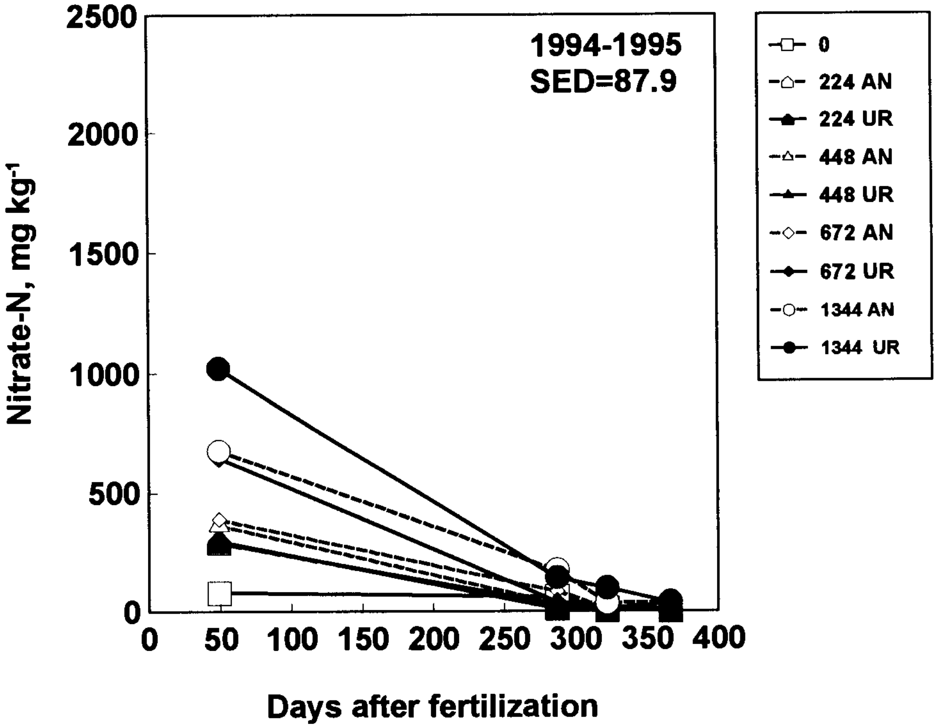
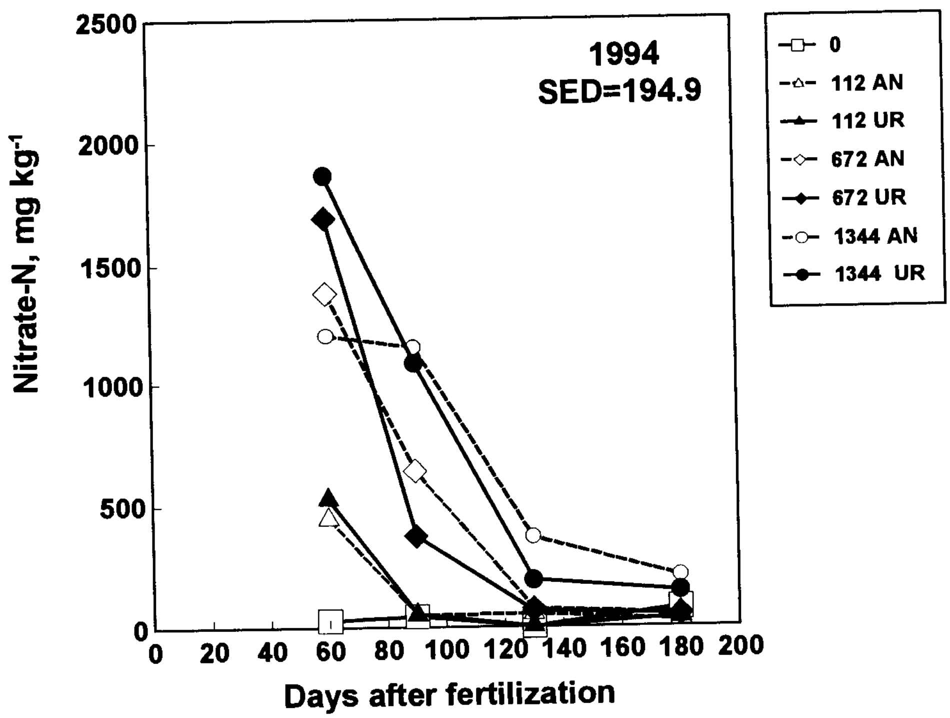


Figure 8. Bermudagrass forage nitrate-N over time, late-summer applied N, Burneyville, OK, 1994-1995.



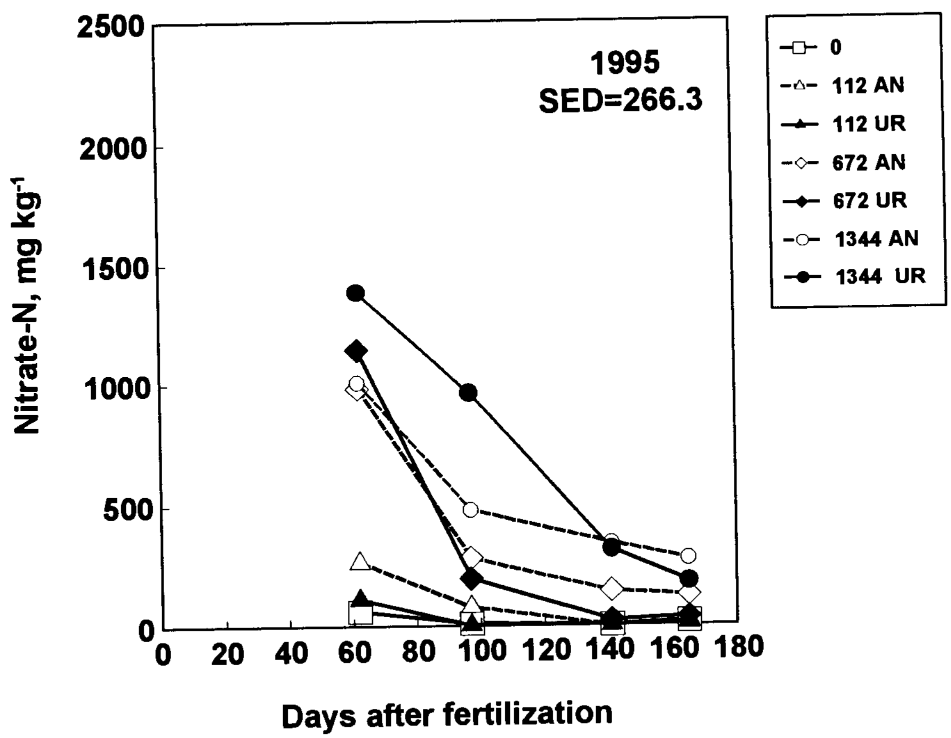


Figure 9. Bermudagrass forage nitrate-N over time, early-spring applied N, Burneyville, OK, 1994 and 1995.

CHAPTER II

USE OF SPECTRAL RADIANCE FOR CORRECTING NITROGEN DEFICIENCIES AND ESTIMATING SOIL TEST VARIABILITY IN AN ESTABLISHED BERMUDAGRASS PASTURE

ABSTRACT

The use of variable rate technology has become increasingly popular for applying plant nutrients. The most widely used method for determining variable fertilizer rates is presently based on soil testing and yield mapping. One field study was initiated in an established Midland bermudagrass (Cynodon dactylon (L) Pers.) pasture 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. The soil at this site was a Minco fine sandy loam (coarse-silty, mixed thermic Udic Haplustoll). Forage samples were collected from the variable rate plots (0.96 X 1.5 m) and analyzed for total N. Spectral radiance readings taken in the red (671 $\pm$ 6 nm) and near infrared (780 $\pm$ 6 nm) wavelengths were used to establish a plant-nitrogen-spectral-index (PNSI). These readings were then correlated with total N removed and biomass. Variable N rates were then applied based on PNSI

readings. In addition, fixed N rate and check (no N applied) plots were evaluated for forage yield. The highest fixed variable N rate was set at 224 kg ha^{-1}. Soil samples were collected in all variable rate plots (1.5 x 2.4m) and analyzed for various soil test characteristics. PNSI and red spectral radiance readings were correlated with bermudagrass forage N removed and yield. Variable N rate plots reduced fertilizer inputs, by 60 %, but did not increase yield over the check. Soil test data showed that the site was extremely variable when samples were collected from small consecutive plots (<$3m^2$), indicating the intense sampling needed for basing variable fertilizer application on soil testing results.

INTRODUCTION

The use of precision farming for applying plant nutrients 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. He also noted that human activities have a substantial impact on variability. The variability can be estimated by dividing the field into small cells of about 1 ha, and basing fertilizer recommendations on nutrient maps. 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 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, NO_3-N, PO_4-P, and 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 size 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 32.3 m grid-point samples increased mapping accuracy by 38 %. Chancellor and Goronea (1994) found that application of nitrogen on 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 nitrogen can be estimated by using spectral radiance measurements at the red (671) and near infrared (NIR) (780) wavelengths. A plant-nitrogen-spectral-index was used to calculate the amount of fertilizer N required to correct in-season winter wheat nitrogen deficiencies. Blackmer et al. (1994) stated that light reflectance near 550 nm was best to separate nitrogen 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, 1665, and 2210 nm) as it related to relative leaf water content, total water potential and turgor pressure. Haggar et al. (1984) showed that soil and green vegetation spectral reflectance vary at different wavelengths, that green vegetation rises sharply at 650 nm and plateaus at 750 nm while soil continues to increase linearly with wavelength. 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 nitrogen-deficient grasses. Green leaf dry matter and infrared IR/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.

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

MATERIALS AND METHODS

A variable nitrogen (N) rate trial was initiated in an established Midland bermudagrass pasture. Spectral radiance measurements were obtained using an integrated sensor and signal processing system. Photodiode detectors included interference filters for red (671$\pm$6nm), near infrared (NIR) (780$\pm$6nm), and green (550$\pm$6nm), with a spectral band width of 0.46m and 0.075m long. Height readings were estimated using an ultrasound sensor based on a sensor element manufactured by Polaroid Corp. A plant-nitrogen-spectral-index (PNSI) was calculated using sensor measurements obtained for NIR and red uncalibrated voltage readings. PNSI was calculated based on work by Stone et al. (1996), Perry and Lautenschlager, (1984), and Duncan et al. (1993). The highest PNSI values corresponded to the highest total nitrogen content in the plant. 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. With approximately 10 readings per second, an average total of 75-100 readings were recorded from each 2.4 x 1.5 m plot. Red, NIR, green and height were determined from each plot by averaging the collected readings. All sensor readings were taken in the same direction (south).

Whole plots (2.4 X 45.7 m) consisted of check (no-nitrogen), fixed (242 kg N ha^{-1}) and variable rate (N rate dependent on PNSI readings) treatments. Each whole plot was subdivided into 30 subplots (2.4 x 1.5 m). The experimental design was a split-plot randomized complete block with 3 replications. The third replication was infested with crabgrass and was not included in the forage yield results.

Forage samples were collected from the variable rate plots prior to and after fertilization (0.96 X 1.5 m) 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 was analyzed for total N, by dry combustion, (Schepers et al., 1989), and total P (only prefertilization) using the vanadomolybdate method without the use of H_2SO_4 in the digest (Barton, 1942; and Bolin and Stamberg 1944).

Surface soil samples (0-15cm) were taken from all variable rate plots prior to fertilization. Samples were analyzed for pH (1:1 soil:water), organic C and total N (dry combustion, Schepers et al., 1989), NH_4-N and NO_3-N (2M KCl extract, Lachat, 1989), K and P (Melich III extract) and total P (colorimetrically by the vanadomolybdate method without the use of H_2SO_4 in the digest, (Barton, 1942; and Bolin and Stamberg 1944).

Fertilizer treatments were applied after sensor readings were taken and forage was removed. A blanket application of phosphorus (P) as triple superphosphate and potassium (K) as potassium chloride was applied at rates of 48.9 kg ha^{-1} of P and 186 kg ha^{-1} of K, respectively. All fixed rates received 224 kg N ha^{-1} with variable rates receiving N rates based upon a linear PNSI-N rate scale. Variable N rates were applied by hand to the 2.4 X 1.5m plots using ammonium nitrate. The highest PNSI readings received 0 kg N ha^{-1}, and the lowest, 224 kg N ha^{-1}. Nitrogen rates for each variable rate plot are reported in Table 1.

RESULTS AND DISCUSSION

Forage Yield Prefertilization: Prior to any fertilization a contour map of PNSI readings was developed from mean values generated from every plot (2.4 x 1.5 m) from the entire experimental area (Figure 1). Simple correlation coefficients for forage yield, total N, N removal, PNSI, red and NIR combinations are reported in Table 2. PNSI and N removal were significantly correlated for each individual rep and all reps combined. (Table 2). Similarly, red spectral radiance readings were significantly correlated with total N removal, suggesting that this wavelength could be used in bermudagrass without considering NIR. A combination of red and NIR has been used to eliminate the effects of soil, but in a bermudagrass pasture the stand is so dense that the sensor does not see the soil (Haggar et al., 1984).

Results from forage harvest and PNSI data collected from consecutive (2.4 X 1.5 m) plots is reported in Figures 2-3. It is important to note that forage yields ranged from 600 to 1800 kg ha^{-1} over 40 m. Similarly, N removal ranged from 10 to 30 kg ha^{-1}, roughly a 3 fold difference. This large variability was not expected, however, it was important to find that PNSI readings paralleled the severe variations in yield and N removal in both replications (Figure 2-3). There was a linear relationship between PNSI and total N removed in all replications and over replications (Figure 4). It was somewhat disturbing to find that the slopes were different (test not shown) across the different reps. Although there was a significant linear relationship between PNSI and total N removed, there was tendency for a stronger relationship between red spectral radiance readings and total N removed (Figure 5).

Forage Yield Post Fertilization: Analysis of variance for forage yield, total N, and N removal is reported in Table 3. There was no effect of treatment on forage yield, or PNSI, but there was on total N. The single-degree-of-freedom contrast for check vs variable-rate and fixed rate treatments was significant for total N and N removed (Table 3). However no differences were detected between variable-rate and fixed rate treatments. Individual graphs by replication for total yield and N removal, with the mean and standard deviation for each treatment are illustrated in Figures 6-7. Variable fertilizer rate application did not increase yield over the check plot, but did result in lower standard deviations, indicating that the spatial variability decreased as a result of prescribed N application. Although total yields did not increase, total N removal increased with a lower standard deviation in the variable rate plots as compared to the check. The average fertilizer application rate for the variable rate plots was 136 kg N ha^{-1} which was 88 kg N ha^{-1} less than that applied in the fixed rate (224 kg N ha^{-1}).

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 4. None of the soil test variables collected, were correlated with total production, total N or N removal. The optimum soil pH for bermudagrass production is 5.5 to 6.5

(Tisdale et al., 1993). Variability in soil pH within the transects is illustrated in Figure 8. Changes from sub-plot to sub-plot in some cases were generally small, however in rep 3, pH changed by almost 1 unit in 1.5 m. Variation in total N and organic carbon within the transects was similar as was expected (Figures 9 and 10). However, the wide changes in organic carbon (6 - 18 g kg^{-1}) and total N (0.4 - 1.3 g kg^{-1}) over relatively small distances were not expected (Figures 9 and 10). Although total P is not used in fertilizer recommendations it was determined on these samples to further illustrate soil variability (Figure 11). Levels of NH_4-N changed by as much as 8 mg kg^{-1} within 1.5 m intervals (Figure 12). Nitrate-N variability was less than that found with other nutrients, although a spike occurred in the second rep (Figure 13). This could have been due to heterogeneity caused by previous pasturing of this area with fat cattle. Extractable P levels were below that required for optimum growth, which could have confounded efforts to use PNSI spectral reflectance readings as an indicator of solely N deficiencies. The first 20 m of the transects had lower values of extractable P < 30 mg kg^{-1}, with the later section of the transect increasing in P availability, but not above 60 mg kg^{-1}. This contrasted variability in total N and organic carbon, since both were higher in the first 30 m. Extractable K levels were at sufficient levels for crop production, but did vary within each transect, Figure 15.

CONCLUSIONS

For this bermudagrass experiment the ability of PNSI to predict total forage and N removal was not as promising as results on wheat by Stone et al. (1996). There was a significant relationship between spectral reflectance readings and total yield and N removal, which indicates that sensor based variable rate technology could be used in bermudagrass forage production systems. Variable rates of N did not increase yield over the check plot but did decrease the variability within the transect. Results from soil test analysis suggest that substantial field variability is present over very short distances. Results from this sampling indicate that the presence of substantial variability at 1.5 m intervals. The intense sampling that would be required to sample 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 needs.

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Table 1. Variable nitrogen rates applied to variable-rate subplots, Burneyville, OK, 1995.

