Rangeland soil carbon and nitrogen responses to grazing

J.T. Manley, G.E. Schuman, J.D. Reeder, and R.H. Hart

ABSTRACT: Land managers, livestock producers, and the public are concerned about the effects of grazing on soil quality and sustainability of rangeland resources. Pastures at the High Plains Grasslands Research Station near Cheyenne, Wyoming, grazed for the past 11 years at a heavy stocking rate (67 steer-days/ha) under three management systems, were compared to continuous light grazing (22 steer-days/ha) and to livestock exclosures. The heavy stocking rate resulted in slightly less than 50% utilization of the annual forage produced, a level recommended by land management agencies. Prior to initiating this grazing research the rangeland had not been grazed for about 40 years. Soil organic carbon and nitrogen response were evaluated by collecting soil samples to 91 cm (36 in) depth. Soils had higher amounts of carbon and nitrogen in the surface 30 cm (12 in) on the grazed pastures compared to native rangeland where livestock were excluded. However, soil carbon and nitrogen below 30 cm was similar among all grazing treatments. Carbon and nitrogen dynamics were greatest in the surface 30 cm where more than three-fourths of the plant root biomass exists. Grazing strategies and stocking rates imposed for the past 11 years on this mixed grass prairie did not detrimentally affect soil organic carbon and nitrogen levels. The data, in fact, suggest that responsible grazing enhanced the overall soil quality as assessed by these parameters.

Research on grazing lands has historically focused on the effects of various management practices on forage production and animal response; little attention has been given to the impact of grazing on the nutrient dynamics of soils. Recent interest in "soil health" or "soil quality" has directed attention to grazing impacts on soil parameters that make up soil health/quality. Few studies have evaluated the effects of grazing on soil organic matter and its relationship to water and nutrient cycling, and related plant productivity. In general, the available data do not indicate any single or consistent response of soil organic carbon (C) and nitrogen (N) to grazing. Some research has reported increases in both soil organic C and N (Dormaar et al. 1990; Dormaar and Willms 1990a; Ruess and McNaughton), while other studies have found no response in soil organic C and N to grazing (Kieft; Mathews et al.; Milchunas and Lauenroth). Smoliak et al. reported that increased grazing pressure on mixed prairie resulted in decreases in needleandthread (*Stipa comata*) and an increase in blue gram (*Bouteloua gracilis*), which has a greater shallow root mass; hence, soil organic carbon increased. Bauer et al. found that grazing reduced soil organic C and increased soil organic N. These inconsistent findings demonstrate the complex interaction between grazing and soil organic matter.

Many factors determine the response of soil organic matter to livestock grazing. Floate summarized these factors as (a) the initial status of vegetation and soil, (b) environmental factors, especially moisture and temperature, and (c) grazing history (intensity, frequency, duration, and type of animal). Soils with inherently low soil organic C are more prone to change in response to grazing (Dormaar et al. 1977) than soils high in organic C. Precipitation and temperature limit above-ground biomass production and soil organic matter (Parton et al.), and influence rates of litter decomposition and nutrient cycling (Charley). Year-to-year fluctuations of environmental conditions may affect differences in biomass production as much as grazing (Ashby et al.; Milchunas and Lauenroth).

Grazing intensity, frequency, and duration all affect the plant community and the magnitude and direction of change in soil organic C and N. Light grazing can result in greater species diversity and production compared to areas where livestock grazing is excluded (Johnston). On the other hand, high intensity and/or early season grazing have been found to have a greater negative impact on litter and live plant biomass than light intensity and/or late season grazing of mixed prairie pastures in Canada (Naeth et al.). Moderate grazing of mixed grass prairie in North Dakota resulted in greater litter decomposition and soil N mineralization than either heavy or no grazing (Shariff et al.).

