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Residual nitrogen effects on soil, forage, and steer gain

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Abstract

Nitrogen fertilization is a common practice on introduced grass pastures established on marginal farmland in the Southern Great Plains. The efficiency of N fertilizer use on pastures and concern about nitrate movement into substrata prompted this study of residual N effects following fertilization. The study was conducted on Old World bluestem (*Bothriochloa ischaemum* L.) pastures on Pratt soil (sandy, mixed thermic Psammentic Haplustalfs) in western Oklahoma where the 57-year average annual precipitation is 566 mm yr^{-1}. Herbage production and steer gains were quantified over 3 summer grazing seasons on paddocks fertilized annually with 0, 34, 68, or 102 kg N ha^{-1} yr^{-1} during the preceding 5 years. Peak standing ungrazed herbage yields were 2- to 4-fold greater in paddocks fertilized the preceding 5 years and were linearly related to the total N applied the previous 5 years. Steer weight gain responded linearly to N with an average of 0.63 kg gain over 3 years per kg N applied over the preceding 5 years. No differences (P > 0.05) in soil nitrate concentrations to a depth of 2.8 m were measured among the N rate treatments. Overall, substantial effects of residual N were measured in both herbage mass and steer weight gain for 3 years following 5 years of N fertilization.

Key Words: Southern Plains, marginal farmland, grass fertilization, Old World bluestem, *Bothriochloa ischaemum*, forage quality

Resumen

La fertilización nitrogenada es una práctica común en las praderas de pastos introducidos establecidas en las tierras agrícolas marginales de las Grandes Planicies del Sudeste. La eficiencia del uso de fertilizante nitrogenado en praderas y la preocupación acerca del movimiento de los nitratos hacia el substrato motivo la realización de este estudio de los efectos del nitrógeno residual seguido de la fertilización. Este estudio se condujo en praderas de "Old World Bluestem" (*Bothriocloa aschaemum* L.) en suelo Pratt (sandy, mixed thermic, Psemmentic Haplustalfs) localizadas en el oeste de Oklahoma, en donde el promedio de precipitación de 57 años es de 566 mm yr^{-1}. La producción de forraje y las ganancias de los novillos se cuantificaron en 3 estaciones de apacentamiento en verano en potreros que habían fertilizado anualmente durante 5 años con 0, 34, 68 o 128 kg ha-1 yr^{-1} de nitrógeno. Los rendimientos máximos de producción del forraje sin apacentar fue de 2 a 4 veces mayor en los potreros fertilizados durante los 5 años previos y estuvieron linealmente relacionados con la cantidad total de nitrógeno aplicado en los 5 años. Las ganancias de peso de los novillos respondieron linealmente a la aplicación de nitrógeno con un promedio en 3 años 0.63 kg de ganancia por kg de nitrógeno aplicado en los 5 años anteriores. No se encontraron diferencias (P > 0.05) entre tratamientos de nitrógeno con respecto en las concentraciones de nitratos medidas hasta una profundidad de 2.8 m. En general, se midieron efectos substanciales del nitrógeno residual tanto en la producción de forraje como las ganancias de peso de los novillos durante 3 los tres años posteriores a 5 años de fertilización nitrogenada.

Nitrogen (N) fertilization of introduced grass pastures is a common practice in western Oklahoma and adjacent areas in Texas (Dahl and Cotter 1984, Berg and Sims 1995). These pastures are usually established on marginal farmland that are deficient in plant-available N as a result of up to 100 years of cultivation and subsequent erosion (Haas et al. 1957). Management of N fertilized pastures requires a balance among production, profit, and environmental quality (Bock and Hergert 1991).

A single application of 68 kg N ha^{-1} yr^{-1} in April to WW Spar Old World bluestem (*Bothriochloa ischaemum* L.) pastures in western Oklahoma generally resulted in maximum forage mass and steer weight gain (Berg and Sims 1995). However, fertilizer N-use efficiency in steer weight gain was greater for a lower N application rate of 34 kg N ha^{-1} yr^{-1}. Fertilizer N-use efficiency averaged 3.3 kg steer weight gain per kg N applied with the first 34 kg N ha^{-1} yr^{-1} increment, 1.0 kg for the second 34 kg N ha^{-1} yr^{-1} increment (total of 68 kg N ha^{-1} yr^{-1}) and was negligible for the third 34 kg N ha^{-1} yr^{-1} increment (total of 102 kg N ha^{-1} yr^{-1}).

This study is a continuation of an earlier N rate study reported by Berg and Sims (1995). The objectives of the present study were to determine the residual N effects after 5 years of pasture fertilization on: 1) concentrations of nitrate, ammonium, total N and organic C in the soil; and 2) herbage mass, forage nutritive value, and steer weight gain in the ensuing 3 years without fertilization.

Materials and Methods

This study was conducted on the Southern Plains Experimental Range near Fort Supply (99° 23'W, 36° 27'N) in western Oklahoma. Soils are predominately a deep loamy sand (Pratt series-sandy,

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mixed, thermic Psammentic Haplustalfs). Prior to cultivation, the land supported a sand sagebrush (*Artemisia filifolia* Torr.)-mixed grass prairie with sand bluestem (*Andropogon hallii* Hack.), sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray), blue grama (*Bouteloua gracilis* (H.B.K.)Lag.), switchgrass (*Panicum virgatum* L.), and little bluestem (*Schizachyrium scoparium* (Michx.) Nash) as dominant grasses (Berg 1994).

