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Indiangrass and caucasian bluestem responses to different nitrogen sources and rates in the Ozarks

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Abstract

Alternatives to cool-season grasses are needed for summer forage production on droughty, infertile soils in the Ozarks. The objective of this research was to compare nitrogen (N) sources and application rates for improving forage production, crude protein concentration, and apparent fertilizer N recovery by 'Rumsey' indiangrass [*Sorghastrum nutans* (L.) Nash] and caucasian bluestem [*Bothriochloa caucasia* (Trin.) C.E. Hubbard]. Pure stands of each species were treated with urea, NH_4NO_3, or $(NH_4)_2SO_4$ at 0, 56, 112, and 168 kg N ha^{-1} from 1985-1987. In 1988 the $(NH4)_2SO_4$ treatment was discontinued and in 1990 the N rates were increased to 0, 78, 157, and 235 kg N ha^{-1}. Forage yields, crude protein concentrations or both were greater with NH_4NO_3 compared to urea in 3 out of 6 years for indiangrass and 4 out of 6 years for caucasian bluestem. Indiangrass forage yields increased with increasing N rates up to 168 kg N ha^{-1}. Caucasian bluestem forage yields peaked at 101 kg N ha^{-1} in 1985, 132 kg N ha^{-1} in 1986, 122 kg N ha^{-1} in 1987, 129 kg N ha^{-1} in 1989, and 161 kg N ha^{-1} in 1990. Crude protein concentrations of both species increased linearly with N rates in most years. At the lowest N rate (56 kg N ha^{-1}) caucasian bluestem was more efficient than indiangrass in apparent fertilizer N recovery, but at greater N rates the 2 species were similar in fertilizer N recovery. Forage yield and crude protein concentration of both species responded similarly to $(NH_4)_2SO_4$ and NH_4NO_3.

Key Words: *Sorghastrum nutans* (L.) Nash, *Bothriochloa caucasia* (Trin.) C.E. Hubbard, urea, ammonium-nitrate, ammonium-sulfate, fertilizer N recovery.

Tall fescue (*Festuca arundinacea* Schreb.) and other cool-season grasses are the predominant pasture species in the Ozarks. However, Ozark soils are generally shallow, rocky, and low in available nitrogen (N), phosphorus (P), water holding capacity, and pH. Low soil fertility and water holding capacity, combined with high summer temperatures and periodic drought severely reduce cool-season grass forage production during the summer months.

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Native warm-season grasses grow well in acid soils (Jung et al. 1988, Staley et al. 1991), are more efficient in the use of water (Stout et al. 1986), N (Brown 1978, Brown 1985, Staley et al. 1991), P (Wuenscher and Gerloff 1971, Morris et al. 1982), and maintain growth at higher temperatures (Black 1971) than cool-season grasses. Griffin et al. (1980) compared the quality of big bluestem (*Andropogon gerardii* Vitman) and switchgrass (*Panicum virgatum* L.) to tall fescue and concluded that warm-season grass dry matter intake and dry matter digestibility were equal to or superior to summer or fall harvested tall fescue.

Nitrogen fertilizer can increase forage production and quality in warm-season grasses (Perry and Baltensperger 1979, Hall et al. 1982). However, not all N sources are equally efficient in increasing forage production and quality. Economic and environmental concerns require that the most efficient source and rate of N be evaluated before recommendations are made to livestock producers. Urea is more concentrated, less hazardous to store and transport, and generally cheaper than ammonium nitrate (NH_4NO_3), but is considered to be an inferior source of N for use on pastures (Wilkinson and Langdale 1974). The presence of plant residues may increase ammonia (NH_3) volatilization losses (Hargrove 1988), reducing recovery of N applied as urea. However, Westerman et al. (1983) concluded that urea was an efficient source of N for bermudagrass (*Cynodon dactylon* L.) growing on moderately acid soils in Oklahoma. The low pH of Ozark soils and the practice of burning warm-season grass residues in the spring prior to urea application could reduce NH_3 volatilization losses (Jackson and Burton 1962), making urea an efficient source of N for warm-season grasses under these conditions.

Surface application of soluble sulfate salts may decrease exchangeable aluminum (Al^{3+}) through the formation of Al-hydroxyl-sulfate minerals or precipitation of Al^{3+} as $Al(OH)_3$ following the exchange of SO_4^{2-} for the OH ligand on hydrous oxide surfaces (Mathews and Joost 1989). Sulfate (SO_4^{2-}) salts could improve subsoil fertility and root penetration by reducing exchangeable Al^{3+} toxicity (Mathews and Joost 1989). This suggests that the use of ammonium sulfate [$(NH_4)_2SO_4$] may be an efficient source of N for warm-season grasses on acid soils with high Al content.

Indiangrass [*Sorghastrum nutans* (L.) Nash] and caucasian bluestem [*Bothriochloa caucasia* (Trin.) C.E. Hubbard] grow later into the fall than other warm-season grasses (Waller et al.

1985, Soil Conservation Service 1993) and could be used in the Ozark region to provide high quality forage during the summer months. However, there is no information on appropriate N sources and rates to use in management of these species in the Ozarks. The objective of this research was to identify the best N source and appropriate application rates for improving yield and protein content of indiangrass and caucasian bluestem grown for forage production in the Ozarks.