Subplot distance, m	Nitrogen Rate kg N ha^{-1} Rep 1	Rep 2	Rep 3
1.524	0	0	0
3.058	132	0	0
4.572	55	0	0
6.096	129	112	0
7.620	191	0	80
9.144	136	0	0
10.668	141	0	0
12.192	167	76	0
13.716	205	66	0
15.240	186	67	0
16.764	22	73	34
18.288	195	118	139
19.812	139	148	90
21.336	124	146	59
22.860	211	160	136
24.384	194	123	157
25.908	185	89	139
27.432	153	143	78
28.956	98	181	108
30.480	0	177	52
32.004	133	210	28
33.528	178	186	74
35.052	200	206	125
36.576	168	217	134
38.100	0	192	160
39.624	148	185	182
41.148	179	163	159
42.672	194	131	108
44.196	138	141	174
45.720	0	75	152

Table 2. Simple correlation coefficients and significance levels for forage production, total N, N removal, PNSI, red and NIR spectral radiance readings, Burneyville, OK, 1995.

	Forage Yield kg ha^{-1}	Total N g kg^{-1}	N Removal kg ha^{-1}	PNSI	Red
Rep 1 (n=27)					
Total N	-0.48 *				
N Removal	0.86 **	0.2			
PNSI	0.39 *	0.08	0.53 **		
Red	-0.68 **	0.12	-0.71 **	-0.81 **	
NIR	0.22	0.17	0.38 *	0.93 **	-0.65 **
Rep 2 (n=26)					
Total N	0.37				
N Removal	0.97 **	0.55 **			
PNSI	0.80 **	0.37	0.80 **		
Red	-0.83 **	-0.42 *	-0.83 **	-0.95 **	
NIR	0.85 **	0.38	0.85 **	0.97 **	-0.96 **
All Reps (n=53)					
Total N	-0.17				
N Removal	0.92 **	0.22			
PNSI	0.60 **	0.09	0.66 **		
Red	-0.74 **	0.01	-0.73 **	-0.86 **	
NIR	0.55 **	0.14	0.63 **	0.95 **	-0.79 **

**, * - significant at the 0.01 and 0.05 probability levels, respectively.

Table 3. Analysis of variance and single-degree-of-freedom-contrasts for PNSI, forage yield, total N, and N removal for the harvest after fertilization, Burneyville, OK, 1995.

Source	df	PNSI	Forage Yield kg ha^{-1}	Total N g kg^{-1}	N Removal kg ha^{-1}
		Mean Squares			
Rep	1	3.9	1102499	0.04	755.4
Trt	2	0.3	425725	6.62 *	1534.0
Contrast					
CK vs VR and FX	1	0.2	220537	17.01 **	3201.2 *
VR vs FX	1	0.3	792263	0.33	1123.0
Rep*Trt (a)	2	2.7	784408	0.35	465.8
Sub-plot	26	1.5 **	112553	0.93	69.4
Trt*Sub-plot	52	0.9 **	51114	0.11	43.3
Error (b)	78	0.4	96904	0.07	73.7
SED		0.5	254	0.22	7.0
CV, %		26	30	11	31
Treatment Means					
Check			994	2.27	22.5
Variable-rate			949	2.80	26.4
Fixed			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.

Table 4. 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} ---------------------		
Rep 1								
Min	5.3	0.6	6.7	164.3	4.6	1.7	5.7	154
Max	6.2	0.9	11.4	278.9	13.5	2.4	60.4	225
Mean	5.7	0.7	9.0	235.5	7.6	1.9	26.4	179
STD	0.2	0.1	1.2	31.7	1.8	0.2	15.5	20
Rep 2								
Min	5.4	0.4	5.4	138.8	4.7	1.2	7.0	144
Max	6.2	1.3	17.3	336.5	14.7	9.0	55.1	256
Mean	5.7	0.7	9.2	199.9	7.7	2.0	20.2	179
STD	0.2	0.2	3.2	40.5	2.3	1.3	11.8	25
Rep 3								
Min	5.1	0.5	6.4	167.0	4.6	1.7	10.6	145
Max	6.2	1.1	13.6	326.7	11.9	5.4	35.5	273
Mean	5.8	0.8	10.0	233.9	8.0	2.6	21.6	193
STD	0.3	0.2	1.8	33.9	1.7	0.9	6.4	28
All Reps								
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	0.2	0.1	2.2	38.8	1.9	1.0	12.0	25

pH - 1:1 soil:water, Total N and Organic C - dry combustion, NH_4-N and NO_3-N - 2M KCl extract, K and P - Melich III extraction, Total P vanadomolybdate method.
STD - standard deviation from the mean.

(VR-variable rate, C-check, R-reading plot, FR-fixed rate)

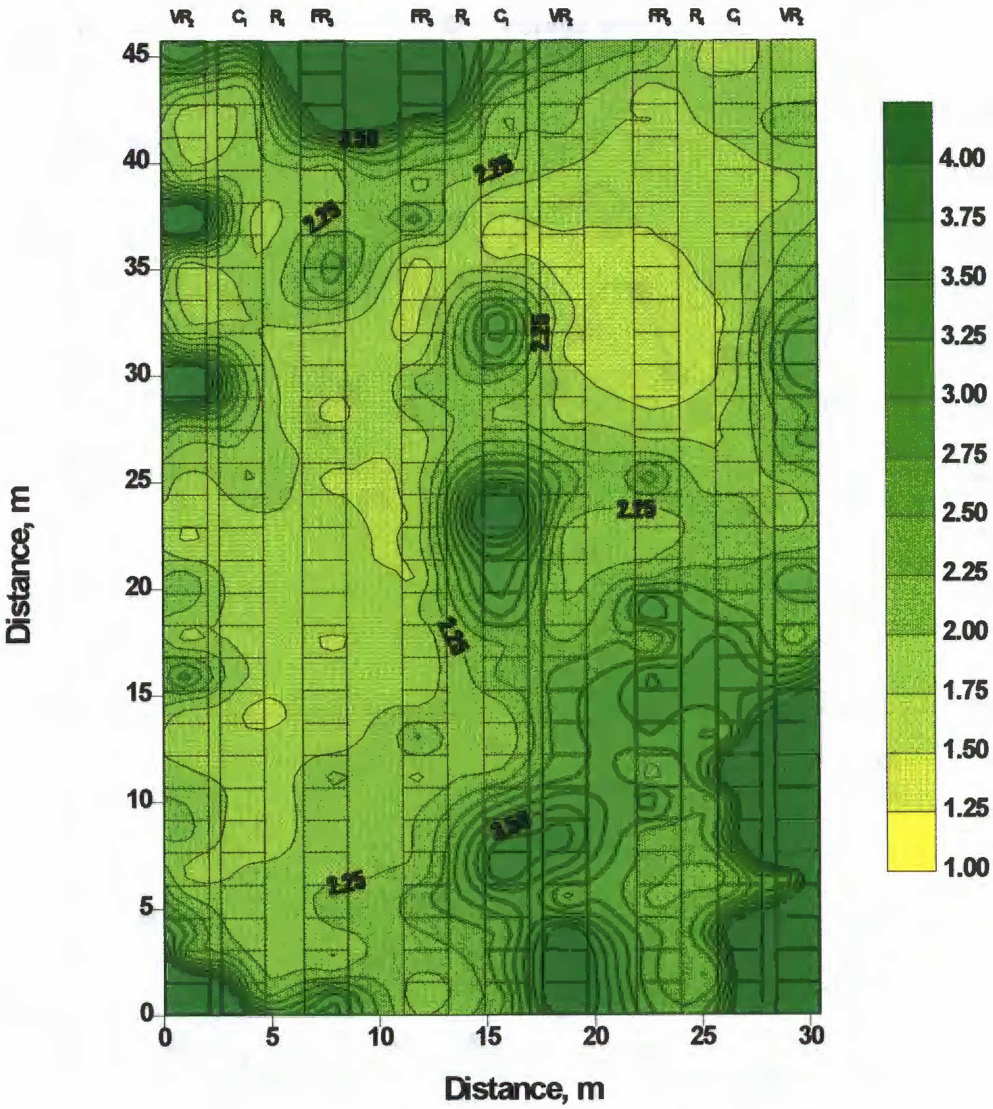
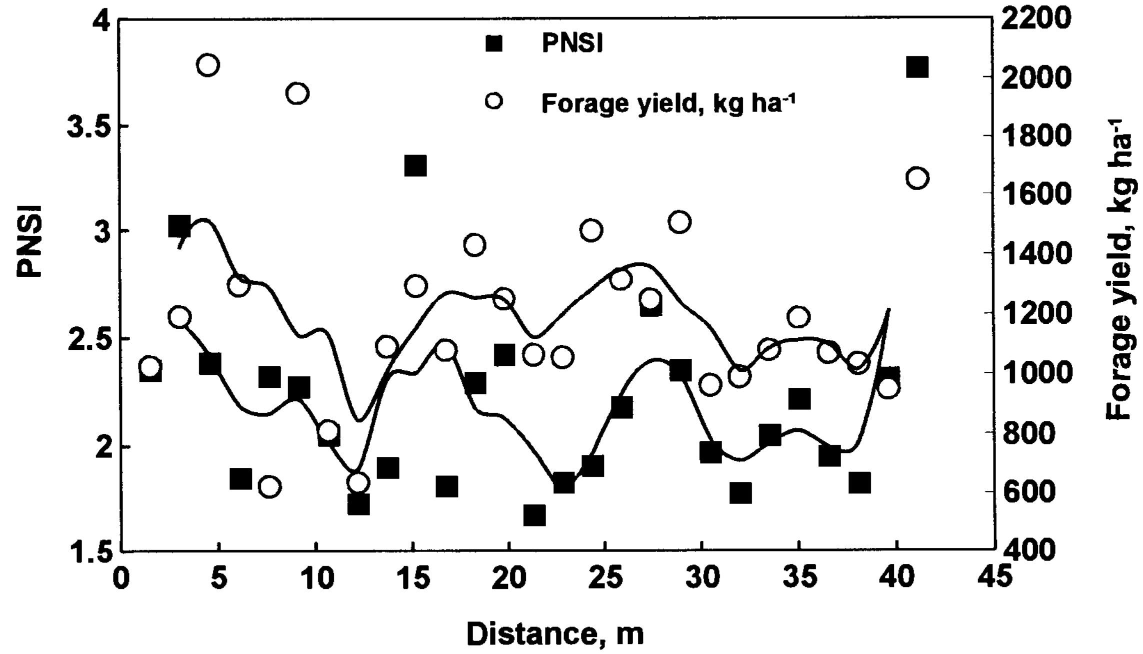


Figure 1. Contour map of PNSI readings, Burneyville, OK, 1995



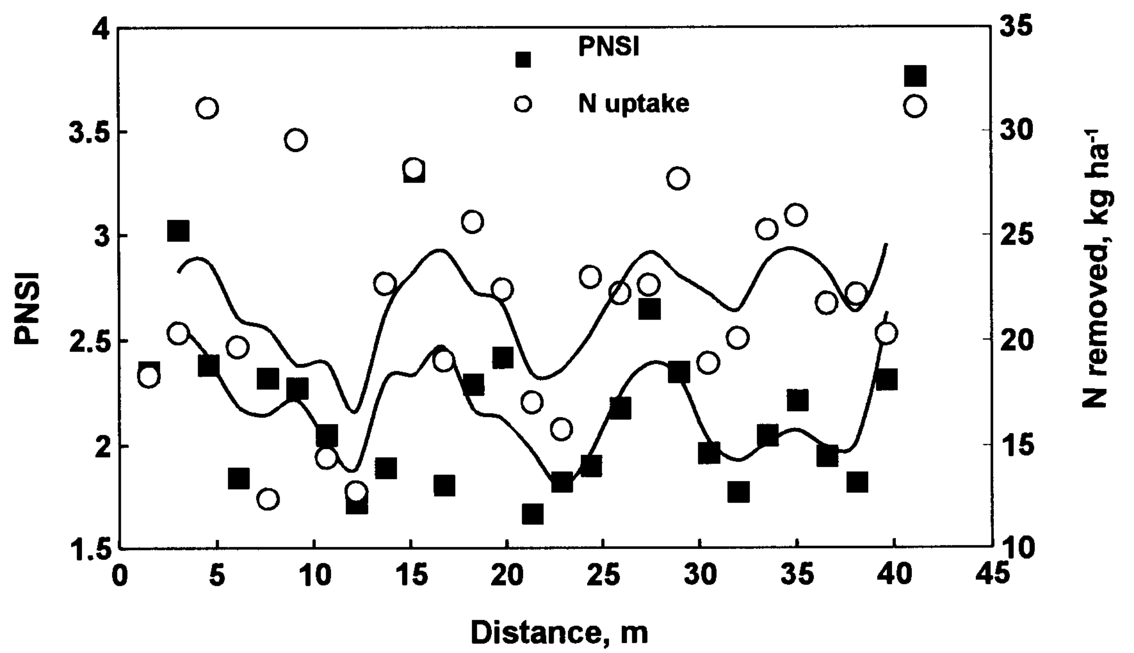
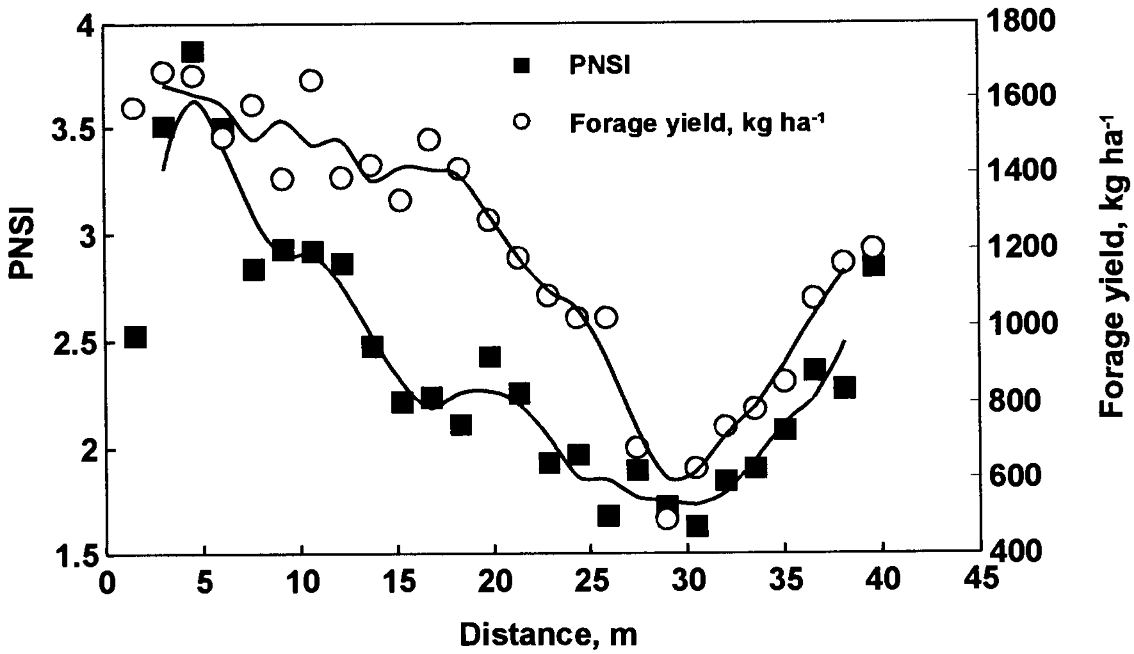


Figure 2. Variabilty in bermudagrass forage yield, N removed and PNSI, and weighted average trendlines, rep 1, Burneyville, OK, 1995



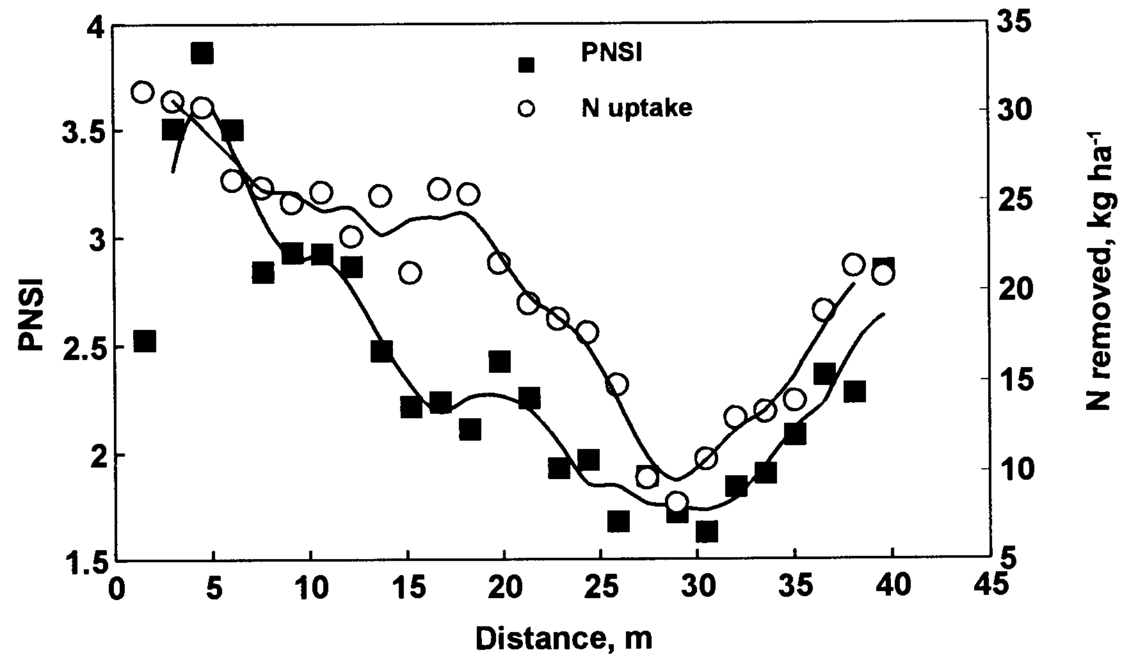


Figure 3. Variabilty in bermudagrass forage yield, N removed and PNSI, and weighted average trendlines, rep 2, Burneyville, OK, 1995