The study area was farmed for about 40 years before 'WW-Spar' Old World bluestem was established in the early 1980's. The bluestem pasture was fertilized with 68 kg N ha^{-1} yr^{-1} and grazed in 1986 and 1987. In 1988 the pasture was divided into 16 paddocks and ammonium nitrate treatments of 0, 34, 68, and 102 kg N ha^{-1} yr^{-1} were broadcast applied in April of each year in a randomized complete block design with 4 replications. The N treatments were repeated for 5 years between 1988 and 1992 (Berg and Sims 1995). Incremental N rates were obtained by repeat applications of fertilizer, on the same day, with a drop spreader calibrated for the 34 kg N ha^{-1} yr^{-1} rate. Thus, the total amount of N applied over the 5-year period was 0, 170, 340, and 510 kg N ha^{-1} for the respective annual N treatments. Paddocks were 1.2 ha for the control (no N) and 0.8 ha for each N-fertilized treatment.

Paddocks were grazed 4 of the 5 years N fertilizer was applied (Berg and Sims 1995). A low temperature of –20 °C on 22 December 1989, following a dry fall (4 mm precipitation October through December 1989) resulted in extensive winterkill of WW-Spar Old World bluestem. To allow forage recovery, the bluestem pastures were not grazed during the 1990 growing season.

Soil sampling was designed to test differences among N-rate treatments following 5 years of N fertilization. Samples were taken in the spring of 1988 prior to N fertilization and again in the spring of 1993, approximately 1 year following the last application of N fertilizer. Two groups of soil samples were taken; the first was to characterize fertility in the surface 15 cm of soil, the second was to determine nitrate (NO_3) and ammonium (NH_4) movement and accumulation to a depth of 2.8 m. Prior to soil sampling in 1988 and 1993, forage aftermath was burned in March. For the soil fertility sampling, because of soil heterogeneity within paddocks caused by topography and erosion, 3 representative 6 x 10 m areas within each paddock were permanently marked and sampled in 1988 and resampled in 1993. Twenty-eight random 2-cm diameter cores were taken to a depth of 15 cm in each 6 x 10 m sampling area, composited by 5 cm increments, and air dried. Soil samples were passed through a 2 mm sieve to remove roots and foreign material prior to storage or analysis. Thus, 9 soil samples, composited from 28 subsamples, were collected in 1988 and again in 1993 for analyses from each paddock (3 areas x 3 depths). Data were averaged from the 3 areas (subsamples) per paddock for later statistical analyses. Nitrate was determined by 1 M KCl extraction and Cd reduction (Gelderman and Fixen 1988), extractable ammonium by 1 M KCl extraction and the indophenol blue method (Keeny and Nelson 1982), total N by a Kjeldahl procedure (Bremner and Breitenbeck 1983), and organic C by the Mebius method (Nelson and Sommers 1982). Soil samples were air dried and stored in a cool, dry area and all analyses made in 1994.

Nitrate and ammonium concentrations to a depth of 2.8 m were determined in 4-cm diameter soil cores taken at increments of 0-0.4, 0.4-1.2, 1.2-2.0., and 2.0-2.8 m. One core was taken per paddock in 1988, the location marked, and another core taken in 1993 within 0.5 m of the original location. Samples were air dried and nitrate and ammonium determined by methods given above.

Precipitation measured at the Southern Plains Experimental Range headquarters, about 1.5 km from the research site, was 459 mm in 1993, 480 mm in 1994, and 457 mm in 1995 (Table 1). The 57 year mean is 566 mm yr^{-1}. January through June precipitation was 257 mm in 1993, 201 mm in 1994, and 338 mm in 1995; the 57 year January through June precipitation mean is 290 mm. Average annual precipitation for the previous 5 years, beginning in 1988 was 503, 679, 560, 409, and 503 mm, respectively.

Peak standing herbage mass was harvested within five, 1.25 x 4 m exclosures within each paddock on 15 July 1993, 28 June 1994, and 1 July 1995. The exclosures were moved annually. Herbage was cut at a 7-cm height with a Hegge sickle bar plot harvester on 1.25 X 4 m areas within each exclosure, collected as one sample, and weighed. Herbage mass in each paddock was also cut at a 7-cm height with a Hegge sickle bar plot harvester by randomly sampling five, 1.25 x 4 m areas within each paddock at the time steers were placed in the paddocks, 3 weeks later, and when the steers were moved. Herbage subsamples, of approximately 300 g size, were collected and dried at 57°C to determine dry matter content. These dried samples were ground to pass a 1-mm screen and analyzed for N (Bremner and Breitenbeck 1983) and in vitro dry matter digestibility (Tilley and Terry 1963 as modified by White et al. 1981). Nitrogen concentration was multiplied by 6.25 to estimate crude protein.

In this monoculture pasture, herbage mass sampled to a stubble height of 7 cm was considered to approximate the available forage mass for the grazing animal. Thus, herbage allowance was calculated as the average herbage mass in each paddock within each sampling interval divided by the number of steers and steer weight (kg) in the paddock over that period.

