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Optimizing Hay Yield Under Lower Nitrogen Rates for Selected Warm-season Forages

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ABSTRACT

Nitrogen (N) influences the productivity and quality of hay depending on forage species. With increasing N costs, there is need to optimize production per unit of N applied. This study investigated how rates of N under 168 kg ha^{-1} (150 lb acre^{-1}) affected yield and forage quality as measured by crude protein (CP) and relative feed value (RFV) on six warm-season grass forages under a single-cut hay system. Forages tested were bermudagrass (*Cynodon dactylon*) Var Ozark, switchgrass (*Panicum virgatum*), eastern gamagrass (*Tripsacum dactyloides*), indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), and big bluestem (*Andropogon gerardii*). Forage dry matter yields averaged 3.83 and 6.76 Mg ha^{-1} for 0 Kg N ha^{-1} plots and 168 Kg N ha^{-1} plots, respectively. Significant yield differences were observed with increasing rates of N for all forage species studied. Switchgrass produced more forage than the other species at all N rates. Crude protein and relative feed value were generally unaffected by N rate. Although economic analysis revealed production potential related to N fertilizer application had not been reached, economic returns ranging from $12-$492 ha^{-1} (about $5-$203 acre^{-1}) were realized depending on forage species and N application rate. Lowering N application rates may be a suitable strategy for forage producers to manage risks associated with escalating energy costs.

INTRODUCTION

Forages, especially warm-season grasses, play a significant role in animal nutrition because they are productive during the hot summers, therefore filling in the slump left by cool-season perennial grasses (Fike et al., 2005; Scarbrough et al., 2004). Most of the warm-season grasses are photoperiod sensitive and determinate in growth, especially switchgrass (*Panicum virgatum*) and big bluestem (*Andropogon gerardii*) Mitchell et al. (2001), making it important to maximize their productive potential to increase fodder and hay for livestock during this small growth window. In well-managed systems, pasture and hay can supply annual nutrition requirements with minimal supplementation from other feeds. Hay, though expensive to produce, supplies growers with much needed feed in winter months when pastures are dormant (Kallenbach et al., 2003).

Nitrogen fertilization of grasses has been shown to increase yield and also decreases dead material and reduces concentration of neutral detergent fiber while increasing crude protein (Hall, et al., 2003). Also, N fertilization favors grass development by increasing its competitive utilization of light, nutrients, and water. However, N applied in excess of plant requirements may contribute to leaching below the effective root zone (Hall et al., 2003).

Warm-season grass species often used for forage production in Missouri, Kansas, Illinois, and Indiana include bermudagrass (*Cynodon dactylon*), switchgrass, eastern gamagrass (*Tripsacum dactyloides*), indiangrass (*Sorghastrum nutans*), little bluestem (*Schizachyrium scoparium*), big bluestem, sorghum-sudan (*Sorghum bicolor*), pearl millet (*Pennisetum americanum*), and lately Red River crabgrass (*Digitaria species*) (McLaughlin et al., 2004; Silveira et al., 2007; Fike et al., 2005). Amounts of N required by forages for optimum production depends on their usage (grazing vs haying), but also in the cultivar, soil type, and environmental factors (Silveira et al., 2007). For bermudagrass, maximum economic yields have been attained by applying 268 kg N ha^{-1} (Eichhorn, 1989). Coastal bermudagrass, eastern gamagrass, indiangrass, and switchgrass have been shown to produce average yields of 8.3, 4.5, 7.8, 6 Mg ha^{-1}, respectively, when using N at 371 kg ha^{-1} from swine effluent spray (McLaughlin, et al., 2004). Such high N application rates, however, may be limited in the future due to increased N costs. Consequently, there is a need to investigate how lower rates of N affect yield and forage quality. Accordingly, our objective was to determine dry matter yield, crude protein (CP), and relative feed value (RFV) for six warm-season grasses under a single-cut hay system using N application rates of 168 kg ha^{-1} or less. Warm-season grasses investigated were: bermudagrass, switchgrass, eastern gamagrass, indiangrass, little bluestem, and big bluestem.