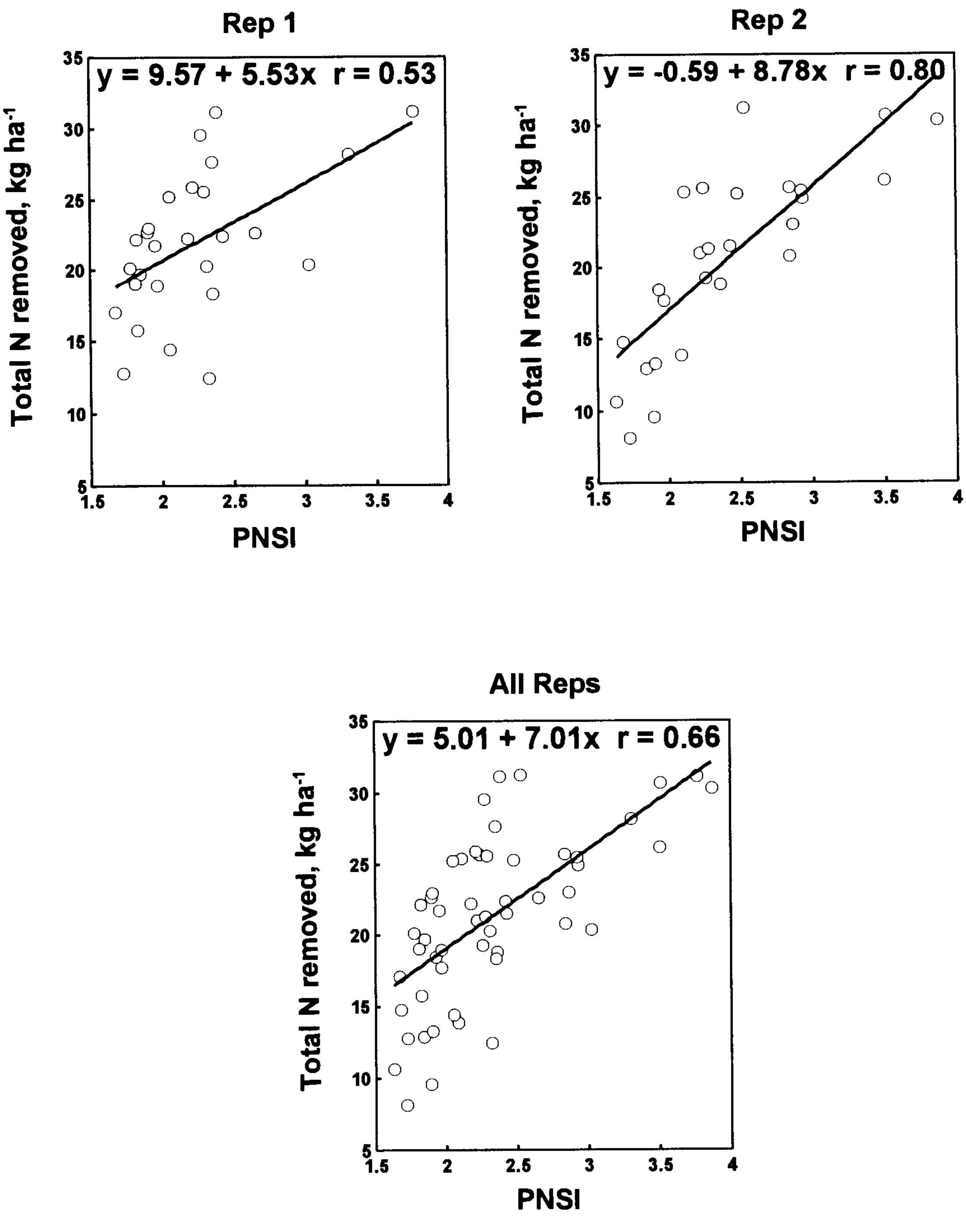


Figure 4. Correlation of total N removed versus PNSI spectral radiance readings by rep and all reps combined, Burneyville, OK, 1995

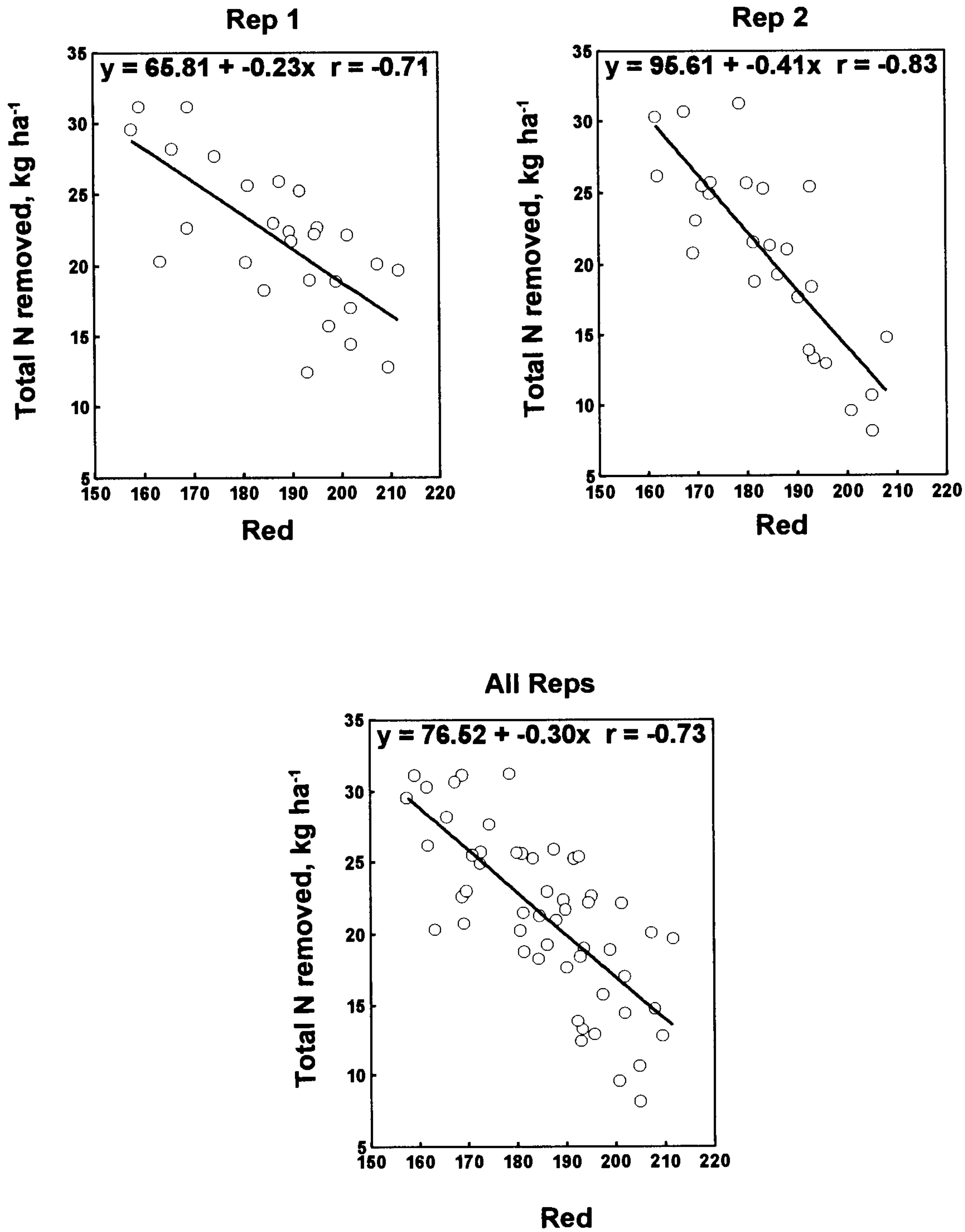


Figure 5. Correlation of total N removed versus red spectral radiance readings by rep and all reps combined, Burneyville, OK, 1995

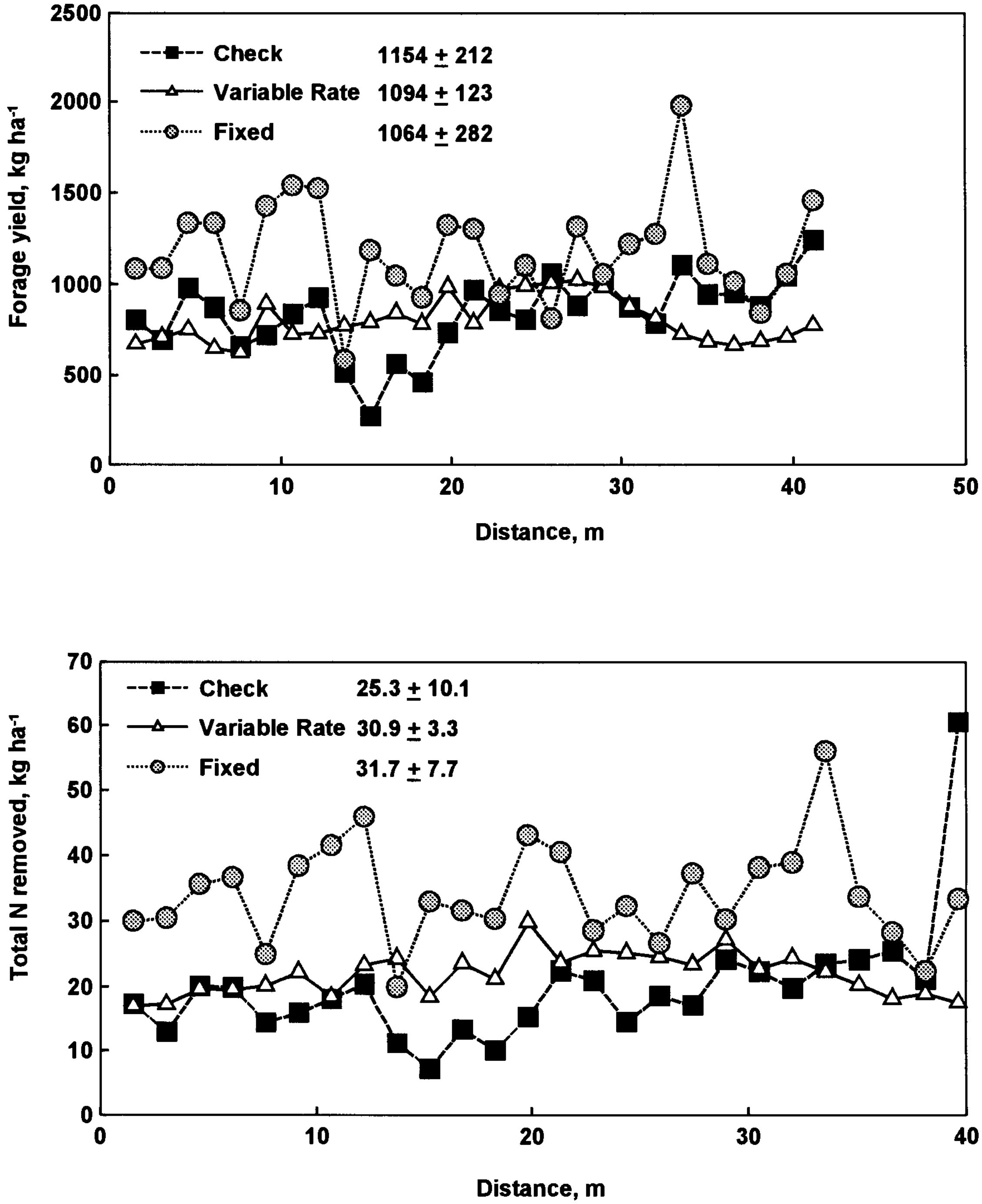


Figure 6. Variability of bermudagrass forage yield and N removed from rep 1, Burneyville, OK 1995

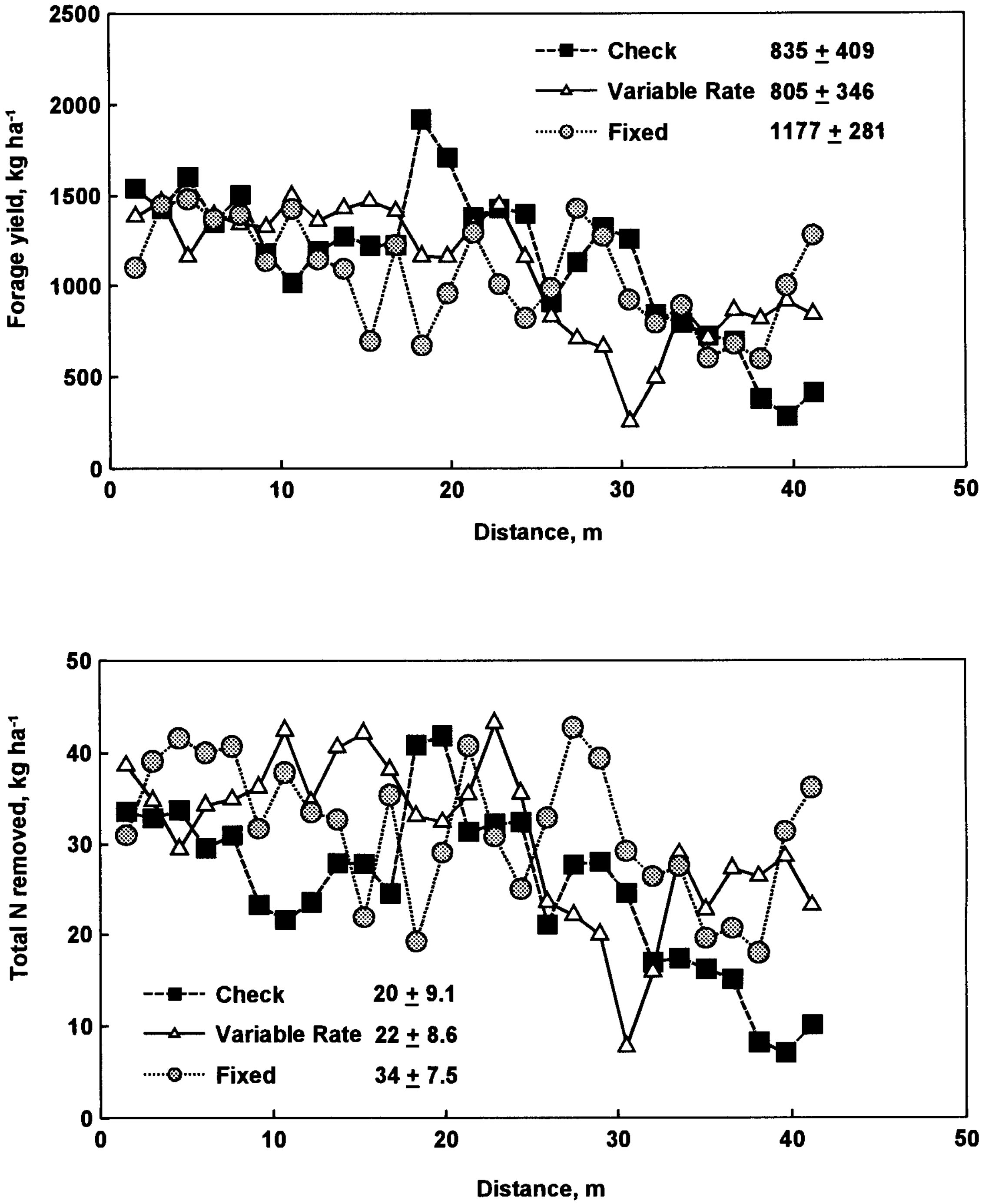


Figure 7. Variability of bermudagrass forage yield and N removed from rep 2, Burneyville, OK 1995