Yearling steers were placed in the paddocks in June when grass height was visually estimated to be between 15 and 20 cm. Steers were grazing similar Old World bluestem forage prior to the beginning of this summer grazing study. Steers grazed Old World bluestem in this study at or near peak nutritive value and when grass growth rates were generally high until mid July or early August. Steers, crosses of Hereford or Angus with Simmental, Limousin, or Brahman, were implanted with 200 mg progesterone and 20 mg

Table 1. Monthly precipitation (mm) during the years of the study (1993–1995) compared to the 57-year mean at the Southern Plains Experimental Range, 1940–1989, Ft. Supply, Okla.

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
	-----	-----	-----	-----	-----	-----	(mm)	-----	-----	-----	-----	-----	
1993	36	36	40	56	78	11	59	86	22	10	17	10	459
1994	12	17	28	74	55	15	78	48	28	64	26	34	480
1995	15	4	103	28	115	73	53	13	36	0	1	18	457
Mean	21	19	57	53	83	33	63	49	29	25	15	21	465
56-year	14	24	40	46	90	76	71	64	52	42	28	21	566

estradiol benzoate in May. Initial weights of the 56 steers used each year averaged 298 ± 3 (SE) kg in 1993, 232 ± 3 kg in 1994, and 257 ± 3 kg in 1995. Steers were weighed on the morning they were placed in the paddocks, and the day after they were removed. All steer weights followed an 18 hour fast without feed or water.

The number of steers used during the first 3 weeks was based on experience from the earlier 5-year N fertilization study by Berg and Sims (1995) and from previous studies at the Southern Plains Experimental Range (Sims and Dewald 1982). Steer numbers were adjusted slightly for the second grazing interval in an attempt to maintain similar amounts of forage mass per steer in each paddock. Because of variation in herbage growth, the subsequent grazing level was not always precise. Thus, care must be exercised in interpreting average daily weight gain and gain ha^{-1}. Steer weight gain per paddock was the experimental unit used in the statistical analysis (SAS Institute 1985).

Cattle were removed and the pastures allowed to regrow before fall dormancy. Number of continuous grazing days was 35, 33, and 42 days in 1993, 1994, and 1995, respectively. Aftermath was burned in March 1993, but mowed and dropped in place in March of 1994 and 1995.

Residual N fertilizer use efficiency was calculated for each year (1993–95) by subtracting steer weight gain $ha^{-1}yr^{-1}$ on the unfertilized paddocks from steer weight gain $ha^{-1}yr^{-1}$ on paddocks N fertilized over the 1988–1992 period and then dividing by the total amount of N applied over the 1988–1992 period.

For the soil analyses our major interest was 5 years differences (deltas between 1988 and1993) as affected by N treatments; therefore, the delta values were used in statistical analyses. Soil sampling design was a randomized complete block with rate of N as the treatment variable. Observations were made at incremental depths vertically within treatments. The analysis of variance (AOV) model was a randomized complete block with a block effect, N rate effect and depths analyzed as a repeated factor, which allowed for adjustment for correlation between depths when testing for depths and the depth x N rate interaction effects. The significance levels for N rates were determined by F tests and significance levels for depth and the depth x N rate interaction were determined by Kendall's Tau. Analysis of variance was conducted for steer weight gain ha^{-1} as affected by N rates over years and for each year; treatment effects were also partitioned into linear, quadratic, cubic, and residual components by year. Peak standing herbage mass for each year (1988–1994) was analyzed using a repeated measure, 2-way AOV with correction for correlation between successive years. The AOV was conducted for average daily steer gain (ADG) and forage nutritive components. Duncan's new multiple range test ($P < 0.05$) was used to separate treatment effects on steer ADG. Statistical analyses was conducted using SAS Institute (1985) procedures.

Results and Discussion

Soil N and C

In the soil fertility analyses of the surface 15 cm, nitrate was low with no significant change ($P > 0.05$) following 5 years of pasture fertilization compared to non-fertilization (Table 2). Ammonium concentration increased ($P < 0.01$) with increased N application, however, overall ammonium concentrations were lower in 1993 than in 1988. Extractable mineral N (nitrate and ammonium) has been commonly used as a routine soil test for plant-available N in cultivated soils (Dahnke and Johnson 1990). However, peak herbage standing mass (Fig. 1) indicated that substantially more N was available to plants in paddocks receiving higher N rates in the preceding 5 years. Thus, routine agricultural soil tests for extractable nitrate and ammonium appear to be of little to no value in predicting N availability to plants in these and similar pastures. An exception to this might be when excessive fertilizer N is applied. Soil incubation tests (Dahnke and Johnson 1990) however, may be useful for quantifying N which becomes available from mineralization of organic N in pastures.

Table 2. Soil nitrate, ammonium, total N, and organic C concentrations to 15 cm soil depth before (1988) and after (1993) 5 years of N fertilization and grazing of an Old World bluestem at the Southern Plains Experiemental Range, Ft. Supply, Okla.