MATERIALS AND METHODS

The study site was located near LaDue, Missouri. Soils in this region are predominantly Hartwell silt loams and Hartwell silty clay loams on 0-5 % slopes (*Fine, mixed, active, thermic, Typic Argialbolls*). These soils are somewhat poorly drained to moderately well-drained and are formed in very thin loess and shale bedrock. They are best suited for grass and some legume production for hay or pasture. At the time of establishment, soil pH was 6.9 and all macro- and micronutrients fell within a range adequate for forage production.

The selected warm-season grasses were established in April of 2002 (year 0), in 3 m by 4.6 m (10ft x 15 ft) plots following University of Missouri guidelines on seeding rates for establishing forages (Roberts and Gerrish, 2001). The experimental design was a randomized complete block with six warm-season grass forages each split by four N levels of 0, 56, 112, and 168 kg N ha^{-1} (0, 50, 100, 150 lb N $acre^{-1}$) applied annually. Nitrogen source was ammonium nitrate applied between April 15 and May 15 of each study year. Forage yield, CP, and RFV data were collected for three years (2003-2005) between May and June when forages were at or near boot stage.

At harvest, a one meter (39-inch) swath was removed from the center of each plot with a flail type mower, weighed, and recorded. Wet forage yields were adjusted to dry weight by drying a subsample to constant weight at 57°C (135°F). The dry samples were ground and analyzed for CP, neutral detergent fiber (NDF), and acid detergent fiber (ADF) using near-infrared reflectance spectroscopy. Both NDF and ADF were used to compute RFV for the samples as follows (Holland and Kezar, 1990):

$$RFV = (\%DDM \times \%DMI) / 1.29 \text{ where}$$

$$\%DDM = 88.9 – (\%ADF) (0.779) \text{ and}$$

$$\%DMI = 120 / \%NDF.$$

All data were subject to analysis of variance using SAS (SAS, 1997). A Duncan multiple range test procedure was used for mean separations at $P<0.05$.

Economics of fertilizer N application were done following the marginal cost (MC) equals marginal revenue (MR) approach for profit optimization (Doll and Orazem, 1984). For this study, the following assumptions were applied. Nitrogen fertilizer costs for the three year period were averaged in order to determine the cost per pound of fertilizer. The forage was assigned a value based on warm-season grass hay values as reported by United States Department of Agriculture (USDA) in October of each of the growing seasons (USDA, 2009). Using the partial budget approach, all other costs were held constant and only the value of forage relating to N fertilizer were calculated (Table 5).

RESULTS AND DISCUSSION

Growing Conditions

Variable climatic conditions played a major role in establishment and annual forage yields for all the warm-season grasses. Air temperatures were above normal and precipitation was below normal during the establishment period. During this time, precipitation during the summer months (June - September) came in one or two rainfall events leaving many days dry and hot (Table 1). Bermudagrass had to be irrigated twice after sprigging to survive. Eastern gamagrass had lower germination rates than the rest and germinated later than other warm-season grasses. However, warm-season grasses persist better in dry weather and heat than cool-season grasses (Mitchell et al., 2001). The stands persisted through the dry season in year 0 and were not reseeded.

Forage yields

Yields increased with increasing N fertilization. There were significant differences in yield for N rate and year. There were no significant differences in yield for year x N rate interactions for all the grass species except for big bluestem and switchgrass (Table 2).

Bermudagrass: Missouri studies have shown the yield of bermudagrass to increase linearly for N rates from 0 to 336 kg ha^{-1} (Hansen et al., 2000). In Florida, a maximum of 112 kg N ha^{-1} should be applied for each cutting (Mylavarapu, 2003). In our study using 168 kg N ha^{-1} yielded the highest rate that was significantly different from any lower rates (Table 2). These results indicate bermudagrass require higher rates of fertilization than most other warm-season forages.