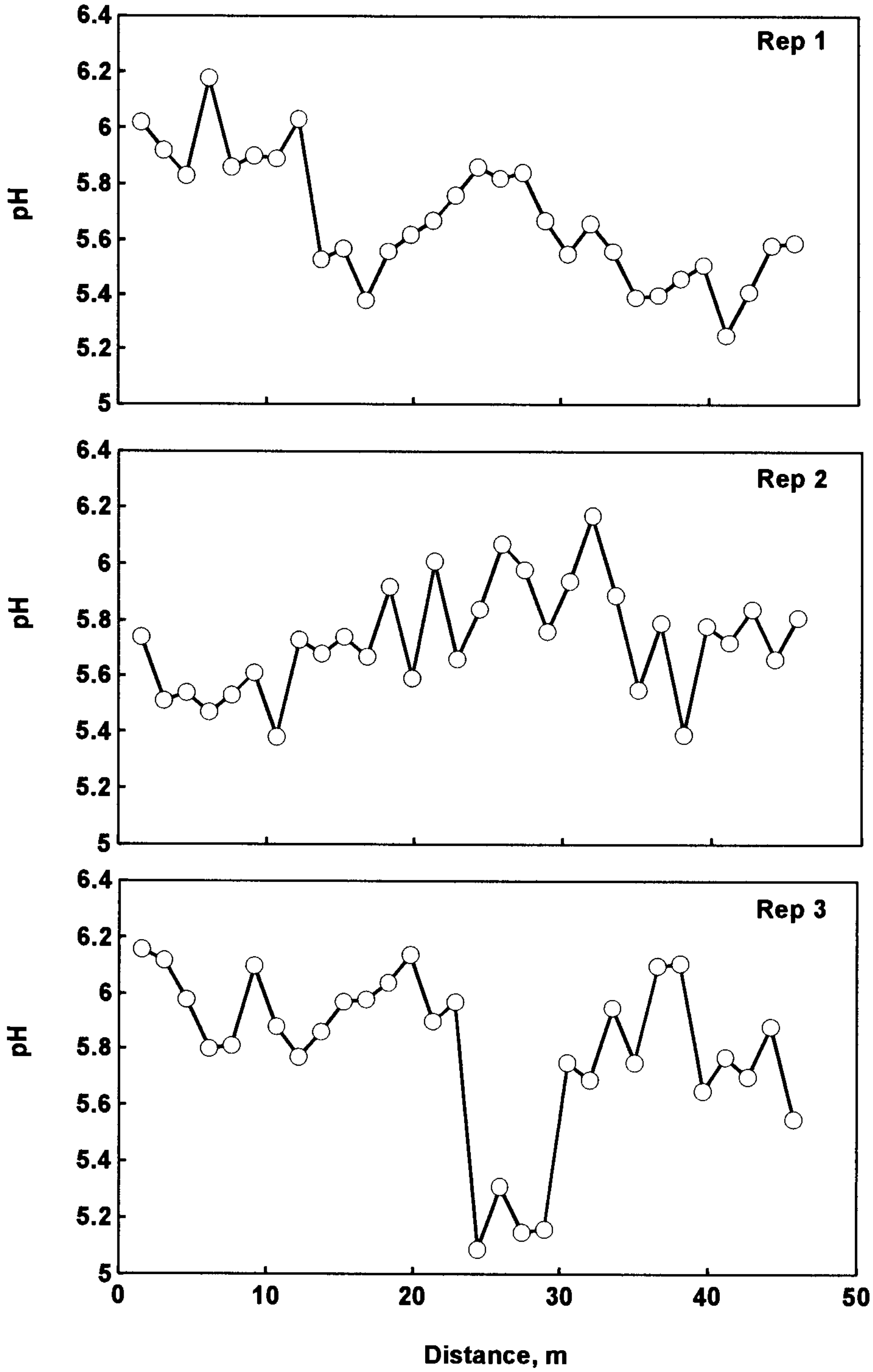


Figure 8. Soil pH variability with distance, Burneyville, OK, 1995

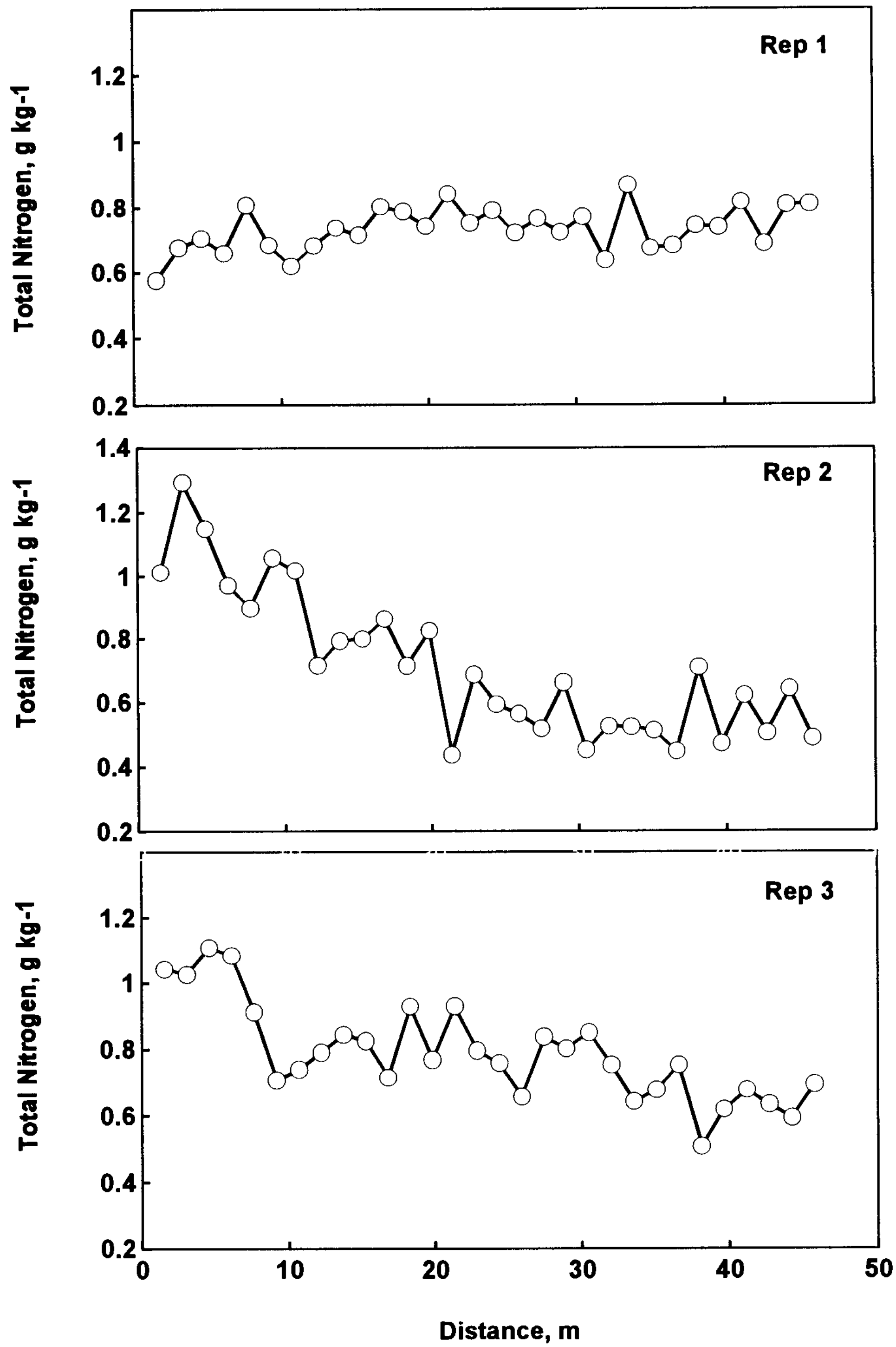


Figure 9. Soil total nitrogen variability with distance, Burneyville, OK, 1995

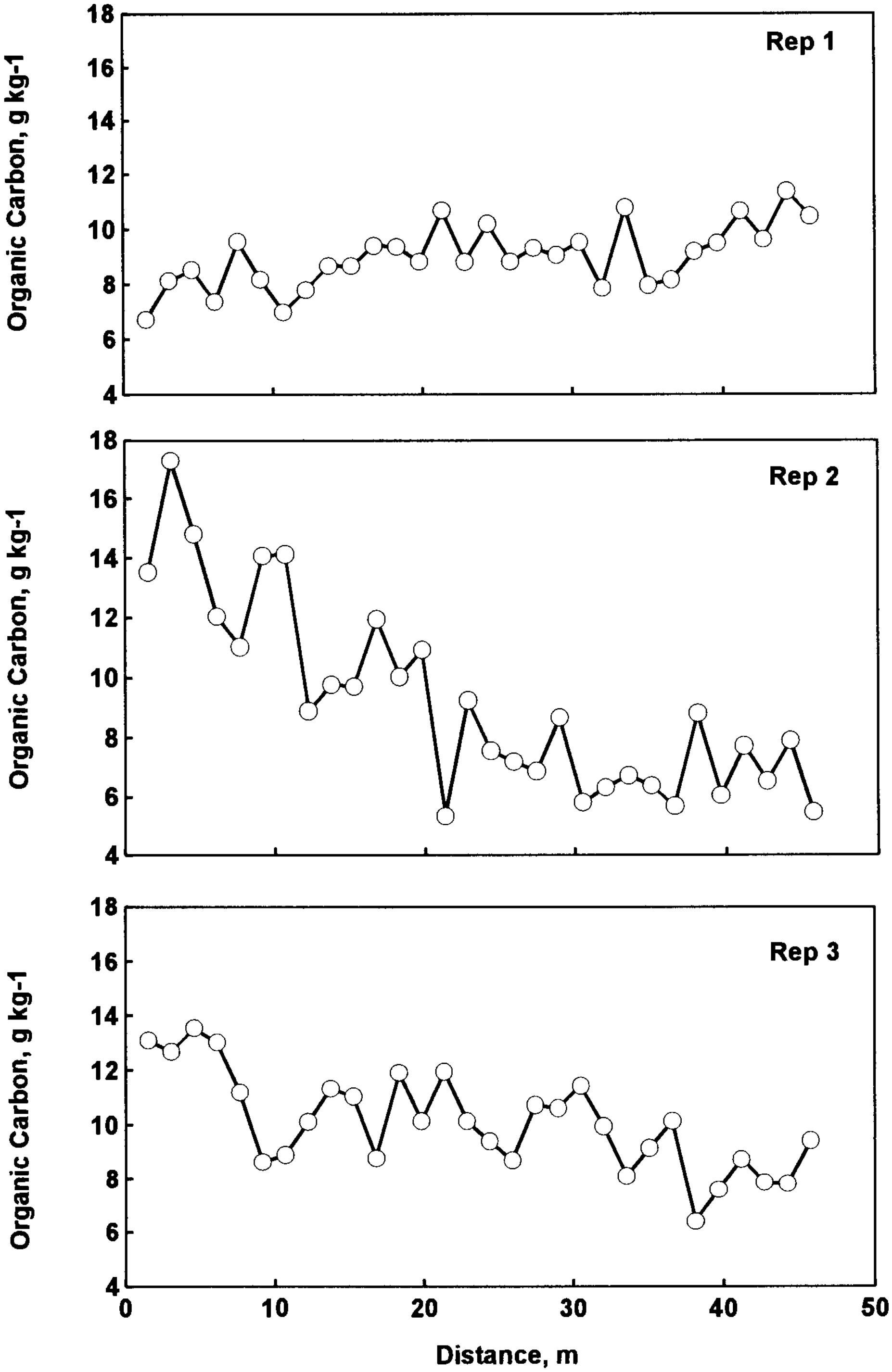


Figure 10. Soil organic carbon variability with distance, Burneyville, OK, 1995

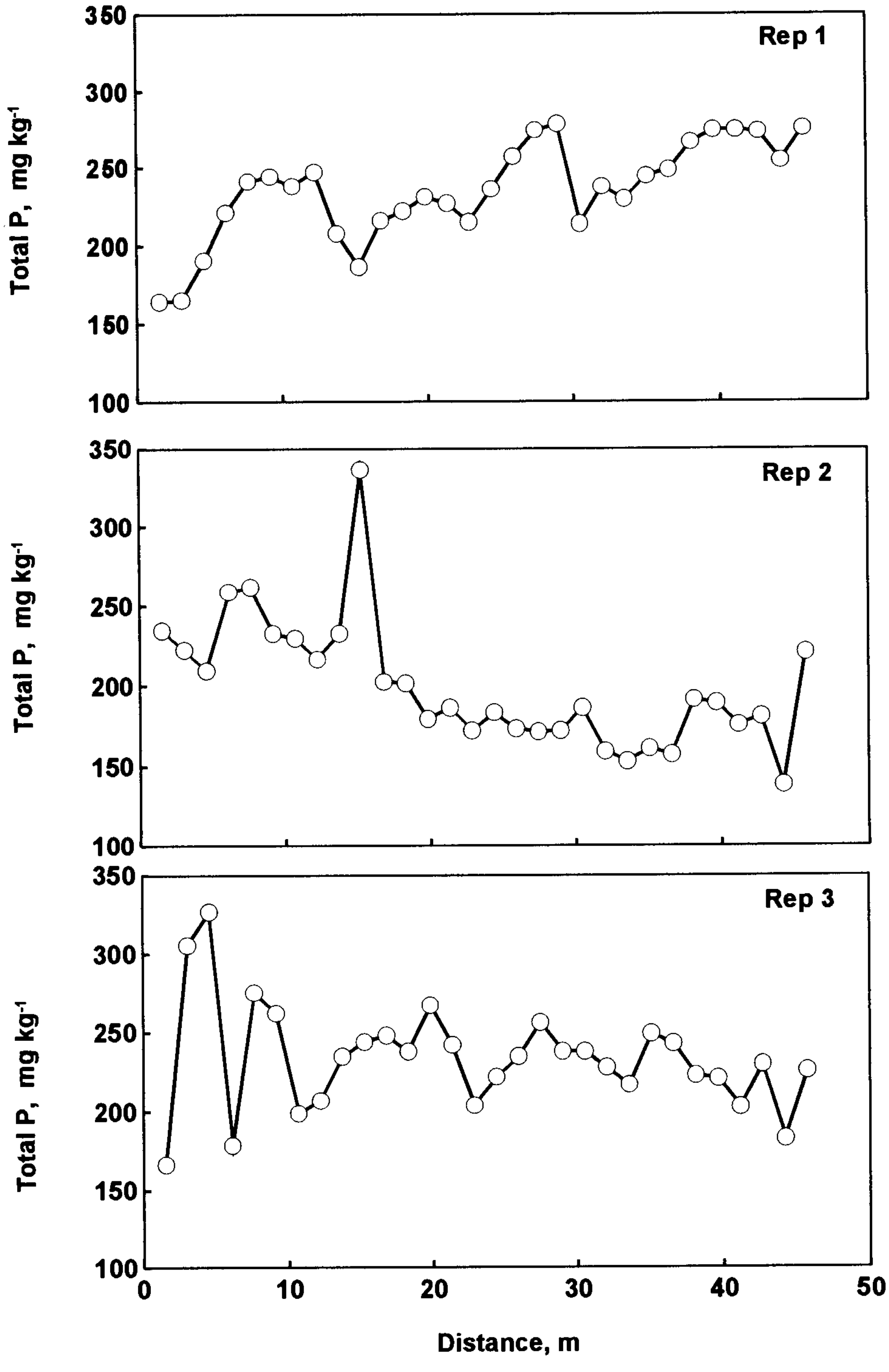


Figure 11. Soil total phosphorus variability with distance, Burneyville, OK, 1995