Component	Total N (kg ha^{-1}) applied (1988–1993)							
Depth	0		170		340		510	
cm	1988	1993	1988	1993	1988	1993	1988	1993
Nitrate	(mg N kg^{-1})[1]							
0–5	0.3 ± 0.5[2]	0.6 ± .07	0.4 ± .05	0.8 ± .16	0.05 ± .05	0.9 ± .09	0.5 ± .20	0.9 ± .07
5–10	0.3 ± .04	0.5 ± .01	0.3 ± .07	0.5 ± .07	0.3 ± .02	0.6 ± .03	0.4 ± .20	0.6 ± .08
10–15	0.1 ± .01	0.3 ± .09	0.2 ± .04	0.5 ± .03	0.1 ± .02	0.4 ± .0.4	0.3 ± 1.4	0.4 ± .06
Ammonium	(mg N kg^{-1})[3]							
0–5	6.7 ± .7	3.5 ± .5	9.8 ± 2.1	4.8 ± .8	7.0 ± .8	4.6 ± .3	7.4 ± .4	5.1 ± .6
5–10	5.9 ± .6	1.8 ± .1	6.3 ± .8	1.9 ± .5	5.7 ± .5	2.6 ± .2	5.0 ± .8	2.9 ± .4
10–15	3.8. ± .2	2.1 ± .3	4.4 ± .4	2.0 ± .3	3.1 ± .1	2.2 ± .1	2.9 ± .5	2.0 ± .1
Total N (	g N kg^{-1})[4]							
0–5	0.77 ± .09	0.87 ± .09	0.93 ± .17	1.03 ± .19	0.73 ± .05	0.92 ± .05	0.81 ± .10	0.86 ± .07
5–10	0.58 ± .03	0.58 ± .05	0.63 ± .06	0.63 ± .07	0.57 ± .03	0.58 ± .05	0.52 ± .03	0.52 ± .03
10–15	0.50 ± .03	0.46 ± .04	0.52 ± .06	0.54 ± .06	0.46 ± .04	0.52 ± .03	0.44 ± .03	0.44 ± .03
Organic	C (g C kg^{-1})[5]							
0–5	7.9 ± .9	9.1 ± .8	9.5 ± 2.0	12.2 ± 2.6	7.5 ± .6	10.9 ± .5	8.4 ± 1.2	10.4 ± .9
5–10	5.5 ± .4	5.8 ± .7	5.8 ± 0.8	4.4 ± 1.8	5.4 ± .3	6.0 ± .4	5.1 ± .5	4.7 ± .2
10–15	4.6 ± .4	4.6 ± .3	4.7 ± 0.6	5.2 ± 0.7	4.3 ± .3	5.0 ± .5	4.1 ± .3	4.3 ± 2

[1]P > F for differences in nitrate levels between years for N treatments = 0.85, soil depths = 0.09, and N X soild depths = 0.98.
[2]Standard error (s.e.), n = 4.
[3]P > F for differences in ammonium levels between years for N treatments = 0.01, soil depths = 0.01, and for N X soil depths = 0.87.
[4]P > F for differences in total N levels between years for N treatments = 0.13, soil depths = 0.01, and for N X soil depths = 0.68.

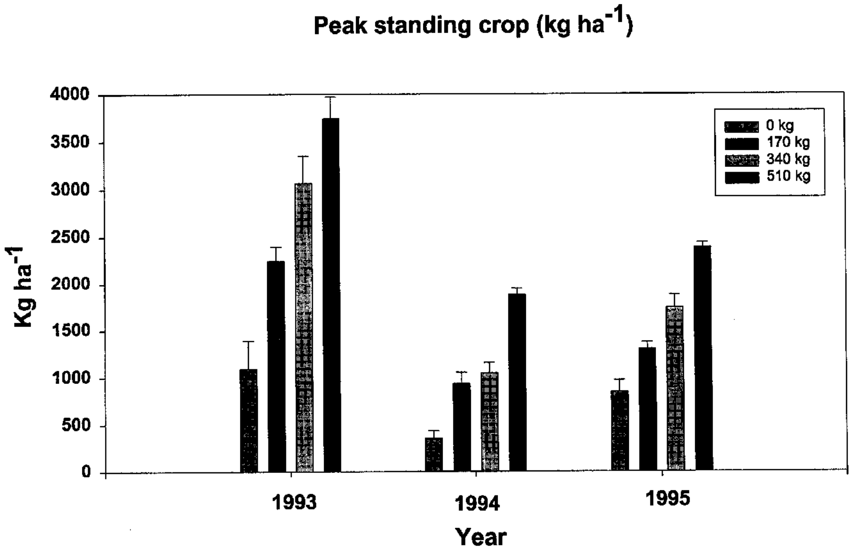

Fig. 1. Peak standing herbage mass (kg ha^{-1} ± s.e.) in 1993, 1994, and 1995 in exclosures within paddocks. Paddocks were fertilized with a total of 0, 170, 340, and 510 kg N ha^{-1} during the previous 5 years at the Southern Plains Experimental Range, Ft. Supply, Okla.

Total soil N and organic C concentrations increased in the surface 5 cm in all treatments over the 1988–1993 period. However, our major interest was whether or not there was a greater change in total N and organic C in the N-fertilized paddocks than in the unfertilized paddocks. Thus, we calculated the change from 1988 to 1993 in total N and organic C for each N treatment and subjected the data to AOV. No significant change was measurable in total N ($P = 0.13$), but organic C increased ($P = 0.03$) with increased N application (Table 2).

The potential for movement of mineral N into substrata and eventually into groundwater has been a concern with N fertilization of pastures. There was more ($P < 0.05$) extractable nitrate in all treatments to a depth of 2.8 m in 1993 than in 1988 (Table 3). However, most levels of extractable nitrate, about 1 mg N kg^{-1} soil (1 ppm extractable nitrate N), were low. Higher nitrate concentrations were found at depths of 1.2 to 2.8 m in some soil samples from the higher N rate treatments; however, this was not consistent among replications and thus N treatments x depths interaction was not significant ($P > 0.05$). We believe that more intensive sampling is needed to quantify nitrate movement than the single adjacent soil cores we took per paddock in 1988 and 1993.