Big Bluestem: Big bluestem responded to each increase in N above 112 kg ha^{-1}, producing significantly higher yields at 168 kg N ha^{-1} of 6.7 Mg ha^{-1} compared to 5.2 Mg ha^{-1} when using 112 kg N ha^{-1}. Big bluestem was one of the species to show N rate x year interactions (Table 2). Big bluestem was most responsive to N in the third year, least in the second year, and intermediate in the first year. The general N recommendations for Missouri are 45-67 kg ha^{-1} (Henning, 1993). In Oklahoma, research has shown yields of 2-3.4 Mg ha^{-1} at N rates of 69 kg ha^{-1} (Springer and Gillen, 2007). For the study area, these results suggest using at least 112 kg ha^{-1} on big bluestem to achieve better yields.

Little Bluestem: The critical N rate for little bluestem was 112 kg N ha^{-1} yielding 5.8 Mg ha^{-1} (Table 2). Increase of N to 168 kg ha^{-1} did not increase yields significantly. Little bluestem is persistent and competes with weeds very well once established. Little bluestem is not utilized much in many areas but this study shows it can persist and give good yields comparable to big bluestem and indiangrass. These results suggest using 112 kg N ha^{-1} for little bluestem would be adequate for growers with similar soils and climatic conditions.

Eastern Gamagrass: Eastern gamagrass is hard to establish even with seed scarification, therefore allowing weed competition. At 56 kg N ha^{-1} there was a slight increase in yield and when this rate was increased to 112 and 168 kg ha^{-1}, the yield response was significant (Table 2). Nitrogen fertilization trials conducted at two sites in northern Missouri show gamagrass responding linearly to N additions up to 336 kg ha^{-1}, to produce more than 11 Mg ha^{-1} (Roberts and Kallenbach, 1999). In order to get a good stand and reduce weed pressure, it is recommended that farmers re-seed each fall for the first two years of establishment (Aberle et al., 2003). For the study area, these results suggest using at least 112 kg N ha^{-1} on eastern gamagrass. Higher rates may encourage proliferation of weeds.

Table 1. Monthly total precipitation and average air temperature at Windsor, Missouri (16 km from the study site), during the 2002-2005 (year 0, 1, 2, and 3). Historic averages represent 30 years of data.

	Monthly Total Precipitation					Average Air Temperature				
	Year 0	Year 1	Year 2	Year 3	Historic Average	Year 0	Year 1	Year 2	Year 3	Historic Average
Month	mm					°C				
Jan	64	15	43	140	41	1	-3	-2	-1	-2
Feb	20	13	25	74	51	3	-1	0	4	1
Mar	30	79	140	23	79	4	6	8	6	7
Apr	99	97	66	56	94	14	13	13	13	13
May	168	130	211	61	132	16	18	19	18	18
Jun	86	71	137	185	114	24	22	21	24	23
Jul	56	33	191	33	99	27	27	24	26	26
Aug	76	99	132	196	94	26	27	22	26	25
Sep	66	170	94	28	109	23	19	21	22	20
Oct	69	94	109	66	91	12	13	15	15	14
Nov	13	79	94	43	86	5	7	9	8	7
Dec	28	74	30	10	53	2	2	1	-3	1
Annual	775	952	1272	914	1044					

Table 2. Three-year average dry matter yield for six warm-season grasses fertilized with different rates of N near LaDue, Missouri.

Nitrogen Rate	Bermuda-grass	Big bluestem	Little bluestem	Eastern gamagrass	Indian-grass	Switch-grass
Kg/ha	*Mg/ha*					
0	3.81b‡	3.74c	4.14c	2.98b	4.17c	4.17c
56	4.14b	3.94c	5.24bc	3.23b	4.77c	5.11b
112	4.52b	5.06b	5.82ab	4.59a	5.69b	6.65ab
168	6.90a	6.65a	6.50a	5.00a	7.21a	8.33a
				P<[w]		
Year	0.0001	0.0051	0.0005	0.0026	0.0001	0.0001
N-rate	0.0001	0.0001	0.0011	0.0002	0.0001	0.0001
Year X N-rate	0.6203	0.0209	0.5656	0.7760	0.1336	0.0133

‡ Within column, values followed by the same letter are not significantly different at $P = 0.05$ by Duncan multiple range test.
[w] Probability level.

Table 3. Three year averages of percent crude protein (CP) for warm-season forages fertilized with different rates of N near LaDue, Missouri.