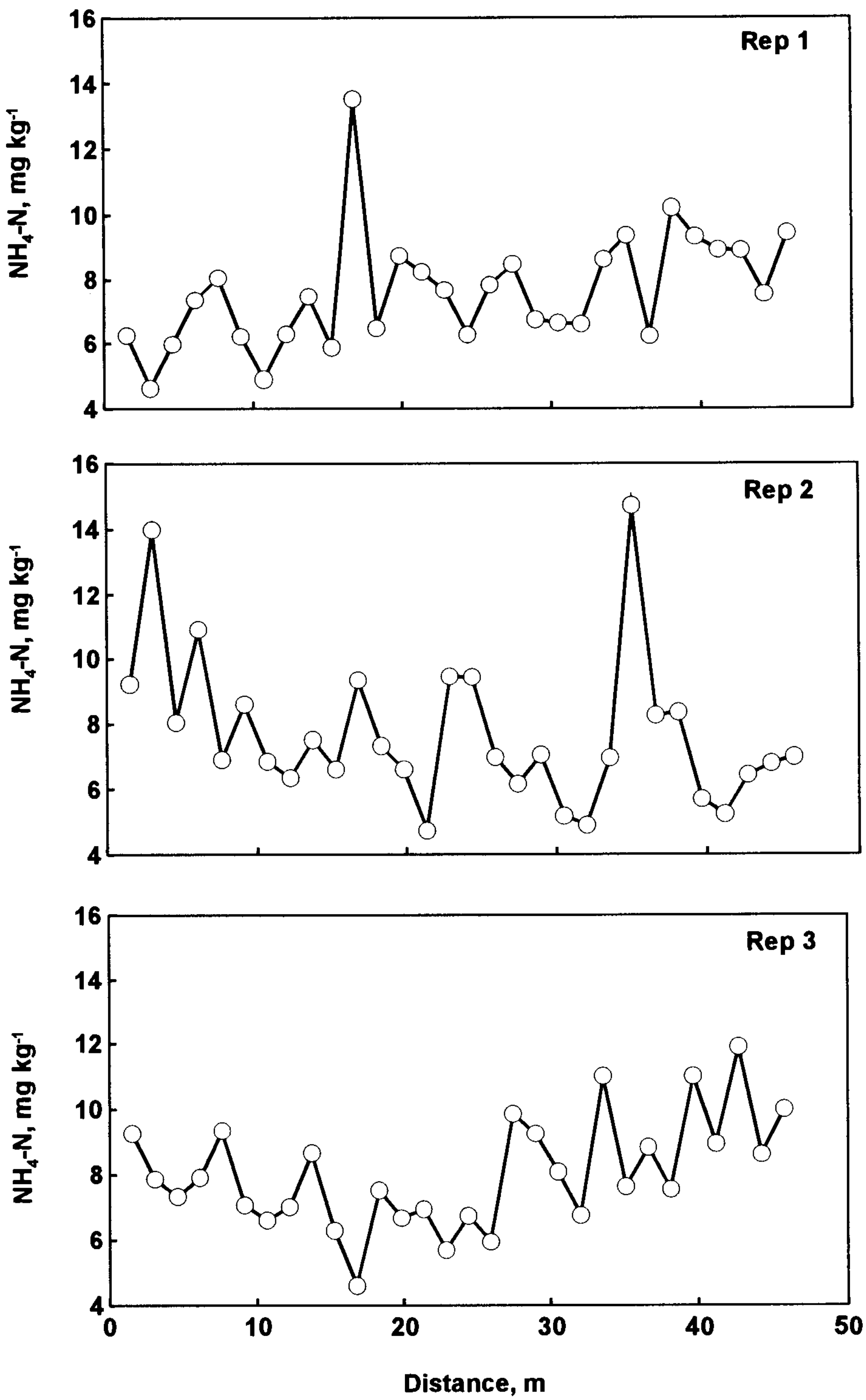


Figure 12. Soil NH_4-N variability with distance, Burneyville, OK, 1995

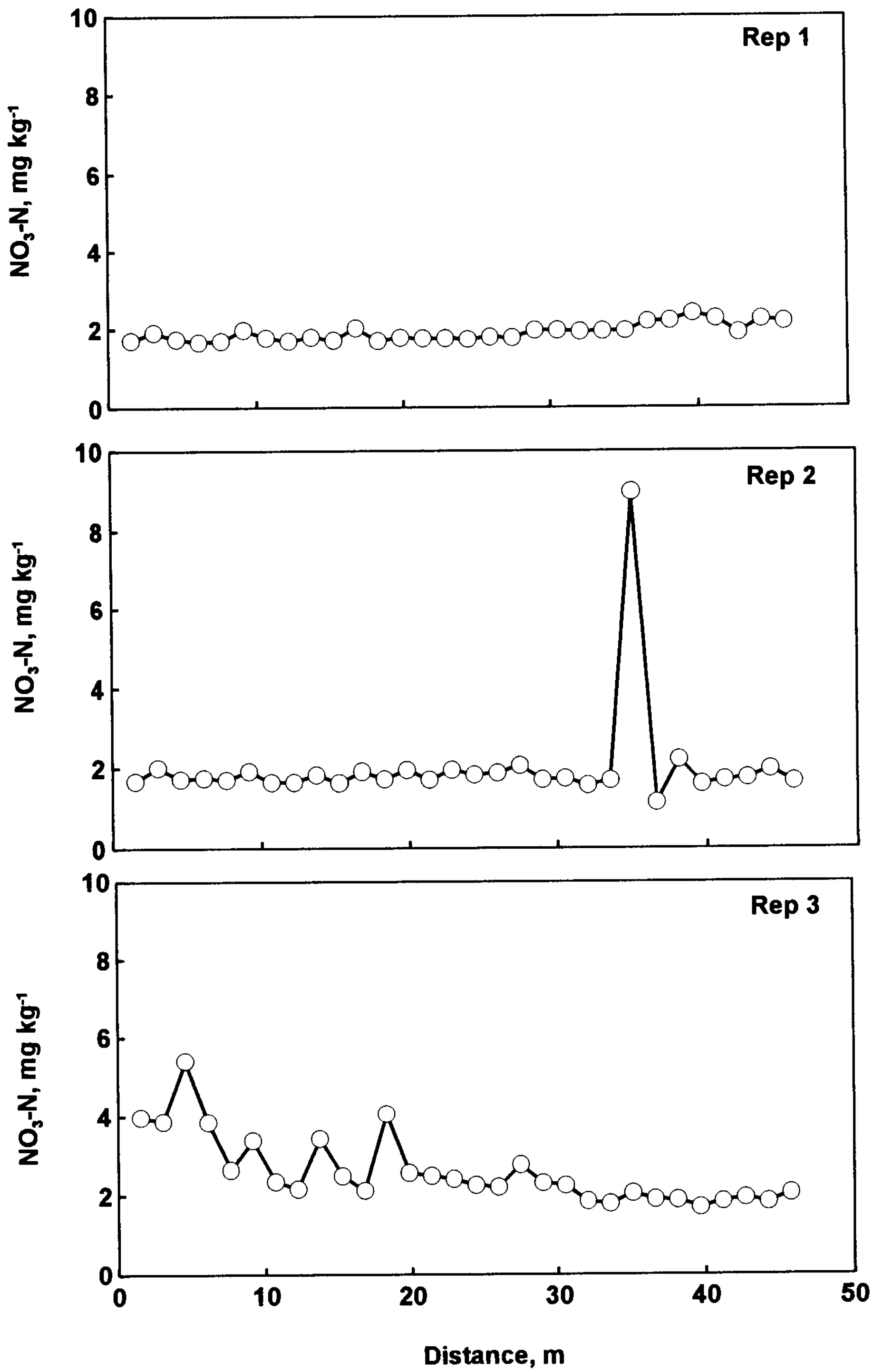


Figure 13. Soil NO_3-N variability with distance, Burneyville, OK, 1995

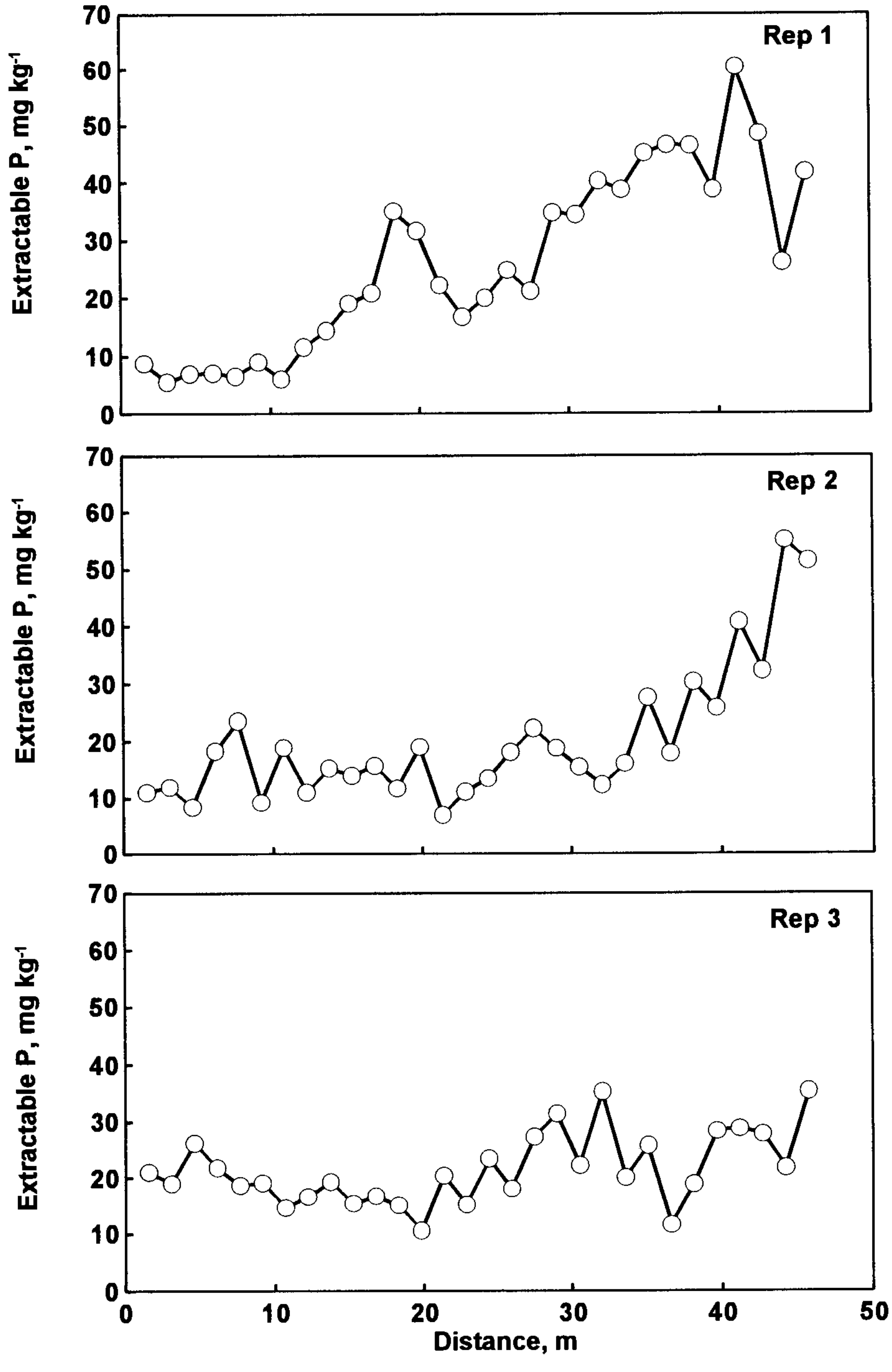


Figure 14. Soil extractable P variability with distance, Burneyville, OK, 1995

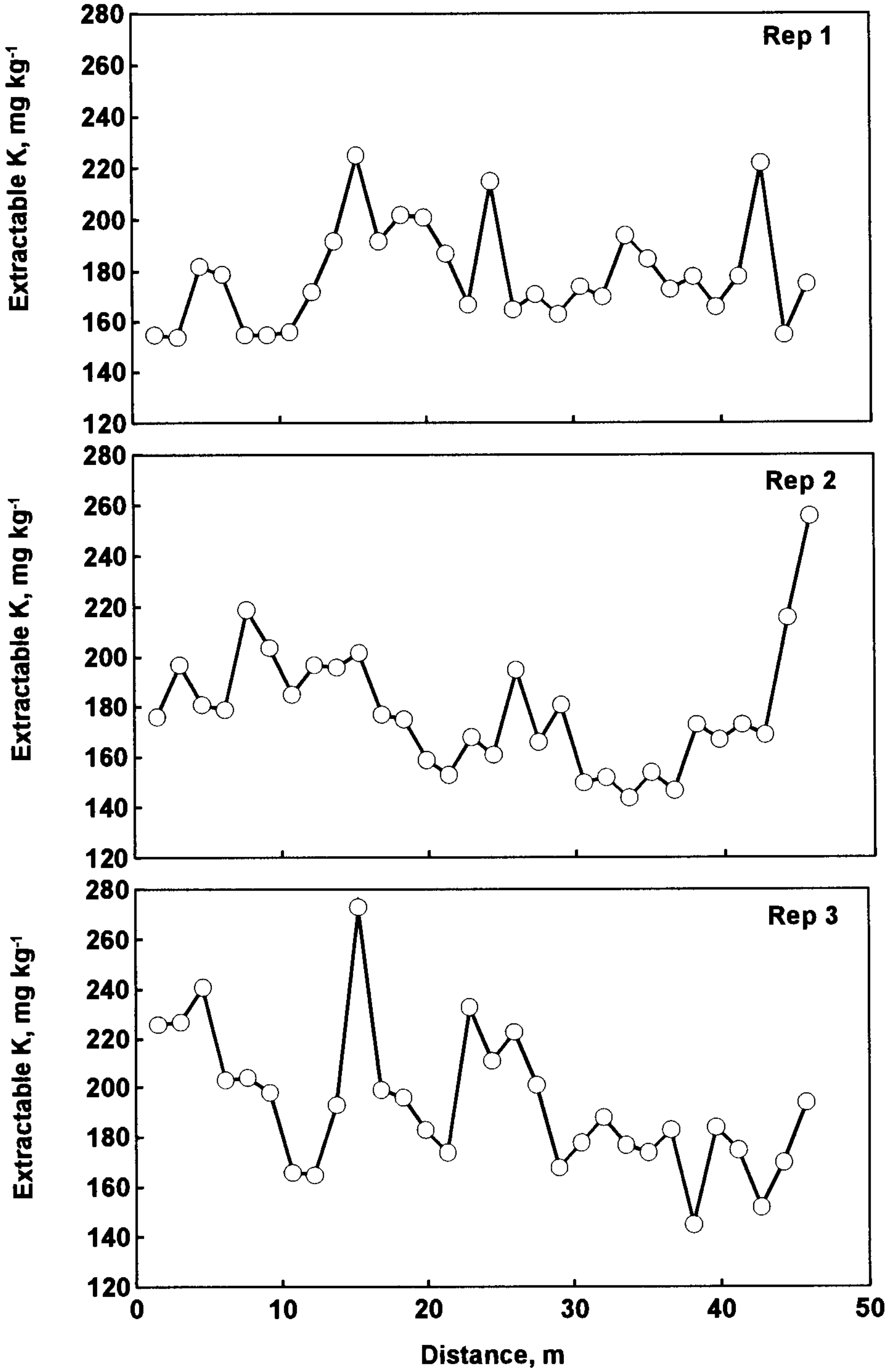


Figure 15. Soil extractable K variability with distance, Burneyville, OK, 1995

APPENDIX

Table 1. Treatment means, by harvest for forage yield and N removal, late-summer applied N, Ardmore, OK, 1993-1994.

Trt	N rate kg ha^{-1}	Source	Harvest Date 10-3-93	5-26-94	6-29-94	8-9-94
			Forage yield, Mg ha^{-1}			
1	0	x	1.37	1.60	0.71	0.98
2	0	x	1.23	1.92	0.73	0.84
3	224	AN	4.38	2.26	1.22	1.73
4	448	AN	4.09	2.99	1.59	3.02
5	672	AN	4.40	2.77	2.09	4.49
6	1344	AN	3.55	2.55	2.64	5.77
7	224	UR	4.14	1.91	0.76	1.13
8	448	UR	3.87	1.98	1.15	1.75
9	672	UR	3.69	2.30	1.11	2.11
10	1344	UR	3.16	2.73	2.62	3.94
SED			0.33	0.41	0.33	0.40
CV, %			12	22	27	19
			Nitrogen removal, kg ha^{-1}			
1	0	x	20.8	32.3	13.4	14.2
2	0	x	17.0	42.4	15.7	12.7
3	224	AN	119.8	54.8	23.9	27.7
4	448	AN	123.4	98.2	34.4	52.9
5	672	AN	131.6	86.6	52.0	90.1
6	1344	AN	116.3	97.1	72.5	159.8
7	224	UR	96.1	44.3	18.9	16.5
8	448	UR	104.4	50.5	21.8	27.2
9	672	UR	107.2	62.5	24.4	32.8
10	1344	UR	89.2	95.7	67.4	79.2
SED			8.3	11.2	9.2	8.4
CV, %			10	21	33	20

SED - standard error of the difference between two equally replicated means, CV - coefficient of variation, %, AN - ammonium nitrate, UR - urea.

Table 2. Treatment means, by harvest for forage yield and N removal, late-summer applied N, Ardmore, OK, 1994-1995.

Trt	N rate kg ha^{-1}	Source	Harvest Date 9-29-94	3-22-95	5-23-95	6-28-95	8-11-95
			Forage yield, Mg ha^{-1}				
1	0	x	1.01	0.15	1.64	0.71	0.58
2	0	x	1.13	0.12	2.13	0.73	0.59
3	224	AN	4.70	0.87	2.29	1.22	1.26
4	448	AN	5.40	1.27	2.78	1.58	1.85
5	672	AN	4.60	1.47	2.73	2.09	2.63
6	1344	AN	4.01	1.07	3.03	2.64	3.16
7	224	UR	3.90	0.65	1.55	0.76	0.80
8	448	UR	4.79	0.81	1.99	1.15	1.13
9	672	UR	5.23	1.08	1.69	1.11	1.34
10	1344	UR	4.10	1.20	2.12	2.62	1.54
SED			0.33	0.14	0.48	0.33	0.37
CV, %			10	19	27	27	30
			Nitrogen removal, kg ha^{-1}				
1	0	x	17.8	2.4	31.0	13.4	8.1
2	0	x	19.0	2.0	41.0	15.7	8.7
3	224	AN	144.5	23.6	49.2	23.9	19.9
4	448	AN	183.7	39.5	69.3	34.4	36.6
5	672	AN	153.3	47.8	78.4	52.0	63.7
6	1344	AN	131.6	35.0	90.9	72.5	72.0
7	224	UR	106.8	13.0	28.6	18.9	11.4
8	448	UR	145.1	19.9	43.2	21.8	16.5
9	672	UR	165.4	28.5	34.1	24.4	19.3
10	1344	UR	126.9	35.0	59.7	67.3	22.4
SED			11.0	3.2	10.8	9.2	6.1
CV, %			11	17	25	33	26

SED - standard error of the difference between two equally replicated means, CV - coefficient of variation, %, AN - ammonium nitrate, UR - urea.