Herbage dynamics

Peak standing herbage yields from exclosures within paddocks that were N fertilized the preceding 5 years were 2- to 4-fold greater than yields from exclosures within paddocks that had not been fertilized (Fig. 1). There were significant differences ($P < 0.01$) in peak standing herbage yields between the N levels and years when residual N effects were measured. These differences were, however, not independent ($P < 0.05$) because the relative difference in herbage mass and amount of N applied during the previous 5 years was not the same in all years, particularly in 1994 (Fig. 1). The increase was linearly related to total N applied with r^2 values of 0.82 in 1993, 0.85 in 1994, and 0.90 in 1995. This linear relationship indicated that N was a limiting factor in herbage mass yields on all residual N treatments each year the residual effect was measured. In contrast, yields of herbage mass during the 5 years that N was applied was curvilinearly related as increasing N fertilizer increments produced smaller increases in herbage mass (Berg and Sims 1995). Precipitation during the growing season for 1993, 1994, and 1995 was 185, 172, and 339 mm, respectively (Table 1). The dynamics of peak standing herbage is a function of available N levels in the soil and recent precipitation. The separate effects on these 2 factors cannot be partitioned in this study. However, the relative responses from the N fertilizer treatments were consistent across all 3 years.

Available herbage mass per 100 kg steer^{-1} weight averaged 60 ± 3 kg across all treatments, grazing periods, and years (Table 4). There were no significant differences in the amounts of herbage mass per 100 kg steer^{-1} between treatments within each period. Over the 3 years, herbage allowance averaged 139 ± 15, 170 ± 20, 133 ± 14, and 172 ± 16 kg forage steer^{-1} for the 0, 170, 340, and 510 kg total N ha^{-1} applied, respectively. There were

Table 3. Soil nitrate, ammonium concentrations to 2.8 msoil depth before (1988) and after (1993) 5 years of N fertilization and grazing of an Old World bluestem at the Southern Plains Experimental Range, Ft. Supply, Okla.

Component	Total N (kg ha^{-1}) applied (1988–1993)							
Depth	0		170		340		510	
m	1988	1993	1988	1993	1988	1993	1988	1993
Nitrate	(mg N kg^{-1})[1]							
0–0.4	0.3 ± 0.1[2]	0.7 ± .0.1	0.3 ± 0.1	0.9 ± 0.1	0.3 ± 0.1	1.0 ± 0.2	0.3 ± 0.1	1.0 ± 0.1
.0.4–1.2	0.4 ± 0.1	0.7 ± 0.1	0.3 ± .07	05. ± .07	0.3 ± .02	0.6 ± .03	0.4 ± .20	0.6 ± .08
1.2–2.0	0.3 ± 0.1	0.7 ± 0.1	0.5 ± 0.2	1.1 ± 0.4	0.3 ± 0.1	1.0 ± 0.4	0.3 ± 0.1	0.5 ± 0.4
2.0–2.8	0.6 ± 0.1	0.8 ± 0.1	0.9 ± 0.3	1.4 ± 0.2	0.9 ± 0.3	2.9 ± 1.5	0.3 ± 1.6	3.0 ± 2.0
Ammonium	(mg N kg^{-1})[3]							
0–0.4	5.2 ± 0.4	2.4 ± 0.3	4.7 ± 0.5	2.5 ± 0.2	5.2 ± 0.3	2.6 ± 0.1	5.1 ± 0.9	2.7 ± 0.3
0.4–1.2	1.9 ± 0.1	2.0 ± 0.4	2.3 ± 0.3	2.0 ± 0.4	2.0 ± 0.4	1.5 ± 0.2	2.3 ± 0.3	1.8 ± 0.6
1.2–2.0	1.6 ± 0.1	1.2 ± 0.2	2.3 ± 0.6	1.9 ± 0.3	1.5 ± 0.3	1.0 ± 0.2	1.8 ± 0.5	3.0 ± 1.2
2.0–2.8	1.6 ± 0.1	1.5 ± 0.2	2.3 ± 0.6	2.1 ± 0.6	1.4 ± 0.2	1.9 ± 0.2	1.1 ± 0.2	.1.5 ± 0.2

[1]P > F for differences in nitrate levels between years for N treatments = 0.21, soil depths = 0.25, and N X soild depths = 0.27.
[2]Standard error (s.e.), n = 4.
[3]P > F for differences in ammonium levels between years for N treatments = 0.52, soil depths = 0.01, and for N X soil depths = 0.31.

Table 4. Stocking density and available herbage per 100 kg yearling steer^{-1} (kg ± se) for 2 summer grazing periods to determine residual N effects over 3 years following 5 years of N fertilization with 0, 170, 340, and 570 kg N ha^{-1} at the Southern Plains Experimental Range, Ft. Supply, Okla.