N-Rate	Bermuda-grass	Big bluestem	Little bluestem	Eastern gamagrass	Indian-grass	Switch-grass
Kg/ha	-------------------------%-------------------------					
0	6.28ab‡	4.80a	5.99a	5.08a	3.68b	4.76a
56	6.03b	4.80a	5.83a	4.81a	3.91ab	4.89a
112	5.98b	5.33a	6.51a	4.86a	4.39ab	5.02a
168	7.07a	5.04a	6.25a	5.74a	4.73a	5.26a

‡ Within column, values followed by the same letter are not significantly different at *P* = 0.05 by Duncan multiple range test.

Table 4. Three year averages of relative feed value (RFV) for warm-season forages fertilized with different rates of N near LaDue, Missouri.

N-Rate (kg/ha)	Bermuda-grass	Big bluestem	Little bluestem	Eastern gamagrass	Indian-grass	Switch-grass
0	93a‡	92a	89a	84a	88a	89a
56	92a	92a	89a	84a	85a	88a
112	93a	90a	91a	84a	88a	90a
168	93a	88a	87a	84a	88a	98a

‡ Within column, values followed by the same letter are not significantly different at *P* = 0.05 by Duncan multiple range test.

Table 5. Economics of N fertilization of six warm-season grasses receiving N at 0-168 kg N ha^{-1} (0-150 lb N $acre^{-1}$). This analysis follows the marginal cost =marginal revenue (MC=MR) approach with the assumptions of \$0.29 kg^{-1} (\$0.13 lb^{-1}) of fertilizer N and \$0.13 kg^{-1} (\$0.06 lb^{-1}) of hay. Prices reflect an average from 2003-2005.

Forage Species	Ferti-lizer N Rate	Forage Yield	*Net Hay	**Hay Value	‡Hay Value without N	‡‡Hay Value with N	^Cost of N	^^Net $ Increase Less Cost of N
	----------kg/ha----------			--------------------$/ha--------------------				
Bermudagrass	0	3799	0	204	494	494	N/A	0
Big bluestem	0	3723	0	199	484	484	N/A	0
Eastern gamagrass	0	2990	0	160	389	389	N/A	0
Indiangrass	0	4158	0	223	541	541	N/A	0
Little Bluestem	0	4164	0	223	541	541	N/A	0
Switchgrass	0	4174	0	224	543	543	N/A	0
Bermudagrass	56	4145	346	19	494	539	16.24	29
Big bluestem	56	3944	220	12	484	513	16.24	12
Eastern gamagrass	56	3222	232	12	389	419	16.24	14
Indiangrass	56	4761	603	32	541	619	16.24	62
Little Bluestem	56	5243	1078	58	541	682	16.24	124
Switchgrass	56	5107	933	50	543	664	16.24	105
Bermudagrass	112	4527	728	39	494	588	32.48	62
Big bluestem	112	5058	1335	72	484	658	32.48	141
Eastern gamagrass	112	4601	1611	86	389	598	32.48	177
Indiangrass	112	5681	1523	82	541	739	32.48	166
Little Bluestem	112	5836	1671	90	541	759	32.48	185
Switchgrass	112	6652	2478	133	543	865	32.48	290
Bermudagrass	168	6886	3087	165	494	895	48.72	353
Big bluestem	168	6655	2932	157	484	865	48.72	332
Eastern gamagrass	168	4991	2001	107	389	649	48.72	211
Indiangrass	168	7217	3059	164	541	938	48.72	349
Little Bluestem	168	6489	2325	125	541	844	48.72	253
Switchgrass	168	8332	4158	223	543	1,083	48.72	492

* Net hay value was calculated as yield at a given N rate – yield at N=0.
** Hay value was calculated as net hay value * average 3-year price of hay (\$0.13 kg^{-1}).
‡ Hay value without N was calculated as forage yield produced without N * price of hay.
‡‡ Hay value with N was calculated as hay value without N + hay value at current N rate.
^ Cost of N was calculated as N rate * average 3-year fertilizer N cost (\$0.29 kg^{-1}).
^^ Net increase less cost of N was calculated as net hay value – cost of fertilizer N.