Table 3. Treatment means, by harvest for forage yield and N removal, early-spring applied N, Ardmore, OK, 1994.

Trt	N rate kg ha^{-1}	Source	Harvest Date 5-26-94	6-28-94	8-9-94	9-26-94
			Forage yield, Mg ha^{-1}			
1	0	x	1.60	0.71	0.98	1.00
2	0	x	1.92	0.73	0.84	1.13
15	112	AN	4.88	1.24	1.50	1.54
11	672	AN	5.37	2.61	5.82	4.00
12	1344	AN	5.01	3.44	6.29	5.10
16	112	UR	4.25	1.30	1.99	1.38
13	672	UR	6.07	2.71	5.67	3.35
14	1344	UR	4.08	2.85	5.95	4.41
SED			0.52	0.32	0.47	0.29
CV, %			21	20	16	13
			Nitrogen removal, kg ha^{-1}			
1	0	x	32.3	13.3	14.2	17.8
2	0	x	42.4	15.7	12.7	19.0
15	112	AN	114.4	28.8	26.3	22.6
11	672	AN	184.7	64.0	147.0	115.4
12	1344	AN	189.9	103.3	159.2	162.0
16	112	UR	84.2	25.6	33.9	19.5
13	672	UR	220.3	71.9	134.0	78.7
14	1344	UR	142.9	80.3	147.4	111.0
SED			24.0	9.5	25.0	9.5
CV, %			22	23	36	17

SED - standard error of the difference between two equally replicated means, CV - coefficient of variation, %, AN - ammonium nitrate, UR - urea.

Table 4. Treatment means, by harvest for forage yield and N removal, early-spring applied N, Ardmore, OK, 1995.

Trt	N rate kg ha^{-1}	Source	Harvest Date 5-23-95	6-28-95	8-11-95
			Forage yield, Mg ha^{-1}		
1	0	x	1.64	0.61	0.58
2	0	x	2.13	0.73	0.59
15	112	AN	3.55	0.74	0.87
11	672	AN	2.50	3.32	3.07
12	1344	AN	1.47	3.60	3.76
16	112	UR	2.81	0.90	0.95
13	672	UR	3.00	2.98	2.22
14	1344	UR	1.57	3.66	3.09
SED			0.41	0.39	0.32
CV, %			21	23	21
			Nitrogen removal, kg ha^{-1}		
1	0	x	31.0	10.7	8.1
2	0	x	41.0	12.7	8.7
15	112	AN	80.6	14.0	13.4
11	672	AN	86.2	107.5	87.0
12	1344	AN	50.8	127.3	109.0
16	112	UR	61.3	18.9	16.1
13	672	UR	95.4	69.7	37.9
14	1344	UR	56.5	100.2	65.2
SED			9.6	11.8	7.6
CV, %			19	25	21

SED - standard error of the difference between two equally replicated means, CV - coefficient of variation, %, AN - ammonium nitrate, UR - urea.

Table 5. Treatment means, by harvest for forage yield and N removal, late-summer applied N, Burneyville, OK, 1994-1995.

Trt	N rate kg ha^{-1}	Source	Harvest Date 9-27-94	5-23-95	6-17-95	8-10-95
			Forage Yield, Mg ha^{-1}			
1	0	x	2.41	1.24	1.87	2.15
2	0	x	2.24	0.98	1.31	1.85
3	224	AN	4.49	1.55	1.88	2.10
4	448	AN	4.76	1.57	2.53	2.60
5	672	AN	4.10	1.65	2.72	2.60
6	1344	AN	4.62	1.68	3.01	2.88
7	224	UR	3.67	1.40	1.87	2.34
8	448	UR	4.88	1.54	2.00	2.34
9	672	UR	5.46	1.76	2.23	2.24
10	1344	UR	4.85	2.09	3.41	2.92
SED			0.54	0.11	0.13	0.27
CV, %			16	8	19	14
			Nitrogen removal, kg ha^{-1}			
1	0	x	34.3	29.6	29.2	26.9
2	0	x	31.1	18.4	19.2	23.8
3	224	AN	118.9	35.7	30.9	27.0
4	448	AN	132.7	37.5	44.5	37.6
5	672	AN	113.5	42.1	51.4	42.5
6	1344	AN	128.7	47.0	60.3	52.1
7	224	UR	72.8	30.1	29.2	29.7
8	448	UR	124.4	37.3	34.4	33.4
9	672	UR	137.2	41.7	39.1	33.4
10	1344	UR	124.0	53.4	71.4	50.6
SED			15.0	3.5	7.8	3.9
CV, %			18	11	23	13

SED - standard error of the difference between two equally replicated means.
CV - coefficient of variation, %, AN - ammonium nitrate, UR - urea.

Table 6. Treatment means, by harvest for forage yield and N removal, early-spring applied N, Burneyville, OK, 1994.

Trt	N rate kg ha^{-1}	Source	Harvest Date 5-26-94	6-28-94	8-9-94	9-26-94
			Forage yield, Mg ha^{-1}			
1	0	x	4.10	2.23	2.71	2.41
2	0	x	3.94	2.06	2.69	2.24
15	112	AN	5.45	2.37	3.46	2.73
11	672	AN	4.54	2.14	3.79	3.24
12	1344	AN	3.48	3.58	3.64	2.38
16	112	UR	4.80	1.81	3.22	2.34
13	672	UR	5.27	2.34	4.03	3.26
14	1344	UR	3.70	3.02	4.01	3.68
SED			0.63	0.15	0.35	0.22
CV, %			18	20	12	10
			Nitrogen removal, kg ha^{-1}			
1	0	x	75.0	37.9	35.7	34.3
2	0	x	65.6	32.5	36.1	31.1
15	112	AN	121.9	46.4	65.3	43.8
11	672	AN	121.3	50.7	78.7	71.7
12	1344	AN	98.8	77.4	113.2	60.3
16	112	UR	105.8	33.9	49.3	37.3
13	672	UR	138.0	45.8	80.4	67.9
14	1344	UR	103.5	62.9	99.7	86.3
SED			17.6	8.9	13.9	5.2
CV, %			21	23	24	12

SED - standard error of the difference between two equally replicated means.
CV - coefficient of variation, %, AN - ammonium nitrate, UR - urea.

Table 7. Treatment means, by harvest for forage yield and N removal, early-spring applied N, Burneyville, OK, 1995.

Trt	N rate kg ha^{-1}	Source	Harvest Date 5-23-95	6-27-95	8-10-95	9-28-95
			Forage yield, Mg ha^{-1}			
1	0	x	1.24	1.87	2.15	1.96
2	0	x	0.98	1.31	1.85	1.75
15	112	AN	1.90	3.73	2.86	1.82
11	672	AN	2.29	3.82	2.53	1.44
12	1344	AN	1.69	3.83	2.55	1.16
16	112	UR	1.77	2.33	2.14	1.07
13	672	UR	2.74	3.58	2.66	1.58
14	1344	UR	1.64	4.53	3.02	1.48
SED			0.21	0.45	0.29	0.31
CV, %			15	10	15	24
			Nitrogen removal, kg ha^{-1}			
--						
1	0	x	29.6	29.2	26.2	36.3
2	0	x	18.4	19.2	23.8	33.3
15	112	AN	53.0	79.9	45.7	37.3
11	672	AN	74.1	99.3	65.4	40.6
12	1344	AN	50.5	109.0	64.6	33.7
16	112	UR	45.2	38.5	28.2	19.6
13	672	UR	83.3	86.2	53.2	37.6
14	1344	UR	54.2	127.9	74.6	39.5
SED			6.5	7.2	5.7	7.3
CV, %			16	12	15	26

SED - standard error of the difference between two equally replicated means.
CV - coefficient of variation, %, AN - ammonium nitrate, UR - urea.

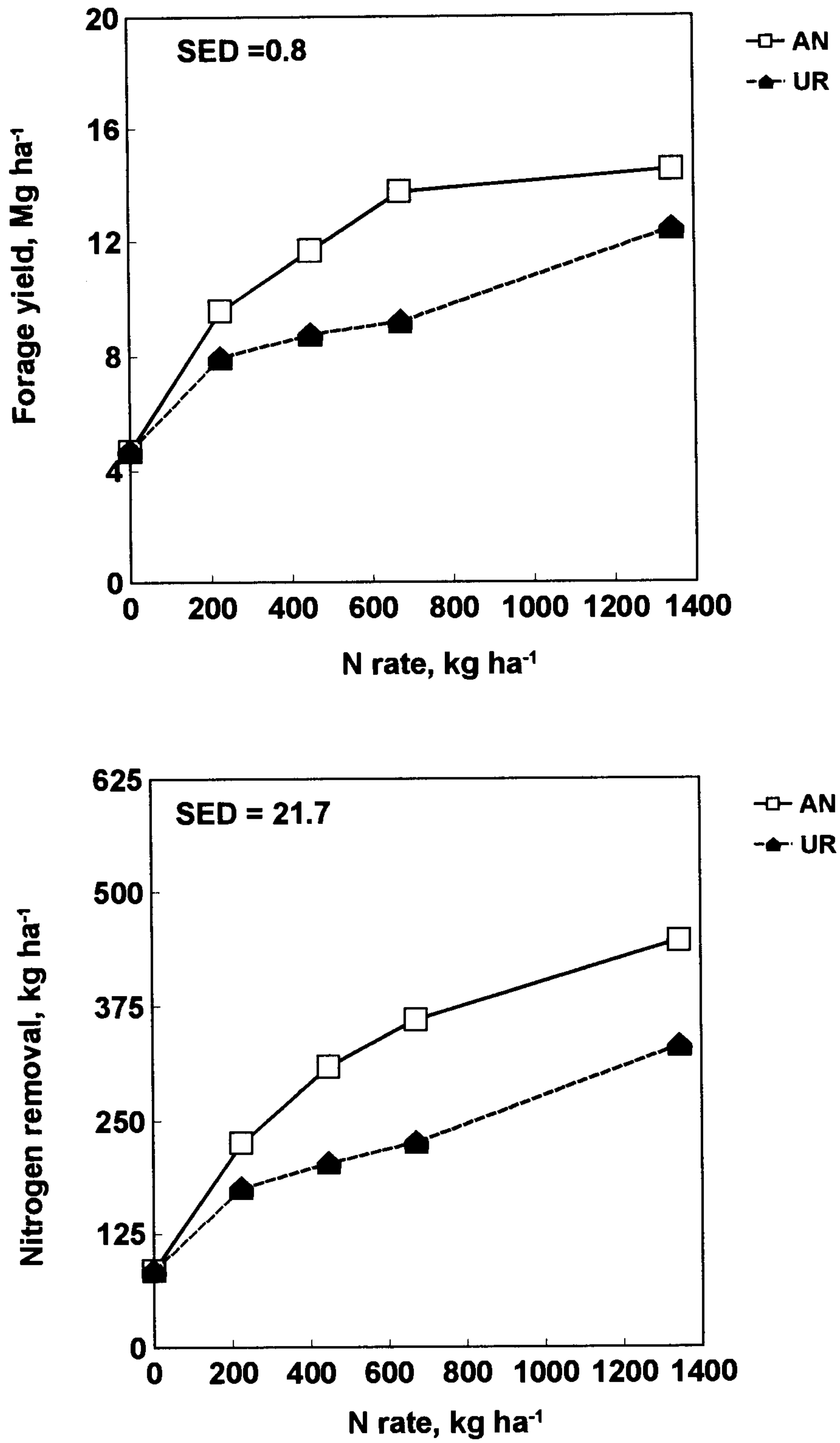
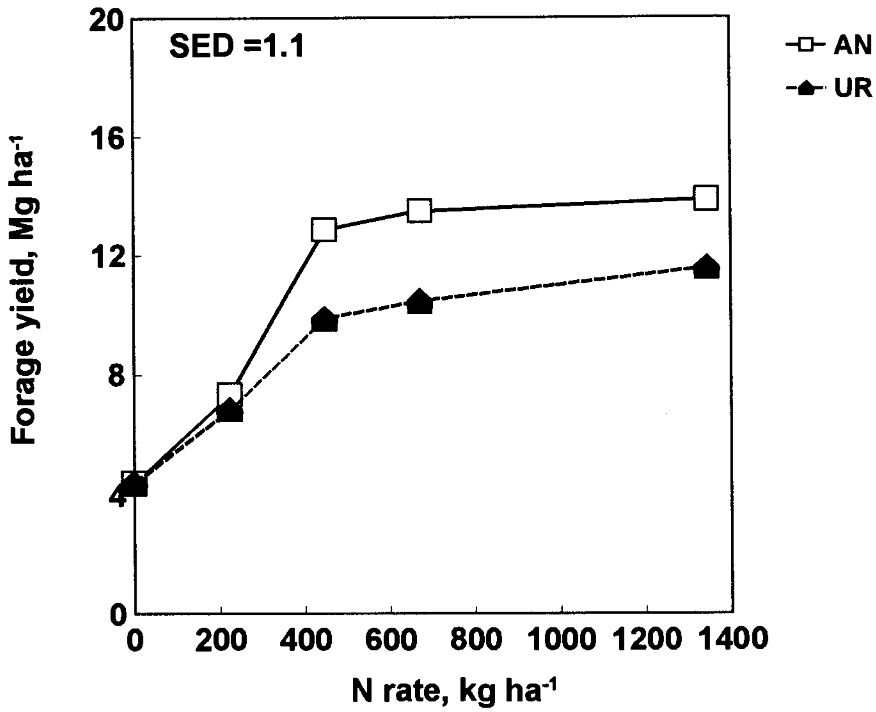


Figure 1. Total bermudagrass forage production and N removal, late-summer applied N, Ardmore, OK, 1993-1994.



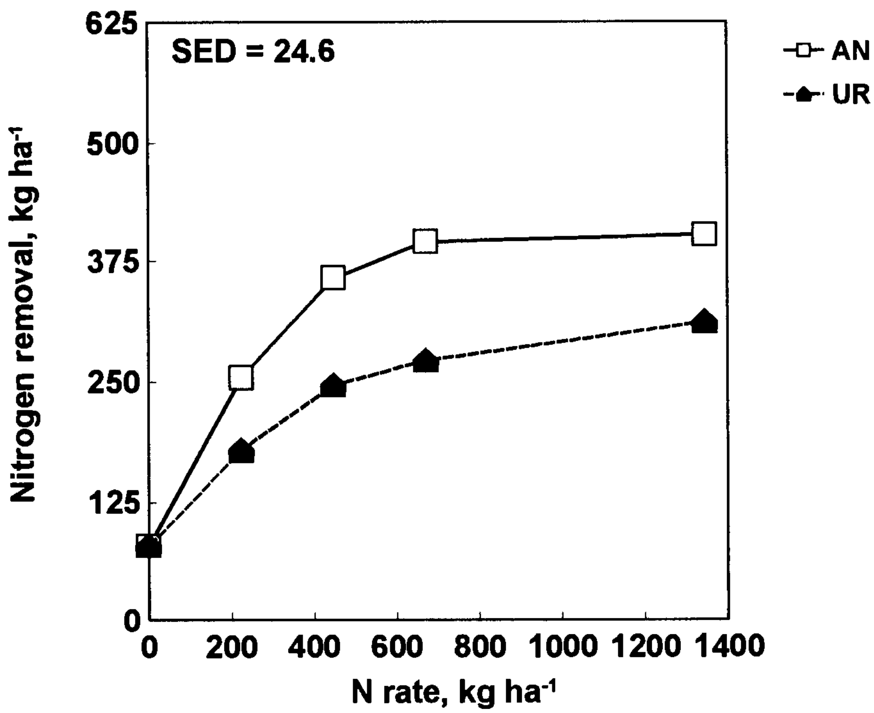


Figure 2. Total bermudagrass forage production and N removal, late-summer applied N, Ardmore, OK, 1994-1995.