Year	Grazing Interval	Total N (kg ha^{-1}) applied from 1988 to 1992							
		0		170		340		510	
		(Steer ha^{-1})	(kg herbage per 100 kg steer)	(Steer ha^{-1})	(kg herbage per 100 kg steer)	(Steer ha^{-1})	(kg herbage per 100 kg steer)	(Steer ha^{-1})	(kg herbage per 100 kg steer)
1993	7 June–29 June	2.5	24 ± 6	3.7	45 ± 14	4.9	36 ± 10	4.9	46 ± 9
	30 June–12 July	2.3	43 ± 9	3.1	84 ± 28	4.3	54 ± 14	4.9	63 ± 16
1994	8 June–27 June	2.5	61 ± 4	3.7	79 ± 11	4.9	70 ± 9	4.9	91 ± 6
	28 June–11 July	2.5	56 ± 5	3.4	93 ± 11	4.9	74 ± 11	5.3	107 ± 6
1995	20 June–11 July	2.5	57 ± 6	3.7	54 ± 9	4.9	48 ± 6	4.9	76 ± 22
	12 July–1 Aug.	2.5	61 ± 14	3.7	51 ± 9	4.1	37 ± 6	4.9	44 ± 12

significant differences in herbage mass, however, between the early and late grazing periods for treatments within years ($P < 0.01$) and between years ($P < 0.01$). Averages for the early (June) and late (July) summer grazing periods were 57 ± 4 and 64 ± 3 kg 100 kg steer^{-1}, respectively. There were significant year effects ($P < 0.01$) for both the June and July periods; treatment effect was significant ($P < 0.05$) only for the June grazing period. The treatment means for the June period were 48 ± 7, 59 ± 11, 51 ± 25, and 71 ± 38 kg 100 kg steer^{-1} for the 0, 170, 340, and 510 kg total N ha^{-1} applied , respectively. Although, there were no significant differences in herbage mass steer^{-1} between treatments within a grazing period, care is still needed in interpretation of the impacts on steer weight gains.

Forage crude protein concentration was considerably higher ($P < 0.05$) on 7 June 1993, compared to 1994 and 1995, in paddocks that had received higher N rates in the preceding 5 years (Table 5). In contrast, on 7 June 1994 and on 19 June 1995 crude protein concentrations were relatively low and similar in all treatments. This may have resulted from sampling all herbage material above a 7 cm height rather than selectively grazed material. Crude protein was low in 1993 and 1994 on all treatments at the end of seasonal grazing. In contrast, crude protein was relatively high at the end of seasonal grazing in 1995. We believe this is a reflection of increased soil N mineralization following favorable March through July 1995 precipitation (Table 1). When these pastures were fertilized during the previous 5 years, mid-summer crude protein levels averaged 5.3, 6.3, 7.2, and 8.8 percent for the 0, 34, 68, and 102 kg N ha^{-1} treatments, respectively (Berg and Sims 1995). Thus, forage crude protein level is an early sign that N is limiting plant production.

In vitro dry matter digestibility (IVDMD) was higher ($P < 0.01$) in June 1993 and 1994 on treatments that had received the higher N rates (Table 5). By the time steers were removed in mid July 1993 and 1994, IVDMD was lower ($P < 0.05$) on treatments that had received the higher N rates. This lower IVDMD was a reflection of a higher proportion of stems and mature seed heads in paddocks that had received the higher N rates. In contrast, few Old World bluestem plants produced seedheads in the 0 N treatment. We have observed a similar absence of Old World bluestem heading in 5 to 10 year old Old World bluestem Conservation Reserve Program (CRP) plantings on N-deficient farmland. During the years of fertilization, IVDMD in early summer averaged 70 to 72 percent and 59 to 61 percent during the mid-July period (Berg and Sims 1995).

Steer gains

Steer average daily gain (ADG) in 1993 was greater ($P < 0.01$) on the higher N treatments (Table 6), probably a reflection of higher crude protein concentration in forage (Table 5). Conversely, steer ADG in 1994 was relatively low on all treatments, again a reflection of low crude protein concentrations in forage. Steer ADG during 1995 averaged 0.89 kg steer^{-1} day^{-1}, apparently a reflection of higher forage protein concentrations later in the grazing season (Table 5).

Weight gains of steers during 1993–1995 increased linearly with increasing N rates applied during the preceding 5 years (Fig. 2). Over the 3 years, steer weight gain averaged 0.63 kg per kg N applied during the preceding 5 years. The value can also be calculated by averaging residual N-use efficiency over 3 years for each N application rate from values of 0.59 ± 0.29 (se) kg steer weight gain per total kg N applied for the 170 kg N application, 0.68 ± 0.06 kg gain per kg N for the 340 kg N application, and 0.63 ± 0.06 kg gain per kg N for the 510 kg N application. Total steer weight gain averaged over the 3 residual grazing years was 185 kg ha^{-1} for the 0 N application, 285 kg ha^{-1} for the 170 kg N ha^{-1} application, 416

Table 5. Crude protein and in vitro dry matter digestibility of Old World bluestems at the beginning and end of seasonal grazing of paddocks fertilized annually for the total N applied (kg N ha^{-1}) during the preceding 5 years at the Southern Plains Experimental Range, Ft. Supply, Okla.