Materials and Methods

The research was conducted from 1985–1990 using established pure stands of 'Rumsey' indiangrass and caucasian bluestem at the University of Missouri Southwest Center, Mt. Vernon, Mo. The Hoberg silt loam (fine-loamy, siliceous, mesic Mollic Fragiudalf) soil at the study site is gently sloping (2–5%) with a fragipan at a depth of 40–90 cm. The fragipan limits root growth, produces a perched water table from December through March, but reduces soil water availability during periods without rain in the summer. The available water holding capacity in the top 40 cm is low, ranging from 4.1–6.4 cm. Soil pH of the top 15 cm was 5.57 with an organic matter content of 34 mg kg^{-1}. Precipitation was measured at the site with a rain gauge (Table 1).

Table 1. Growing season precipitation at the University of Missouri Southwest Center during April through September 1985-1991 and the 28-year average.

Month	Year 1985	1986	1987	1988	1989	1990	28-year average
				(cm)			
April	7.4	10.8	3.2	8.2	0.8	7.3	10.3
May	11.5	5.2	9.8	5.3	12.3	36.5	11.5
June	19.7	12.6	7.1	12.6	12.0	12.0	13.0
July	4.2	2.9	9.3	10.7	19.6	5.8	7.2
August	23.0	10.9	14.3	18.2	9.5	7.8	10.7
September	8.1	27.0	6.0	14.6	9.9	13.3	11.8
Total	73.9	69.4	49.8	62.1	64.1	82.7	64.5

Each stand was divided into 3 blocks of 12 plots (3 × 6 m) and each block was treated with a factorial combination of urea, NH_4NO_3, or $(NH_4)_2SO_4$ at 4 rates equivalent to 0, 56, 112, and 168 kg N ha^{-1}. After 1987 the $(NH_4)_2SO_4$ treatment was discontinued and comparisons were limited to urea and NH_4NO_3 at the same rates. In 1990, the N rates were increased to 0, 78, 157, and 235 kg N ha^{-1}. The stands were burned in April each year and the N treatments applied 4 weeks later in mid to late May. All plots received spring applications of 22 kg P ha^{-1} and 112 kg K ha^{-1} in 1986 and 1987, and 33 kg P ha^{-1} and 112 kg K ha^{-1} in 1988–1990, to replace P and K removed in the forage harvests.

Forage was harvested from a 1 × 2 m strip in the center of each plot at a 5 cm cutting height using a flail type harvester. Fresh forage weights were measured in the field and a subsample collected from each plot, dried at 65°C for 48 hours in a forced-air oven, and weighed to determine percentage dry matter. The dried subsamples were ground in a Wiley mill to pass a 1-mm screen and analyzed for Kjeldahl-N (Bremner and Mulvaney 1982) and crude protein concentrations were estimated (N × 6.25). Apparent fertilizer N recovery was calculated using the formula of Caswell and Godwin (1984). Indiangrass was harvested on 19 July 1985, 26 June 1986, 25 June 1987, 16 August 1988, 4 August 1989, and 7 July 1990. In 1985–1987, caucasian bluestem was harvested on the same dates as indiangrass. In 1988–1990, an initial caucasian bluestem harvest was taken on 5 July 1988, 6 July 1989, and 9 July 1990 and regrowth was harvested on 16 August 1988, 20 September 1989, and 30 August 1990.

Statistical Analysis

Data were analyzed separately for each species and harvest using analysis of variance, and fertilizer sources were compared using preplanned orthogonal contrasts. Contrasts compared forage responses to urea versus the average of NH_4NO_3 and $(NH_4)_2SO_4$, and NH_4NO_3 versus $(NH_4)_2SO_4$. Plant responses to the different N rates were analyzed using orthogonal polynomials for significant linear and quadratic responses (Steel and Torrie 1980). Year effects were treated as repeated measures in time and analyzed using a split-plot design described by Steel and Torrie (1980). Analysis over years was performed for the years 1985 through 1987 and 1988–1989. Data from 1990 were analyzed separately because different N rates were used. Treatment differences were considered significant at the 0.05 probability level.

Results

Indiangrass

Forage Yields

Indiangrass forage yields varied significantly with years, reflecting yearly differences in growing season precipitation (Table 1) and harvest dates. Year by N source and year by N rate interactions were not significant in 1985–1987 or 1988–1989. Indiangrass forage yields did not differ with N source in 1985–1987, and the N source by rate interaction was not significant for these 3 years. Within years, indiangrass forage yields increased linearly with N rate in 1985, but increased curvilinearly with N rate in 1986 and 1987 (Fig. 1). May and June precipitation was below normal in both 1986 and 1987 (Table 1), which may have limited forage production at the higher N rates, producing the curvilinear yield response.

Indiangrass forage yields in 1988 (Fig. 1) and 1989 (Fig. 2) were the greatest for the 6 year period of study. In 1988 and 1989, indiangrass was harvested in August and growing season precipitation prior to harvest was near the long term average (Table 1). Good growing season precipitation and a delay in the forage harvest combined to produce high forage yields. In 1988, indiangrass forage yields did not differ between NH_4NO_3 and urea, and yields increased curvilinearly with N rate. In 1989 and 1990, indiangrass forage yields increased linearly with increasing rate of urea, but increased curvilinearly with increasing rate of NH_4NO_3 (Fig. 2). At intermediate N rates, indiangrass produced 1,300–1,550 kg ha^{-1} more forage when treated with NH_4NO_3 compared to urea, but produced similar yields at the highest rate of both N sources.