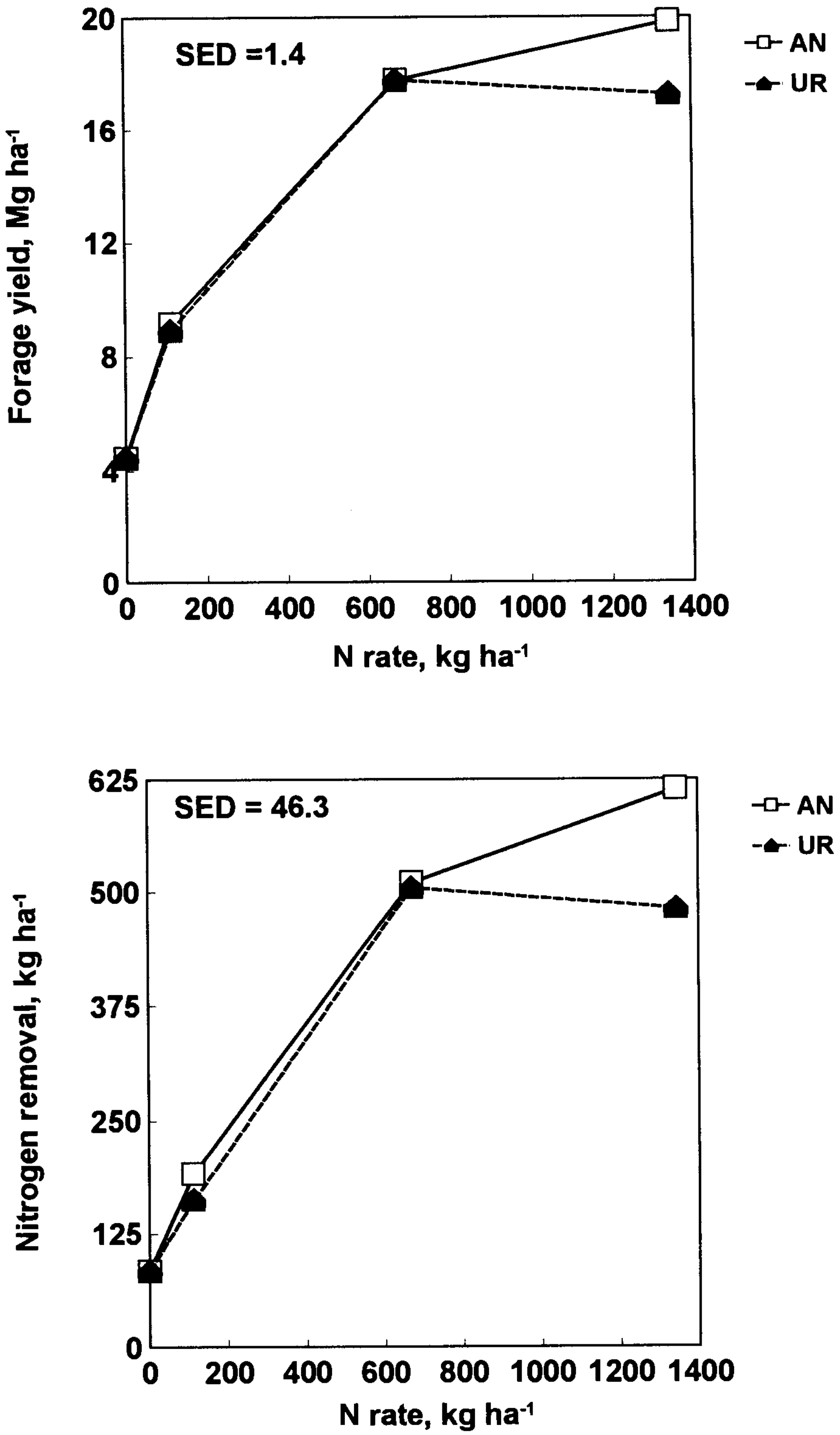
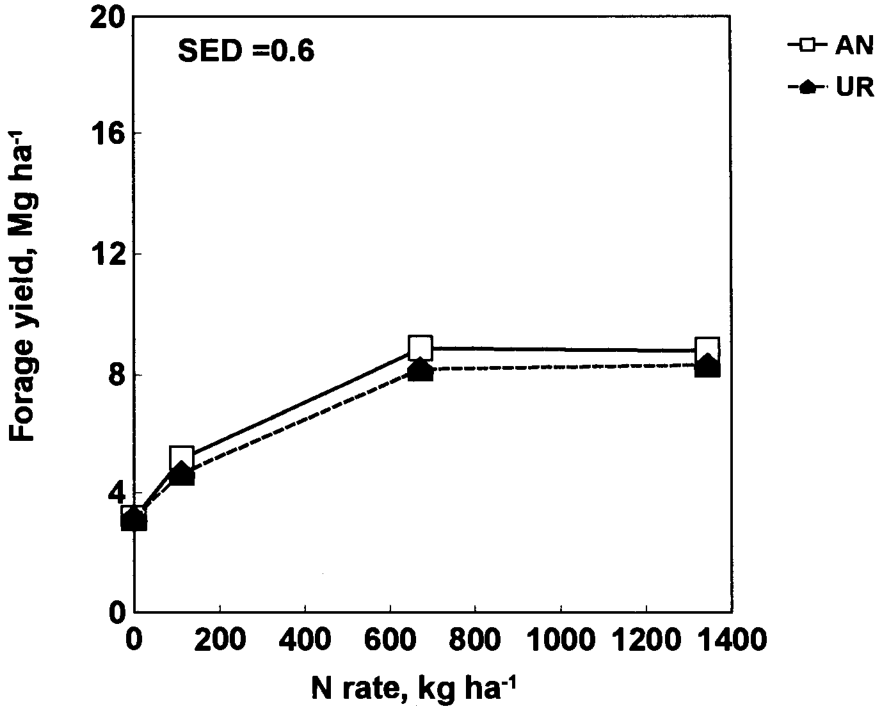


Figure 3. Total bermudagrass forage production and N removal, early-spring applied N, Ardmore, OK, 1994.



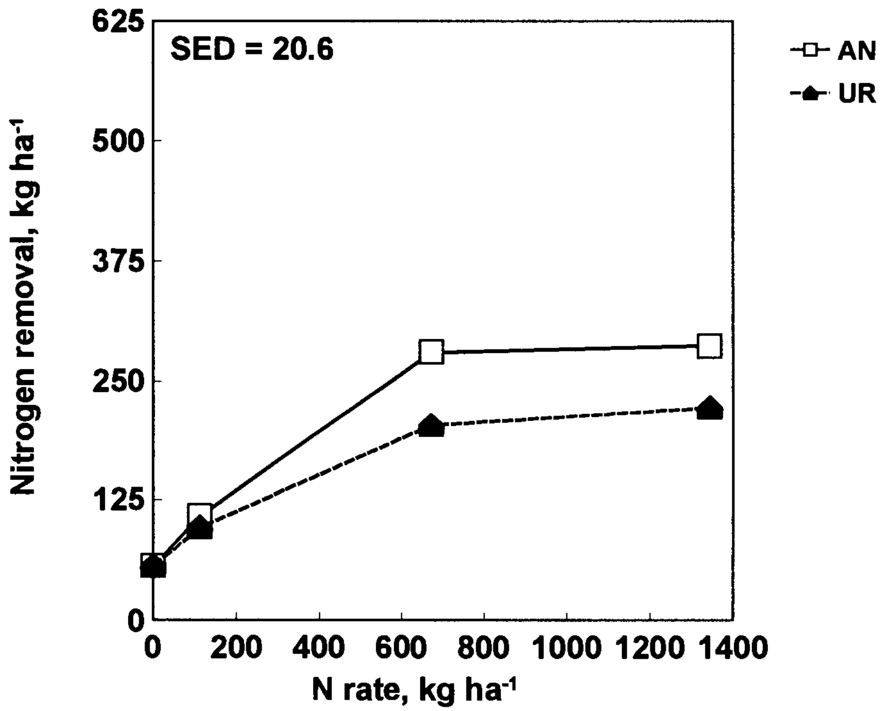
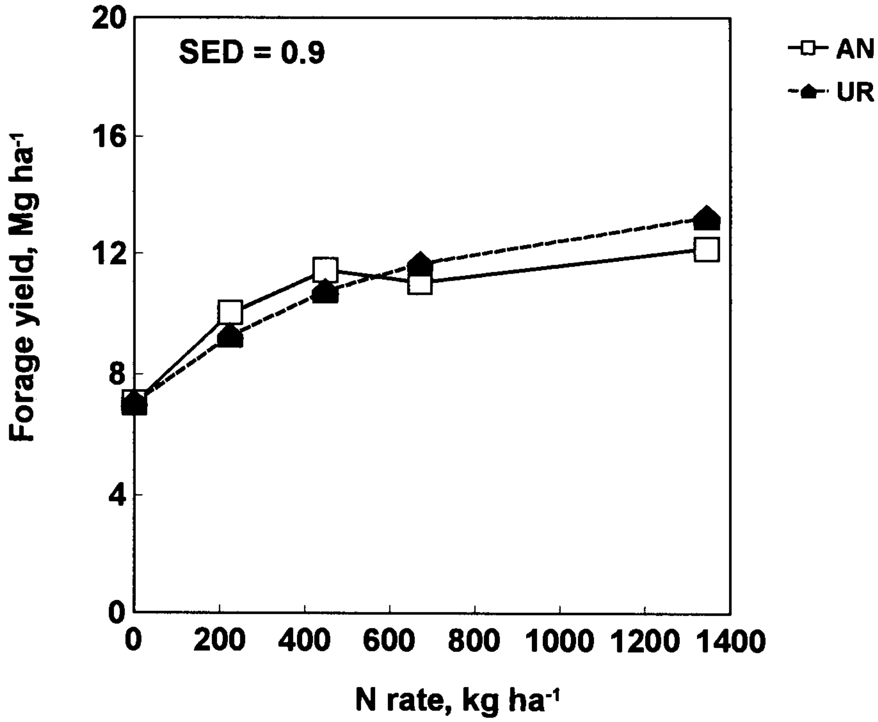


Figure 4. Total bermudagrass forage production and N removal, early-spring applied N, Ardmore, OK, 1995.



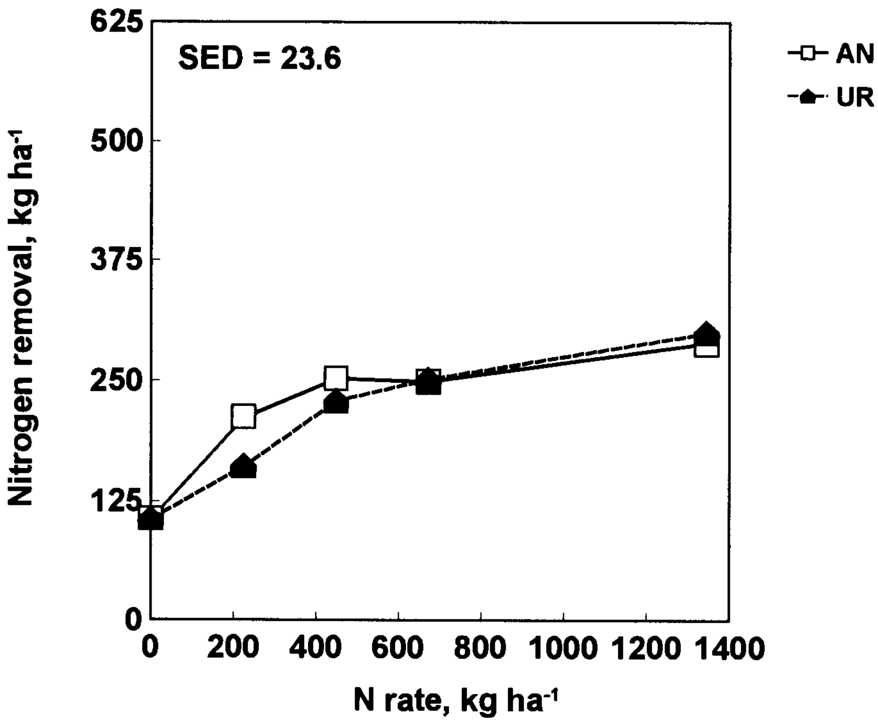
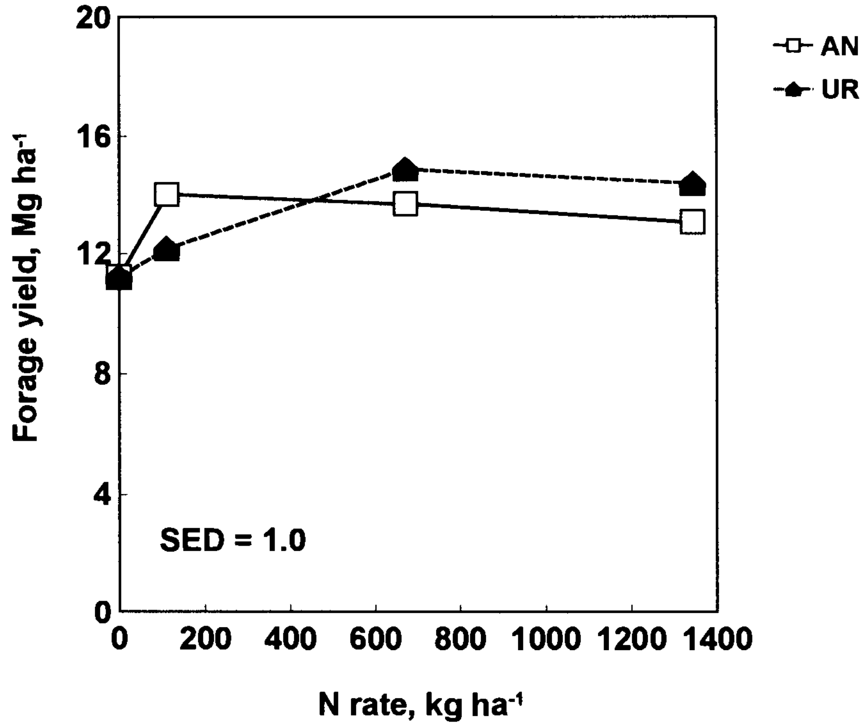


Figure 5. Total bermudagrass forage production and N removal, late-summer applied N, Burneyville, OK, 1994-1995.



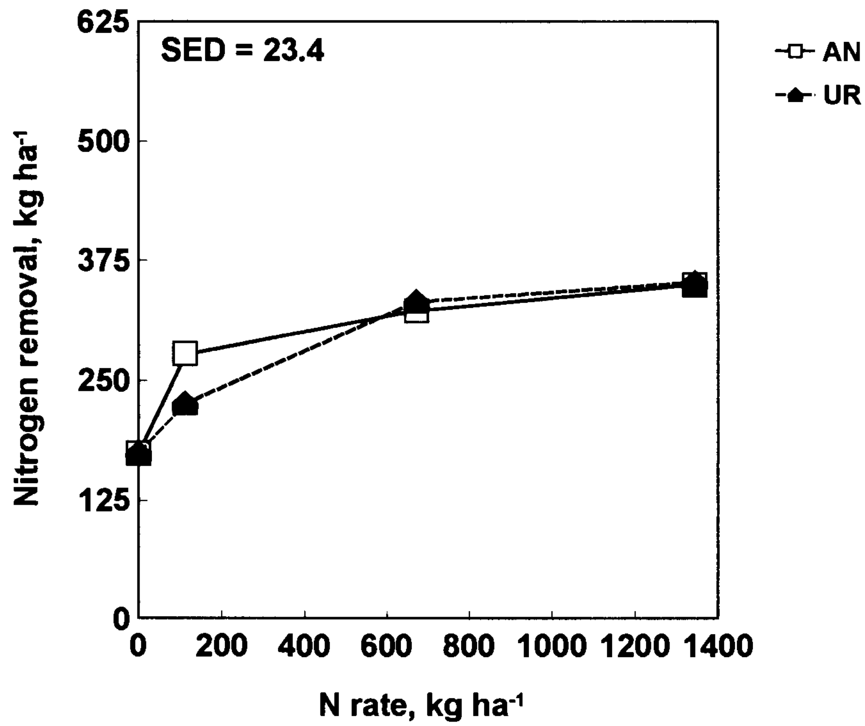
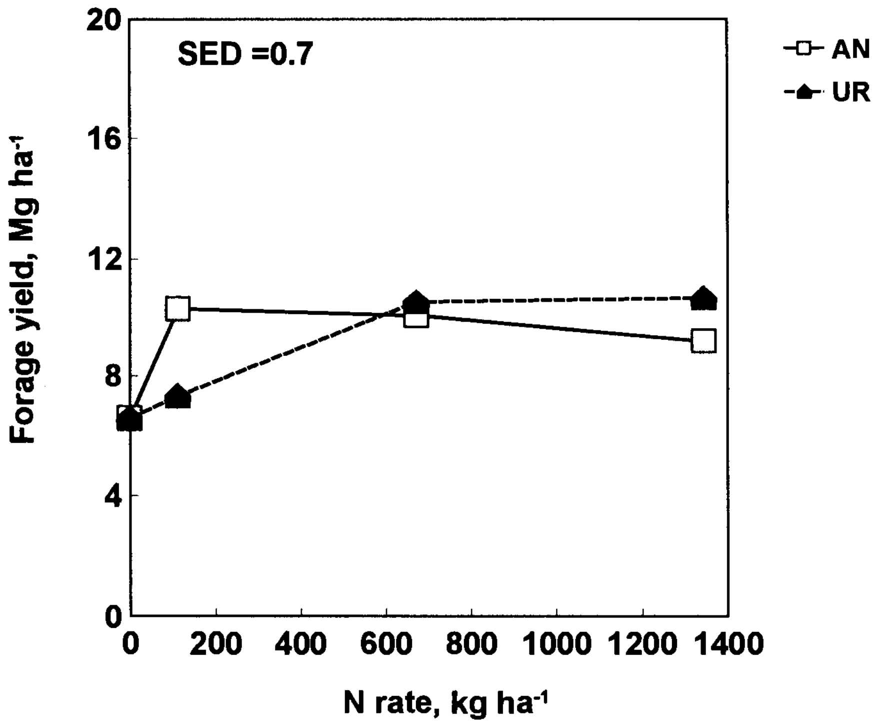


Figure 6. Total bermudagrass forage production and N removal, early-spring applied N, Burneyville, OK, 1994.