Forage component	Date	Total N applied (kg N ha^{-1}) 0	170	340	510
Crude protein		(%)			
	7 June 1993	8.7[c]	9.6[c]	10.9[b]	12.1[a]
	15 July 1993	5.0[a]	4.8[a]	4.6[a]	5.2[a]
	7 June 1994	7.3[a]	7.1[a]	7.6[a]	7.6[a]
	14 July 1994	6.1[a]	5.7[a]	4.8[b]	4.7[b]
	19 June 1995	7.6[a]	7.8[a]	7.6[a]	7.7[a]
	1 Aug. 1995	6.6[b]	7.1[b]	7.9[a]	6.8[b]
In vitro dry matter digestibility					
	7 June 1993	65.7[c]	67.0[bc]	68.4[ab]	69.0[a]
	15 July 1993	56.6[a]	54.2[a]	52.8[b]	51.1[c]
	7 June 1994	62.1[b]	63.5[a]	64.2[a]	64.0[a]
	14 July 1994	57.5[a]	57.3a	52.9[b]	51.3[b]
	19 June 1995	61.0[a]	62.1[a]	62.7[a]	60.1[a]
	1 Aug. 1995	56.6[a]	57.4[a]	54.3[a]	52.9[a]

[1]Values within a date followed by a common superscript are not significantly different ($P > 0.05$).

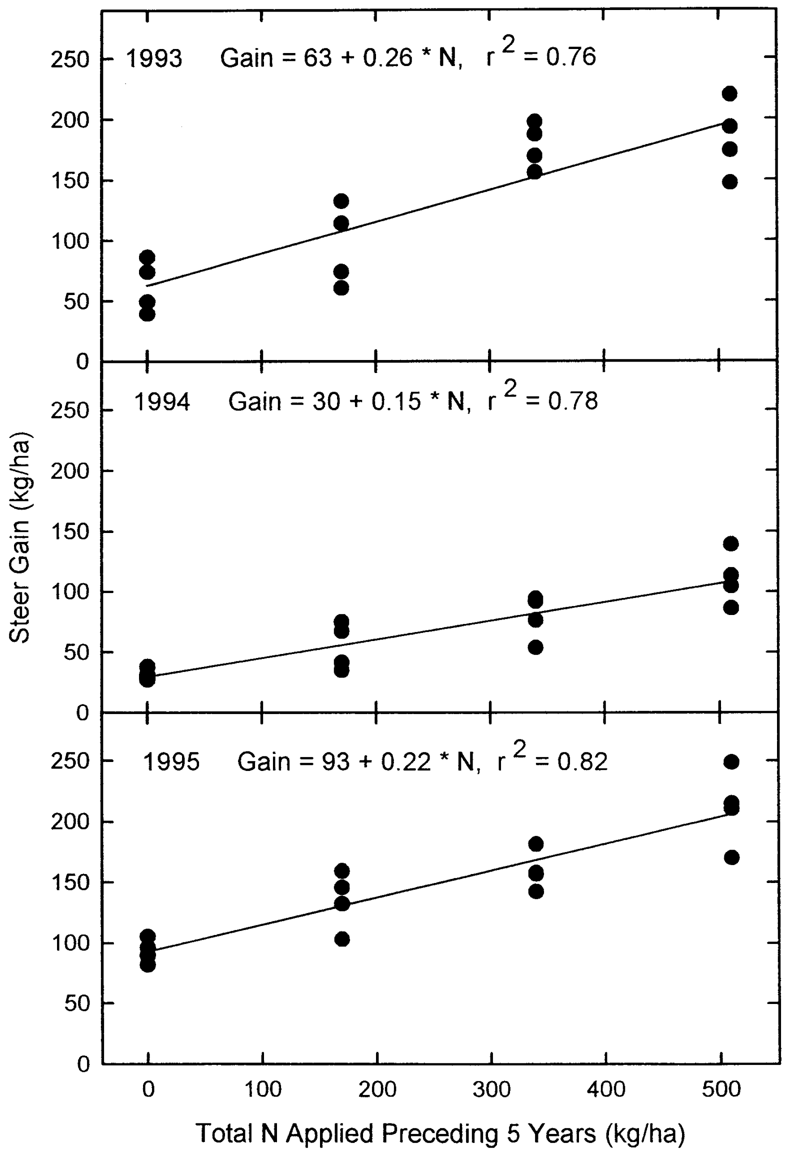

Fig. 2. Steer weight gain over 3 years as related to the total amount of N applied the preceding 5 years at the Southern Plains Experimental Range, Ft. Supply, Okla.

kg ha^{-1} for the 340 kg N ha^{-1} application, and 505 kg ha^{-1} for the 510 kg N ha^{-1} application. We speculate that the residual N effect will be present, but diminish, over the next several years.

The residual N-use efficiency averaging 0.63 kg steer weight gain per kg N applied the preceding 5 years was additive to the fertilizer N-use efficiency previously reported (Berg and Sims 1995). A rigorous summation of fertilizer N-use efficiency during the years N was applied plus the residual effect was not appropriate since the study was N fertilized for 5 years and only grazed for 4 of these years. However, at the 34 kg N ha^{-1} yr^{-1} rate, N-use efficiency averaged 3.3 kg steer weight gain per kg N applied over 4 years the paddocks were N fertilized and grazed (Berg and Sims 1995) and the residual N effect reported here was an additional 0.59 kg steer weight gain per kg N applied. Thus, the summation suggests a N-use efficiency of about 3.9 kg steer weight gain per kg N applied for the most efficient N application rate of 34 kg N ha^{-1} yr^{-1}.