Crude Protein Concentrations

Indiangrass crude protein concentrations increased linearly with N rate in 1985 and 1986, but increased curvilinearly with N rate in 1987. In addition, the magnitude of the linear increase in

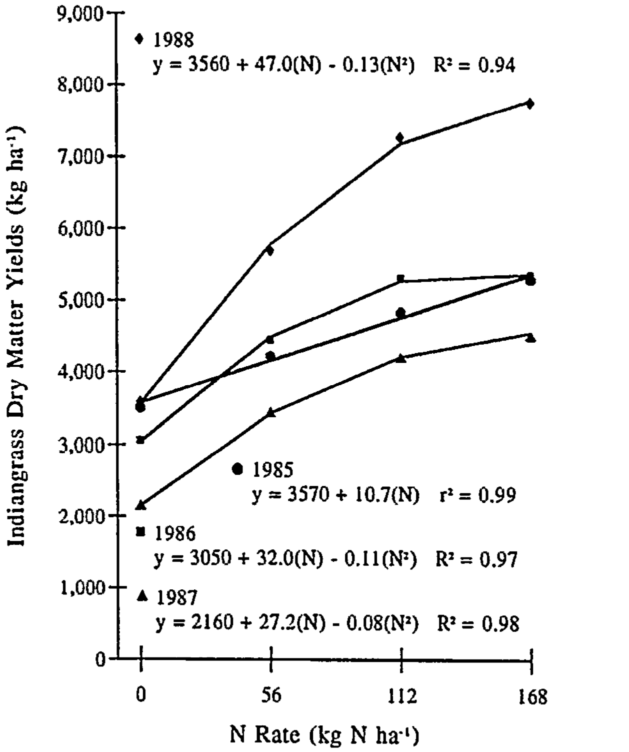

Fig. 1. Indiangrass forage dry matter yields averaged over N sources (urea, NH_4NO_3, and $(NH_4)_2SO_4$) at 4 application rates from 1985-1988.

crude protein concentrations with N rate was greater in 1986 than in 1985, causing an N rate by year interaction (Fig. 3). In 1985, NH_4NO_3 and $(NH_4)_2SO_4$ produced an additional 0.98–1.59% (absolute) crude protein compared to urea at all N rates (Fig. 3). In 1986 and 1987, indiangrass crude protein concentrations did not differ significantly between the 3 N sources (Fig. 3). In 1988 and 1990, indiangrass crude protein concentrations increased linearly with N rate, but the increase was greater for NH_4NO_3 than urea, causing a significant N source by rate interaction (Fig. 4). At low N rates (56 kg N ha^{-1} in 1988 and 78 kg ha^{-1} in 1990), indiangrass crude protein concentrations were similar for NH_4NO_3 and urea. However, at rates greater than 112 kg N ha^{-1}, crude protein concentrations were 0.38–1.50% greater with NH_4NO_3 than urea.

In 1989, indiangrass crude protein concentrations were low at all N rates, with no difference between NH_4NO_3 and urea (Fig. 4). In 1989, abundant May, June, and July precipitation (Table 1) produced the greatest indiangrass forage yields for the 6 year period. The abundant growth may have diluted tissue N levels and high precipitation amounts may have leached fertilizer N from the soil, reducing N uptake.

Apparent Fertilizer N Recovery

Apparent fertilizer N recovery by indiangrass varied significantly with years (Table 2). However, the year by N source and year by N rate interactions were not significant for apparent fertilizer N recovery. In 1985, 4–18% more fertilizer N was recovered by indiangrass fertilized with NH_4NO_3 and $(NH_4)_2SO_4$ compared to urea. Apparent fertilizer N recovery by indiangrass was not significantly different between the 2 NH_4^+ sources. In 1986, apparent fertilizer N recovery by indiangrass was not significantly different between the N sources or rates. In 1987, apparent fertilizer N recovery decreased linearly with increasing N rate, but N recovery did not differ with N source. In 1988–1990, indiangrass recovered 4.3–23.9% more fertilizer N from NH_4NO_3 than from urea. In addition, in 1990 apparent fertilizer N recovery decreased