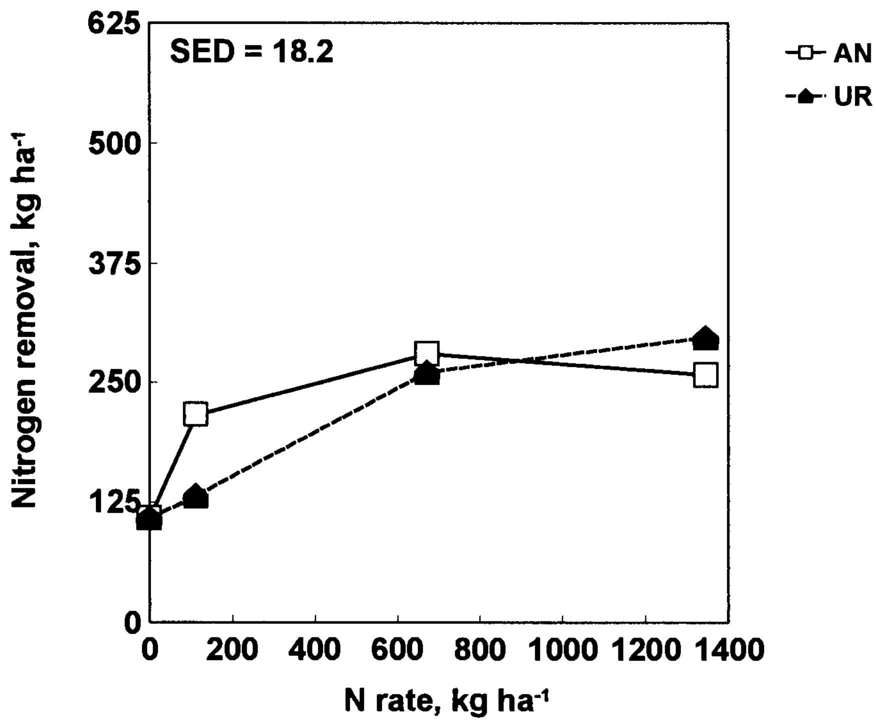


Figure 7. Total bermudagrass forage production and N removal, early-spring applied N, Burneyville, OK, 1995.

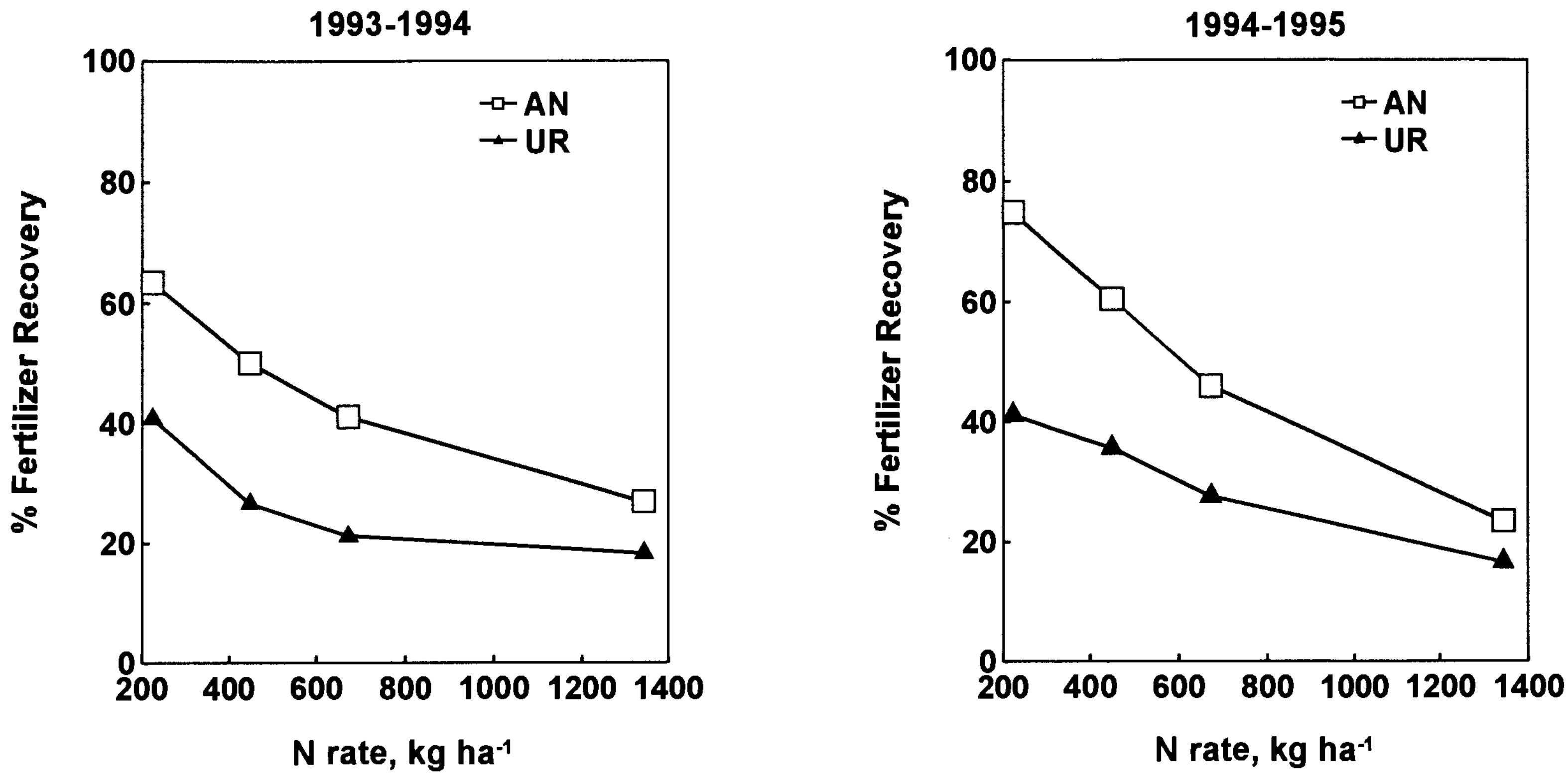
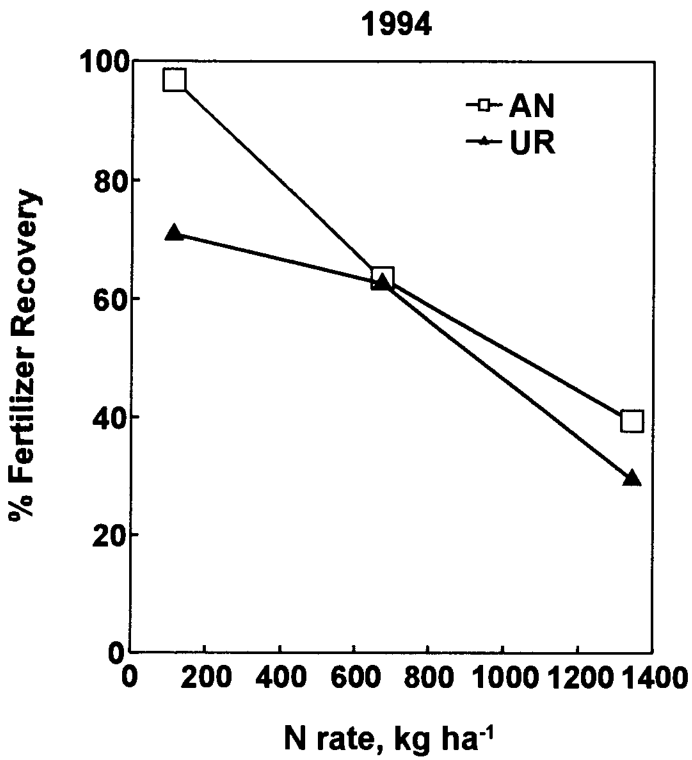


Figure 8. Fertilizer recovery vs nitrogen rates, late-summer applied N, Ardmore, OK, 1993-1994 and 1994-1995.



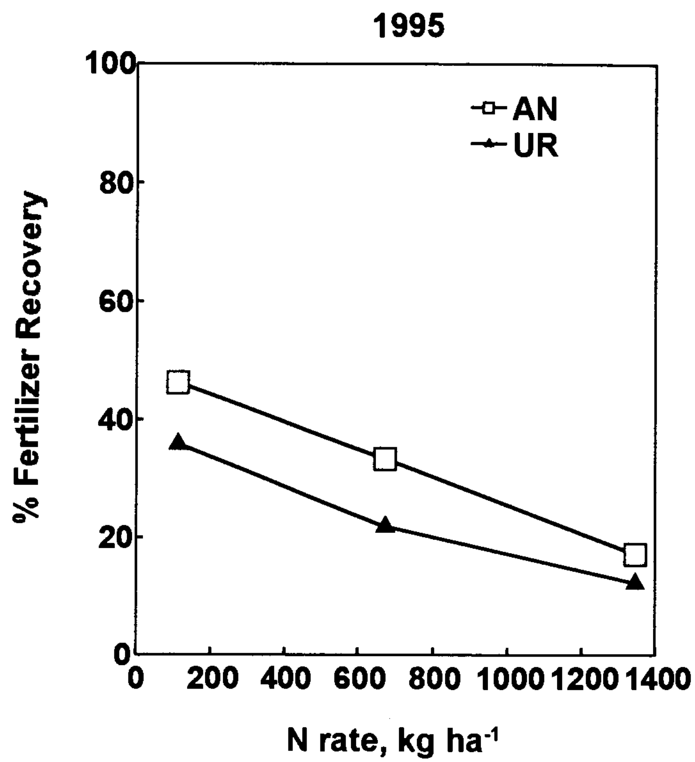


Figure 9. Fertilizer recovery vs nitrogen rate, early-spring applied N, Ardmore, OK, 1994 and 1995.

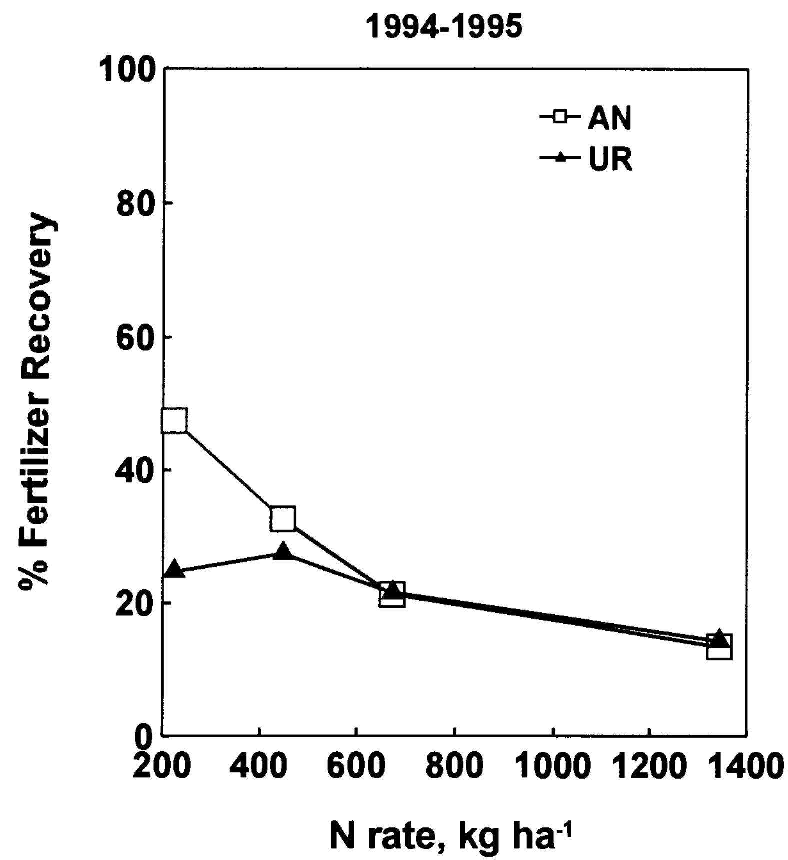


Figure 10. Fertilizer recovery vs nitrogen rate, late-summer applied N, Burneyville, OK, 1995.

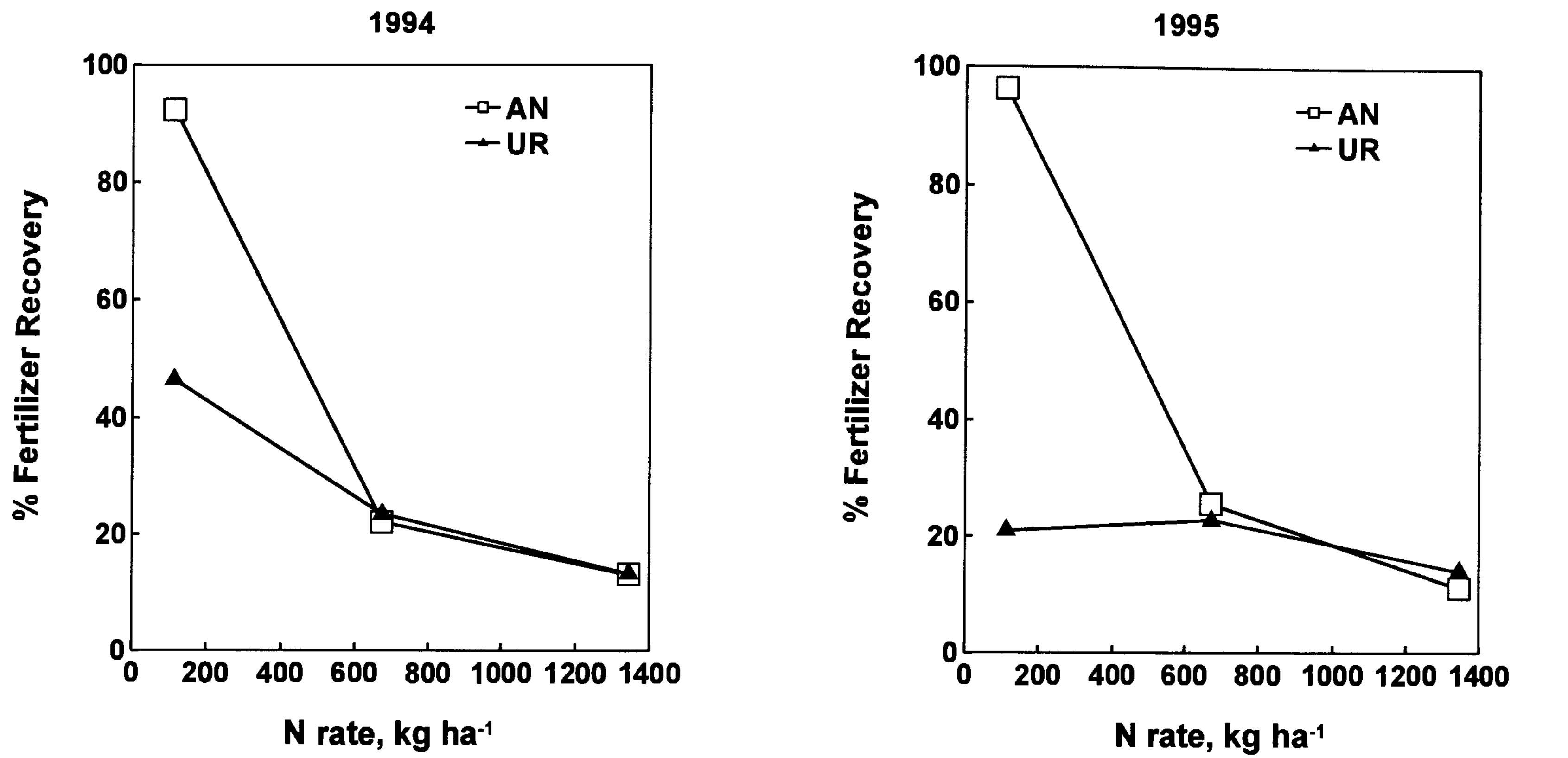


Figure 11. Fertilizer recovery vs nitrogen rate, early-spring applied N, Burneyville, OK, 1994 and 1995.

VITA

Shannon Lynn Taylor

Candidate for the Degree of

Master of Science

Thesis:

BERMUDAGRASS FORAGE YIELD RESPONSE TO HIGH RATES OF APPLIED UREA AND AMMONIUM NITRATE AND THE USE OF SPECTRAL RADIANCE FOR ESTIMATING NITROGEN DEFICIENCIES AND SOIL VARIABILITY

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