Conclusions and management implications

Annual N flux in rangeland is small in relation to the total N in soil, vegetation, and litter (Berg et al. 1997). The major N inputs in rangeland ecosystems are believed to be from atmospheric deposition and protein supplements fed to cattle. Primary outputs are ammonia volatilized from plant and animal wastes and livestock products sold (Woodmansee 1978, Lauenroth and Milchunas 1991). On native sandhills rangeland, 50 years of moderate grazing by cattle had no measurable effect on C and N concentrations in the surface 5 cm of the sandy soil or total N uptake by plants as compared with nongrazed areas (Berg et al. 1997). Fluxes of N in improved pastures would differ from those in rangeland in the amounts of N fertilizer applied and in the magnitude and distribution of livestock wastes distributed, protein supplements used, and products sold. An increase in total N averaging 5 to 8 kg ha^{-1} yr^{-1} over a 20 to 22 year period was found in N-fertilized pastures as compared to adjacent unfertilized pastures in western Oklahoma (Berg 1988).

Nitrogen fertilization can result in soil acidification. Soil pH in the surface 5 cm was reduced from 6.7 to 5.3 by 20 years of N fertilization of improved pastures on loamy sand soils in Oklahoma (Berg 1986). In Kansas, 20 years of 67 kg N fertilization ha^{-1} yr^{-1} decreased the surface pH of a silt loam soil under grass from 5.9 to 5.1 (Owensby et al. 1969). Generally, rangeland and grassland soils are not tillable and mixing lime to correct acidification may be difficult (Owensby and Launchbaugh 1971). Acidification of dryland grain-growing soils is an emerging problem in western North America (Mahler and Harder 1984, McCoy and Webster 1977, Westerman 1981). Plant species and selections within species vary in their sensitivity to acid soils. Foy (1984) found tall warm-season grasses were tolerant to pH of 4.5 to 5.0 while many legumes may be sensitive to acid soil at soil pH of 5.5 to 6.0.

This study indicated that substantial residual N effects can be expected in forage and beef production for several years after 5 years of N application to Old World bluestem pastures established on marginal farmland in the Southern Plains. The 3-year residual N effect resulted in steer weight gain of about 0.6 kg per kg N applied the preceding 5 years. At a custom grazing rate of about \$0.55 kg^{-1} stocker weight gain, this represents an additional return of about \$0.32 per kg of N applied. Economic returns appeared to favor the 34 kg ha^{-1} yr^{-1} pasture fertilization rate. At a cost of \$0.88 kg^{-1} N applied, the return was \$1.80 in steer weight gain (at the custom grazing rate) the year of application plus a potential \$0.30 in steer weight gain from the residual N effect. At higher N rates the return per unit of N applied is lower.

Table 6. Average daily steer weight gains (kg steer^{-1} day^{-1}) and preliminary economic analysis of residual N effects on steer weight gains (kg steer^{-1} day^{-1} and kg ha^{-1}) over 3 summer grazing periods on Old World bluestem paddocks fertlized annually at 4 rates of N applied (kg N ha^{-1}) during the preceding 5 years at the Southern Plains Experimental Range, Ft. Supply, Okla.

	N fertilization rate (kg N kg^{-1})			
Annual	0	34	68	102
Total 5-year	0	170	340	510
Average daily steer weight gains (kg steer^{-1} day^{-1})				
7 June–15 July 1993	0.67^{b1}	0.80^{b}	1.08^{a}	1.09^{a}
7 June–14 July 1994	0.38^{b}	0.45^{b}	0.47^{b}	0.65^{a}
19 June–1 Aug. 1995	0.89^{a}	0.85^{a}	0.83^{a}	1.00^{a}
Total steer gain				
• 3-year gain (kg ha^{-1})	185	285	416	505
• Total N cost ($0.66 kg^{-1} N)	0	$112.20	$224.40	$336.60
Economic component:				
• N-use (kg gain kg N^{-1})	Baseline	0.59	0.68	0.63
• Additional gain (kg ha^{-1})	–	100	231	320
Comparison based on steer ownership				
• Value of gain ($1.10 kg^{-1})	–	$110.00	$254.10	$352.00
• Total sales ($1.10 kg^{-1})	$203.50	$313.50	$457.60	$555.50
• Sales less N costs	$203.50	$201.30	$233.20	$218.90
Comparison based on custom grazing rates:				
• Custom rates ($0.55 kg^{-1})	$101.75	$156.75	$228.80	$277.75
• Return (Custom rate–N)	$101.75	$44.55	$4.40	–$58.85

[1]Steer weight gains within a year followed by a common superscript are not significantly different (P > 0.05).

Preliminary economic returns to the resources used and to management have been estimated for both yearling stocker ownership and custom grazing rates (Table 6). Assuming all other costs are proportional, the 68 kg N ha rate yielded $233.20 per ha for the 3 years of grazing pastures that were fertilized during the previous 5 years. The returns of all 4 fertilizer rates ranged between $203 and $233. Using a custom grazing rate of $0.55 kg^{-1}, returns to fertilizer applied ranged from a low of -$58.85 to a high of $101.75 for the 3 year period. In this case, the unfertilized control had the highest return, followed by the 34 and 68 kg N ha^{-1} at $44.55 and $4.40, respectively. The 102 kg N ha^{-1} rate lost an estimated $58.85 for the 3 years that residual N effects were measured. Additional economic analyses are needed to evaluate net returns for the 5 years of N fertilization plus the 3 years of residual N effects reported here.

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