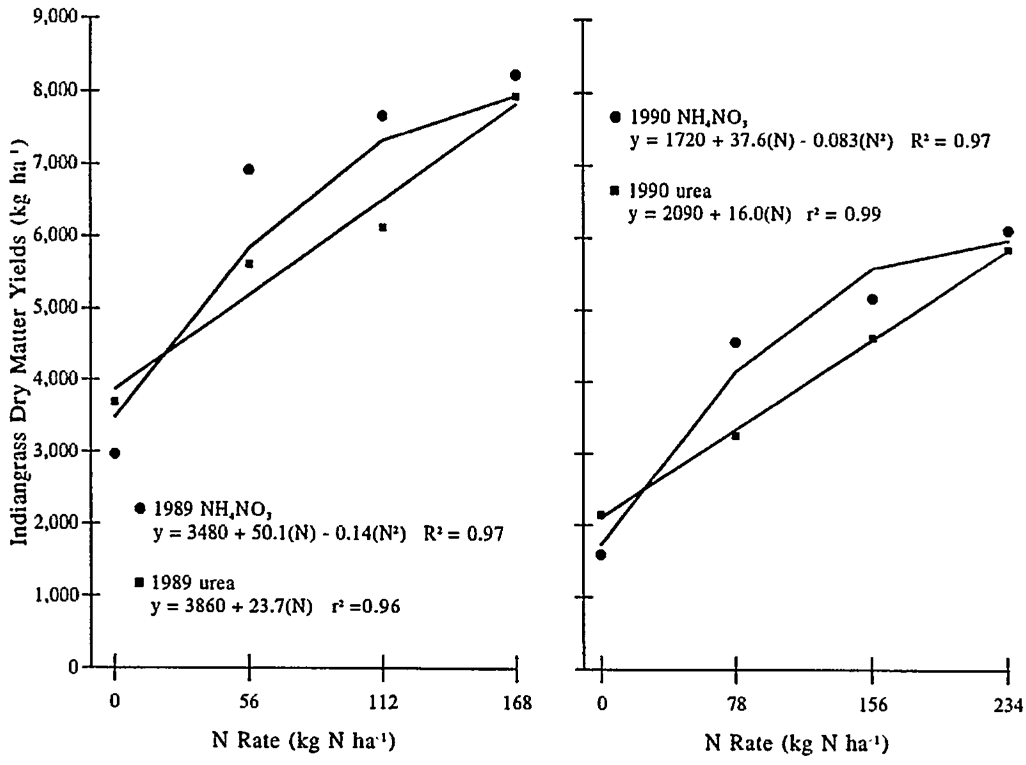

Fig. 2. Indiangrass forage dry matter yields treated with urea or NH_4NO_3 at 4 application rates in 1989 and 1990.

Table 2. Nitrogen uptake in unfertilized control plots and apparent fertilizer N recovery by indiangrass during 1985-1990 when N was applied as urea (U), NH_4NO_3 (AN), or $(NH_4)_2SO_4$ (AS).

N rate	Year						6-year
	1985	1986	1987	1988	1989	1990[1]	average
N uptake in unfertilized control plots							
	---------------- ($kg\ ha^{-1}$) ----------------						
	31	30	20	29	20	17	25
Apparent fertilizer N recovery							
	---------------- (%) ----------------						
Urea							
56	19	42	43	24	29	30	31
112	19	49	45	42	29	28	35
168	24	42	39	32	31	33	33
Ammonium nitrate							
56	37	51	48	48	39	53	46
112	35	51	41	50	40	41	43
168	27	38	36	41	35	37	36
Ammonium sulfate							
56	38	47				50	45
112	36	51				43	43
168	9	40				34	34
Analysis of variance							
	---------------- (P>F) ----------------						
N source	0.01	NS	NS	0.05	0.05	0.01	
AN + AS vs U	0.01	NS	NS	—	—	—	
AN vs AS	NS	NS	NS	—	—	—	
N rate	NS	NS	0.05	NS	NS	NS	
N linear	NS	NS	0.05	NS	NS	NS	
N quadratic	NS	NS	NS	NS	NS	NS	
N source × rate	NS	NS	NS	NS	0.05		

[1]N rates in 1990 were 78, 157, and 235 kg N ha^{-1}.

with increasing rate of NH_4NO_3, but changed little with increasing rate of urea (Table 2), resulting in a significant N source by rate interaction. Other than the linear decrease in apparent fertilizer N recovery with increasing N rate in 1987 and the N source by rate interaction in 1990, N rate had little effect on apparent fertilizer N recovery.

Fertilizer N recovery by indiangrass in our study was lower than the values of 52–66% reported by McMurphy et al. (1975) in Oklahoma. However, apparent fertilizer N recovery was 2-fold greater than values calculated from data by Jung et al. (1990) for indiangrass treated with 75 kg N ha^{-1} in Pennsylvania. Nitrogen uptake by indiangrass on control plots in our study averaged 24.5 kg ha^{-1} and varied considerably with years (Table 2), but was lower than the 40 kg N ha^{-1} reported by Jung et al. (1990) for indiangrass harvested at head emergence in Pennsylvania. Soils at our site and the Pennsylvania site were similar, but the longer growing season in southern Missouri compared to Pennsylvania may in part explain the differences in apparent fertilizer N recovery.

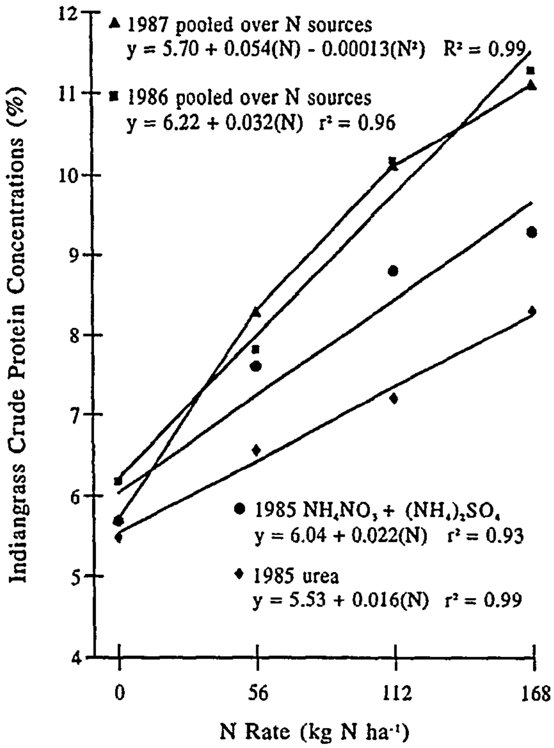

Fig. 3. Crude protein concentrations of indiangrass treated with urea, NH_4NO_3 or $(NH_4)_2SO_4$ at 4 application rates in 1985, and averaged over N sources in 1986 and 1987.