Most research on this subject has compared soil C and N concentrations in the surface soil of grazed pastures and non-grazed exclosures. However, animal grazing has been reported to increase soil bulk density (Bauer et al.; Dormaar and Willms 1990b; Pluhar et al.) and increases in soil bulk density will greatly affect the results if soil C and N concentrations, not total mass, are reported, greatly over-stating the response to grazing treatments (Simpson et al.). Soil organic C and N should therefore be reported based on mass. However, not everyone agrees how to best express and evaluate management effects on C and N changes in soil. Skene suggests that the use of soil bulk density to normalize data may lead to misinterpretation. He and other researchers presently assessing soil C and N dynamics are suggesting that soil volume be considered and that comparisons be made on equal soil volumes even though soil depth may vary because of bulk density. Additionally, since root biomass and distribution affect soil organic matter content and distribution, soil profiles should be sampled sufficiently deep to ensure that a majority of the rooting depth is included in the assessment.

The objective of our research was to evaluate the effects of several grazing management strategies on soil organic C and N after 11 years on a semi-arid mixed grass prairie. Grazing management strategies evaluated included zero, light, and heavy grazing intensities and season-long, rotationally-deferred, and short-duration rotation grazing.

Study sites and methods

Study sites. The research was conducted at the High Plains Grasslands Research Station near Cheyenne, Wyoming. The native rangeland is a mixed-grass prairie, with rolling topography and elevations ranging from 1910 to 1950 m (6266 to 6397 ft). The climate is semi-arid with an annual frost-free period of 127 days and mean (1871-1986) annual precipitation of 338 mm (13.3 in), of which 70% occurs from April 1 through September 30. Dominant soil series are Ascalon and Altvan sandy loams [mixed, mesic, Aridic Argiustoll (Stevenson et al.)].

Dominant cool-season grasses are western wheatgrass (*Pascopyrum smithii*) and needleandthread and the dominant warm-season grass is blue grama. A survey of the plant community prior to initiating the grazing study indicated the range sites of the area were in good condition.

J.T. Manley is a graduate research assistant, G.E. Schuman and J.D. Reeder are soil scientists, and R.H. Hart is a rangeland scientist, Rangeland Resources Research Unit, U.S. Department of Agriculture—Agricultural Research Service, Cheyenne, WY 82009.

J. Soil and Water Cons. 50 (3) 294-298

Reprinted from the *Journal of Soil and Water Conservation*
May-June 1995, Volume 50 Number 3

Prior to establishment of the grazing management phase of the research in 1982, the area had not been grazed by domestic livestock for about 40 years. Grazing strategies, grazing intensities, and pasture design are shown in Figure 1. Soils were sampled where grazing management was continuous season-long at a light stocking rate (22 steer-days/ha), and rotationally deferred, short-duration rotation, and continuous season-long, all at a heavy stocking rate (67 steer-days/ha). The heavy stocking rate resulted in slightly less than 50% utilization of the annual production. Further details of the grazing strategies are given in Hart et al. Before the grazing research started, permanent 50-m (160 ft) line transects were located on near-level (0-6%) sites in each pasture on the Ascalon soil series. The experimental design of the grazing study is a randomized block design with two replicate blocks (Hart et al.).

Soil sampling. In July 1993, soil samples were collected from the continuous season-long, light stocking rate (CL); continuous season-long heavy stocking rate (CH); short-duration rotation, heavy stocking rate (SH); rotationally deferred, heavy stocking rate (RH) pastures, and the exclosure (EX). Soil sample sites were established at 10 m (32 ft) intervals along the permanent 50 m (160 ft) line transects that had been established for evaluating plant community response to the grazing treatments. Five cores were taken on each transect to a depth of 30 cm (12 in) and separated into 0-3.8, 3.8-7.6, 7.6-15, and 15-30 cm (0-1.5, 1.5-3, 3-6, and 6-12 in) increments. Surface plant litter was carefully removed from the area where soil samples were taken. Cores were taken with a hydraulic soil sampling machine with a soil tube diameter of 4.6 cm (2 in). Because of soil moisture limitations, the deeper soil cores [30-91 cm (12-36 in)] were not taken until May 1994. Soil cores were taken to the 91 cm depth, the surface 30 cm increments removed, and samples collected for the 30-46, 46-61 and 61-91 cm (12-18, 18-24, 24-36 in) depths. The individual soil sample increments were placed in sealed plastic bags in coolers and transported to a constant temperature room 15°C (41°F) until analysis. Upon return to the laboratory the samples were broken up by hand and plant crowns and visible roots removed. Duplicate soil cores were collected at the second and fourth sampling locations on each of the transects for determining bulk density (Blake and Hartge) (Table 1).