Indiangrass: Indiangrass was quick to establish and produced good yields in the first year. Indiangrass responded to each increase in N above 112 kg ha^{-1}, producing significantly higher yields at 168 kg N ha^{-1} of 7.2 Mg ha^{-1} compared to 5.7 Mg ha^{-1} when using 112 kg N ha^{-1} (Table 2). The general recommendation is to apply 45-67 kg N ha^{-1}, (Henning, 1993); however, results from this study suggest using at least 112 kg N ha^{-1}, although indiangrass can still respond to higher rates of N.

Switchgrass: Over the three year study, yield of switchgrass increased with N application up to 168 kg N ha^{-1}. Switchgrass was the highest yielding species of all forages producing 8.3 Mg ha^{-1} at 168 kg N ha^{-1}, and also showed an N rate x year interactions (Table 2). Switchgrass was most responsive to N in the first year, least in the third year, and intermediate in the second year. Findings from this study agree with University of Missouri recommendations of using at least 45-67 kg N ha^{-1} for growing switchgrass (Henning, 1993). In order to harvest good quality hay, switchgrass needs to be harvested promptly at boot stage as it becomes stemmy rapidly if allowed to continue growing. Switchgrass is an important forage crop that is rapidly gaining popularity in the renewable energy industry. Findings from this study may help farmers adjust N rates to optimize their forage and hay production goals.

Crude Protein and Relative Feed Value

There were successive increases in CP with increasing rates of N for all forages. However, increases were not significant in all cases except for bermudagrass and indiangrass at 168 kg N ha^{-1} compared to the control (Table 3). Similarly, there were no significant differences in RFV across N rates for all forage species (Table 4). However, all of the RFV were below 100, a value equivalent to full-bloom alfalfa, (Smith and Kallenbach, 2006), indicating quality of the forages although not as good as alfalfa, was sufficient to ensure relatively good intake by livestock.

Economics of Fertilizer Application

The economics of N fertilizer application were evaluated through a traditional cost benefit analysis using the partial budgeting approach (Table 5) (Doll and Orazem, 1984). In this study, optimum profit from N fertilizer application was assumed to exist at the point where the next additional unit of applied fertilizer (in this case \$0.29 kg^{-1}) did not generate an additional \$0.29 in forage revenue.

Economic analysis of forage production data indicated application of fertilizer N at 56, 112, and 168 kg ha^{-1} had a positive economic impact (Table 5). Even at 168 kg N ha^{-1}, MR>MC, revealing production potential related to fertilizer application had not been reached. Increased value from N fertilizer ranged from a low of \$12 for big bluestem at 56 kg N ha^{-1} to \$492 for switchgrass at 168 kg N ha^{-1}. All six forage species exhibited greater economic returns with N fertilizer than if no fertilizer had been applied.

CONCLUSIONS

Nitrogen fertilization increased yields of all warm-season grasses evaluated in this study. Application rates producing significantly greater yields varied by species and season, but generally ranged between 56-168 kg N ha^{-1}. Overall, N application did not affect forage quality parameters.

Increased N costs underscore the importance of applying rates of N resulting in higher dry matter yield per unit cost. Economic analysis of forage production data indicate application of N fertilizer at 56, 112, and 168 kg N ha^{-1} had a positive economic impact ranging from \$12 to \$492 ha^{-1} when assuming a fertilizer N cost of \$0.29 kg^{-1}. While economic returns from N fertilizer application vary depending on management, results from this study support the value of applying N to warm-season grasses at sites with similar soils and growing conditions.

As energy prices increase, input costs related to forage production must be carefully scrutinized. Risks associated with maximizing yield through utilization of energy-intensive inputs (i.e., fertilizer) may be unreasonable for some producers. In such cases, lowering N application rates may mitigate risks associated with forage production.

General production recommendations from this study are as follows: 112 kg N ha^{-1} resulted in dry matter yields for bermudagrass, big bluestem, and indiangrass that were different and could be increased with 168 kg N ha^{-1}. For growers producing eastern gamagrass, little bluestem, and switchgrass, it is not economical to use higher rates of 168 kg N ha^{-1} for yield increases. For substantial yield gains, higher rates of 168 kg N ha^{-1} are recommended for bermudagrass.

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