Caucasian Bluestem

Forage Yields

Caucasian bluestem yields varied significantly with years in 1985–1987 and 1988–89, reflecting differences in growing season precipitation (Table 1) and harvest dates. In addition, in 1988–1989 the year by N rate interaction was significant for both the first and regrowth harvest forage yields. The year by N source interaction was not significant in 1985–1987 or for either harvest in 1988-1989.

In 1985, caucasian bluestem forage yields were significantly greater with NH_4NO_3 and $(NH_4)_2SO_4$ than urea at all N rates (Table 3). Caucasian bluestem forage yields increased linearly with increasing rates of $(NH_4)_2SO_4$, but increased curvilinearly with increasing rates of NH_4NO_3 and urea, with a 1,000 kg ha^{-1} yield decrease at the highest N rate. Campbell et al. (1977) reported decreased dry matter accumulation by spring wheat (*Triticum aestivum* L.) with rates of N exceeding 61.5 kg N ha^{-1}. They concluded that greater rates of N stimulated excessive growth early in the spring which increased transpiration and more rapid use of soil moisture. As a result, plants suffered greater levels of moisture stress during extended periods between rains, depressing dry matter production.

In 1985, caucasian bluestem forage yields peaked at 5,450 kg ha^{-1} at 101 kg N ha^{-1} with NH_4NO_3 and 4,720 kg ha^{-1} at the same N rate with urea. In 1986 and 1987, caucasian bluestem forage yields increased curvilinearly with N rate, with no difference between the N sources both years (Table 3). A maximum yield of 5,590 kg forage ha^{-1} was reached at 132 kg N ha^{-1} in 1986 and a yield peak of 5,690 kg forage ha^{-1} was attained at 122 kg N ha^{-1} in

Table 3. Forage dry matter yields and crude protein concentrations of caucasian bluestem treated with NH_4NO_3 (AN), $(NH_4)_2SO_4$ (AS) or urea (U) at 4 rates.

	1985			1986			1987		
N rate	NH_4NO_3	$(NH_4)_2SO_4$	urea	NH_4NO_3	$(NH_4)_2SO_4$	urea	NH_4NO_3	$(NH_4)_2SO_4$	urea
Dry matter yields									
					(kg ha^{-1})				
0	2440	2510	2420	3110	2880	2490	3450	3540	3550
56	5000	4450	4200	5170	4890	4660	5880	5570	5530
112	5280	4830	4730	5760	4940	5270	5790	5870	5470
168	4250	5940	3690	5610	5530	5240	5810	6230	5410
Analysis of variance									
					(P>F)				
N source		0.05			NS			NS	
AN + AS vs U		0.05			NS			NS	
AN vs AS		NS			NS			NS	
N rate		0.01			0.01			0.01	
N linear		0.01			0.01			0.01	
N quadratic		0.01			0.01			0.01	
N source × rate		0.05			NS			NS	
Crude protein concentrations									
					(%)				
0	5.5	5.7	5.9	5.7	5.7	6.0	5.3	5.2	5.0
56	6.3	6.0	5.3	8.0	8.0	7.1	7.3	7.8	7.1
112	7.6	8.4	7.1	9.9	10.3	9.0	9.0	8.8	8.1
168	8.8	8.3	8.8	12.8	11.8	10.3	8.5	10.0	9.1
Analysis of variance									
					(P>F)				
N source					NS	0.01	NS		
AN + AS vs U		NS			0.01			NS	
AN vs AS		NS			NS			NS	
N rate		0.01			0.01			0.01	
N linear		0.01			0.01			0.01	
N quadratic		NS			NS			0.01	
N source × rate		NS			0.01			NS	

1987.

In 1988, caucasian bluestem forage yields from the first harvest increased linearly with N rate, and did not differ significantly between NH_4NO_3 and urea. However, with the regrowth forage harvest caucasian bluestem forage yields increased curvilinearly with N rate, and the magnitude of the increase was greater for NH_4NO_3 than urea at intermediate N rates, causing an N source by rate interaction (Table 4). Caucasian bluestem forage yields from the regrowth harvest were 2,450 to 2,600 kg ha^{-1} greater than forage yields from the first harvest. In 1988, April precipitation was 2.1 cm below normal, and May precipitation was less than half of normal (Table 1), reducing first harvest yields. In contrast, July precipitation was 3.5 cm and August precipitation 7.5 cm above normal (Table 1), stimulating high regrowth forage yields (Table 4).

In 1989, May and June precipitation was near normal, and caucasian bluestem forage yields were the greatest of the 6 year period. First harvest forage yields increased curvilinearly with N rate, but did not differ significantly between NH_4NO_3 and urea. A maximum forage yield of 7,550 kg ha^{-1} was attained with 129 kg N ha^{-1}. In 1989, July precipitation was 12.4 cm above normal, delaying the regrowth harvest until 20 September, and resulting in the greatest caucasian bluestem regrowth yields for the 3 year period. Regrowth forage yields increased linearly with N rate, with no difference between NH_4NO_3 and urea.

In 1990, first harvest and regrowth forage yields were low, with no significant difference between NH_4NO_3 and urea (Table 4). First harvest yields increased curvilinearly with N rate, in which forage yields peaked at 3,000 kg ha^{-1} with 161 kg N ha^{-1}. Cool spring temperatures and excessive precipitation in 1990 may have reduced first harvest forage yields. The site received 36.5 cm precipitation (25 cm above normal) in May 1990 (Table 1). Inhibition of percolation by the fragipan caused saturated soil conditions which persisted for an extended period of time. Caucasian bluestem does not tolerate saturated soils (Soil Conservation Service 1993).

Caucasian bluestem regrowth yields were also low in 1990. This may reflect slow recovery from the saturated soil conditions in the spring, or below normal July and August precipitation (Table 1). Regrowth forage yields increased linearly with N rate, with no difference between NH_4NO_3 and urea.

Crude Protein Concentrations

In 1985–1987, caucasian bluestem crude protein concentrations increased linearly with N rate in 1985 and 1986, but increased curvilinearly with N rate in 1987. In addition, the magnitude of the linear increase in caucasian bluestem crude protein concentrations was greater in 1986 than in 1985, causing a significant year

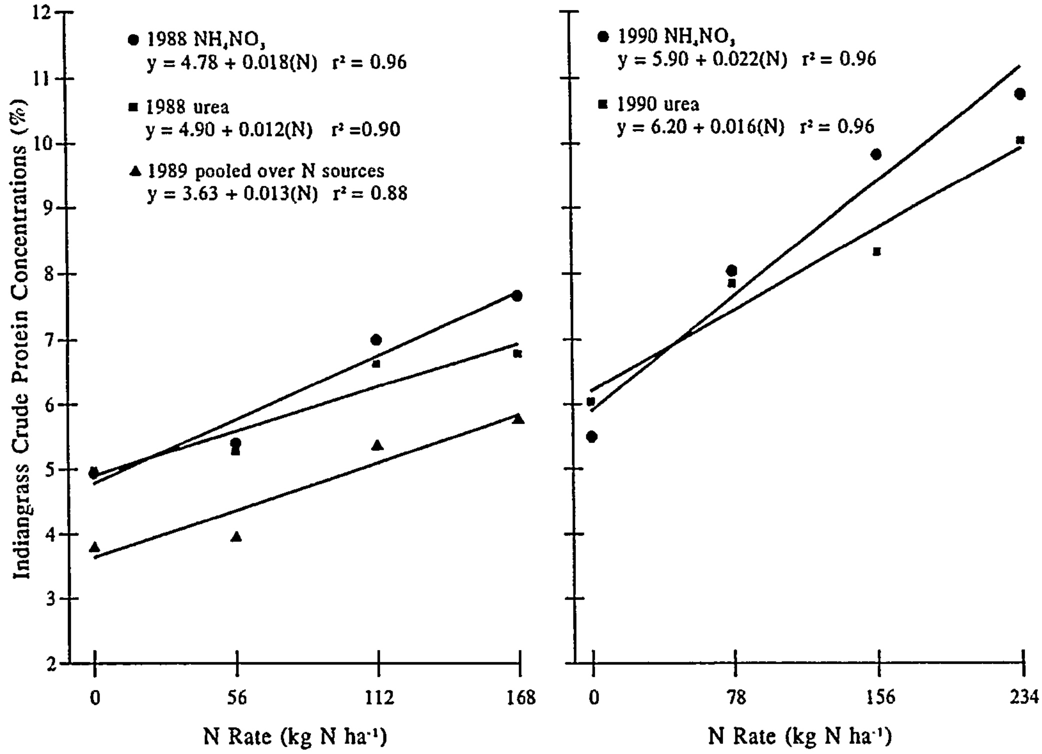

Fig. 4. Indiangrass crude protein concentrations treated with urea or NH_4NO_3 at 4 application rates in 1988-1990.

by N rate interaction. The year by N source interaction was not significant.

In 1985, caucasian bluestem crude protein concentrations did not differ significantly between the 3 N sources (Table 3). In 1986, caucasian bluestem crude protein concentrations increased linearly with N rate, and the magnitude of the increase was greater with NH_4NO_3 and $(NH_4)_2SO_4$ than urea, causing an N source by rate interaction (Table 3). There was no difference between the 2 NH_4^+ sources. In 1987, caucasian bluestem crude protein concentrations increased curvilinearly with N rate, and did not differ significantly between the 3 N sources (Table 3).

In 1988, caucasian bluestem crude protein concentrations from the first harvest increased linearly with N rate, and were greater with NH_4NO_3 than urea. However, with the regrowth harvest in 1988, caucasian bluestem crude protein concentrations increased curvilinearly with N rate, and the increase was greater with NH_4NO_3 than urea, causing an N source by rate interaction (Table 4). This suggests that with the regrowth harvest in 1988, NH_4NO_3 provided a greater residual N response than urea.

Caucasian bluestem crude protein concentrations for the first and regrowth harvests in 1989 were the lowest of the 6 year period. Crude protein concentrations did not differ significantly between NH_4NO_3 and urea for either harvest. Caucasian bluestem crude protein concentrations increased linearly with increasing N rate for the first harvest, but increased curvilinearly with the regrowth harvest (Table 4). The abundant precipitation in 1989 stimulated the greatest caucasian bluestem forage yields for the 6 year period, which may have diluted crude protein concentrations and leached fertilizer N from the soil.

In 1990, caucasian bluestem crude protein concentrations from the first harvest increased linearly with N rate, and were significantly greater for NH_4NO_3 than urea (Table 4). Caucasian bluestem crude protein concentrations for the 1990 regrowth harvest increased linearly with N rate, and the magnitude of the increase was greater for NH_4NO_3 than urea, causing an N source by rate interaction.

Apparent Fertilizer N Recovery

Nitrogen uptake by caucasian bluestem in untreated control plots varied from a high of 29 kg N ha^{-1} in 1987 to a low of 11 kg N ha^{-1} in 1990 (Table 5). These values were lower than an average value of 34.5 kg N ha^{-1} reported for unfertilized caucasian bluestem growing on droughty soils in Pennsylvania (Jung et al. 1990), but greater than an average value of 7 kg ha^{-1} reported for old world bluestem (*Bothriochloa ischaemum* L.) in western Oklahoma (Berg 1990). However, in western Oklahoma, old world bluestem forage yields averaged only 800 kg ha^{-1} without N fertilization (Berg 1990) compared to 2,730 kg ha^{-1} for caucasian bluestem in this study.

Apparent fertilizer N recovery by caucasian bluestem during 1985 through 1987 was significantly greater with NH_4NO_3 and $(NH_4)_2SO_4$ than urea, but did not differ significantly between the 2 NH_4^+ sources (Table 5). In 1985, apparent fertilizer N recovery declined linearly with increasing rate of $(NH_4)_2SO_4$, but showed no consistent change with increasing rates of NH_4NO_3 and urea, causing an N source by rate interaction (Table 5). In 1986 and 1987, apparent fertilizer N recovery declined linearly with increasing N rate, with no significant difference between the 3 N sources.

In 1988, apparent fertilizer N recovery by caucasian bluestem did not differ significantly between N sources or rates (Table 5). In 1989, apparent fertilizer N recovery by caucasian bluestem

Table 4. Forage dry matter yields and crude protein concentrations of caucasian bluestem treated with NH_4NO_3 (AN) or urea (U) at 4 rates.

	1988				1989				1990[1]			
	first		regrowth		first		regrowth		first		regrowth	
N rate	NH_4NO_3	urea	NH_4NO_3	urea	NH_4NO_3	urea	NH_4NO_3	urea	NH_4NO_3	urea	NH_4NO_3	urea
Dry matter yields												
	(kg ha^{-1})											
0	490	690	2040	2370	1750	1870	1860	1620	400	460	730	880
56	1320	1400	4010	3540	5570	6740	2290	2740	2060	2470	1200	930
112	1560	1930	4510	3930	7100	6980	4220	4510	2780	3330	1460	1320
168	2510	2270	4790	5070	7020	7300	6000	5480	2270	2620	1660	1920
Analysis of variance												
	(P>F)											
N source	NS		NS		NS		NS		NS		NS	
N rate	0.01		0.01		0.01		0.01		0.01		0.01	
N linear	0.01		0.01		0.01		0.01		0.01		0.01	
N quadratic	NS		0.05		0.01		NS		0.01		NS	
N source × rate	NS		0.05		NS		NS		NS		NS	
Crude protein concentrations												
	(%)											
0	9.0	8.1	4.4	4.6	4.5	4.3	3.7	3.7	7.7	6.3	4.3	4.5
56	12.1	10.8	5.1	4.6	4.4	4.7	3.4	3.5	7.6	6.1	5.2	4.6
112	14.8	11.4	5.6	5.8	6.0	6.8	3.5	3.6	9.9	8.2	7.2	5.3
168	14.0	13.7	7.9	6.4	6.8	6.8	4.5	4.2	10.7	9.2	8.3	6.3
Analysis of variance												
	P>F)											
N source	0.05		0.05		NS		NS		0.01		0.01	
N rate	0.01		0.01		0.01		0.05		0.01		0.01	
N linear	0.01		0.01		0.01		0.05		0.01		0.01	
N quadratic	NS		0.01		NS		0.05		NS		NS	
N source × rate	NS		0.05		NS		NS		NS		0.01	

[1]N rates in 1990 were 78, 157 and 235 kg N ha^{-1}.

decreased linearly with increasing rate of urea, but did not change significantly with increasing rates of NH_4NO_3, causing an N source by rate interaction (Table 5). Caucasian bluestem had greater apparent fertilizer N recovery when treated with urea compared to NH_4NO_3 only in 1989 (Table 5). This response was not observed with indiangrass. At the 56 and 112 kg N ha^{-1} rates in this study, apparent fertilizer N recovery was generally greater than values calculated from data by Jung et al (1990) for caucasian bluestem treated with 75 kg N ha^{-1} in Pennsylvania, and for old world bluestem treated with 35 and 70 kg N ha^{-1} in western Oklahoma (Berg 1990).

At 56 kg N ha^{-1}, an average of 13% more fertilizer N was recovered by caucasian bluestem than by indiangrass. However, at greater N rates, apparent fertilizer N recovery was similar for the 2 warm-season grasses. Greater apparent fertilizer N recovery by caucasian bluestem was expected because caucasian bluestem was harvested twice in 1988 through 1990, while indiangrass was harvested once. Differences in apparent fertilizer N recovery among warm-season grass species have been reported. For instance, weeping lovegrass [*Eragrostis curvula* (Schrad.) Ness] recovered significantly more fertilizer N than 'Kaw' big bluestem, 'Caddo' switchgrass or indiangrass in Oklahoma (McMurphy et al. 1975).

Discussion

All 3 N sources increased indiangrass and caucasian bluestem forage yields and crude protein concentrations on shallow, droughty soils of the Ozarks, but they were not equally effective. With indiangrass, urea was as effective as NH_4NO_3 in increasing both forage production and crude protein concentrations in 3 of 6 years (1986, 1987 and 1990). With caucasian bluestem, urea was as effective as NH_4NO_3 in increasing both forage production and protein concentrations only 2 of 6 years (1987 and 1989). Similar results were reported by Berg (1993) for old world bluestem in western Oklahoma. Forage yields were greater with NH_4NO_3 than urea 2 out of 4 years, but there was no difference between the 2 N sources the other 2 years. This suggests that despite the low soil pH and the practice of removing grass residues by burning in the spring, urea was less reliable as a N source than NH_4NO_3 at this site.

Because urea is more concentrated, less hazardous to store and transport, generally cheaper and more readily available than NH_4NO_3, it will continue to be widely used by producers. Therefore, other management techniques may be needed that will reduce N losses from urea and improve its effectiveness relative to NH_4NO_3 for increasing forage yields and crude protein concentrations.

Indiangrass and caucasian bluestem forage yield and crude pro-

Table 5. Nitrogen uptake in unfertilized control plots and apparent fertilizer N recovery by caucasian bluestem during 1985-1990 when N was applied as urea (U), NH_4NO_3 (AN), or $(NH_4)_2SO_4$ (AS).

N rate	Year 1985	1986	1987	1988	1989	1990[1]	6-year average
N uptake in unfertilized control plots							
	(kg ha^{-1})						
	22	26	29	24	23	11	22
Apparent Fertilizer N Recovery							
	(%)						
Urea							
56	22	48	60	47	77	26	47
112	28	44	38	43	70	28	42
168	18	36	29	46	56	20	34
Ammonium nitrate							
56	50	71	70	61	52	31	56
112	38	58	49	48	62	32	48
168	21	53	30	55	57	21	40
Ammonium sulfate							
56	37	65	72				58
112	39	50	47				45
168	34	47	42				41
Analysis of Variance							
	(P>F)						
N source	0.01	0.05	0.05	NS	0.05	NS	
AN + AS vs U	0.01	0.05	0.05	—	—	—	
AN vs AS	NS	NS	NS	—	—	—	
N rate	0.05	0.05	0.01	NS	NS	NS	
N linear	0.05	0.05	0.01	NS	NS	NS	
N quadratic	NS	NS	NS	NS	NS	NS	
N source × rate	0.05	NS	NS	NS	0.05	NS	

[1]N rates in 1990 were 78, 157 and 235 kg N ha^{-1}.

tein concentration responses to $(NH_4)_2SO_4$ and NH_4NO_3 were similar each year. There appears to have been no benefit from the SO_4^{2+} salt in increasing indiangrass or caucasian bluestem forage yield, crude protein concentration, or fertilizer N recovery at this site. Warm-season grasses display good tolerance to low soil pH and high exchangeable Al levels (Jung et al. 1988), and did not appear to be limited by these soil properties.

Although this study was not designed to compare the 2 grasses, some interesting differences stand out. Caucasian bluestem forage yields varied considerably with year, and may have been more dependent upon precipitation amounts and distribution during the growing season. Berg (1990) reported significant year-to-year variation in old world bluestem forage yield responses to N fertilizer due to wide variation in growing season precipitation in western Oklahoma. In our study, caucasian bluestem produced greater forage yields than indiangrass in 1987 with a single forage harvest, and in 1989 with 2 forage harvests. But indiangrass produced greater forage yields than caucasian bluestem in 1988 and 1990, even though caucasian bluestem was harvested twice. Indiangrass tended to have greater crude protein concentrations than caucasian bluestem from 1985–1987 when the forage was harvested on the same day. However, in 1988–1990, when the first caucasian bluestem harvest was taken earlier in the growing season to allow for a regrowth harvest, caucasian bluestem had greater crude protein concentrations.

Indiangrass yields increased with increasing N rates up to 168 kg N ha^{-1}. In Iowa, Hall et al. (1982) reported that indiangrass generally responded positively to N through 75 kg N ha^{-1}, and often through 150 kg N ha^{-1}, and in Nebraska warm-season grasses responded to rates of up to 180 kg N ha^{-1} (Rehm et al. 1976).

Caucasian bluestem yields peaked at 101 kg N ha^{-1} in 1985, 132 kg N ha^{-1} in 1986, 122 kg N ha^{-1} in 1987, 129 kg N ha^{-1} in 1989, and 161 kg N ha^{-1} in 1990. In this study, caucasian bluestem forage yields peaked at greater N rates than the 66 kg N ha^{-1} recommended for caucasian bluestem (Berg 1985) and the 70 kg N ha^{-1} recommended for old world bluestem (Berg 1990) in northwestern Oklahoma. However, average growing season precipitation is over 20 cm greater in southwestern Missouri compared to northwestern Oklahoma, allowing greater responses to N.

Our results suggest that for a single forage harvest, indiangrass would be preferred due to its better yield stability. However, under multiple harvests and for late summer forage production, caucasian bluestem would be better. Both grasses grew well on infertile soils of the Ozarks.

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