Table 1. Soil bulk density of various grazing management strategies at varying soil depths

Soil Depth	Grazing Management				
	EX	CL	CH	RH	SH
cm	g/cm³				
0-7.6	1.01*	1.14	1.17	1.17	[illegible]
7.6-15	1.36	1.38	1.41	1.33	1.47
15-30	1.39	1.26	1.47	1.38	1.42
30-46	1.39	1.26	1.47	1.38	1.43
45-61	1.39	1.26	1.47	1.38	1.43
61-91	1.39	1.26	1.47	1.38	1.43

EX=exclosure, CL=continuous light, CH=continuous heavy, RH=rotationally deferred heavy, SH=short-duration rotation heavy

*values are a mean of four replicate samples, two samples taken on each of two transects

PASTURE DIAGRAM

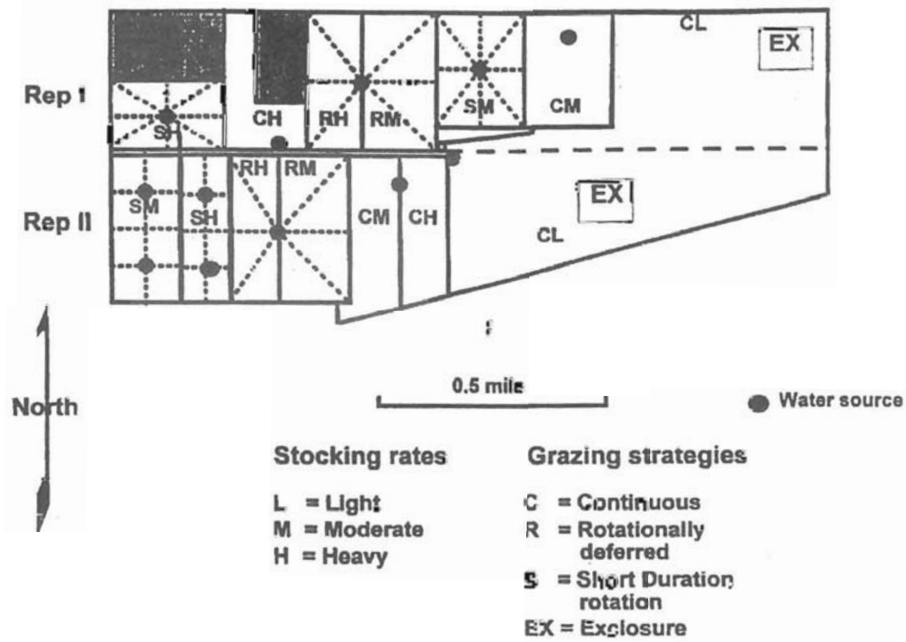

Figure 1. Diagram of grazing systems and stocking rates study, showing replications, grazing strategies, and pasture design

Sample analysis. The soil samples were dried in forced air ovens at 60°C (140°F) to a constant weight. The dried samples were ground to pass a 2-mm (0.08 in) screen. Soil organic N was determined on a subsample by the micro-Kjeldahl method described by Schuman et al. The digest was analyzed for ammonia by continuous flow colorimetric analysis (Technicon TRAACS 800). Soil organic C was determined utilizing a modification of the Walkley-Black procedure (Nelson and Sommers). The modification was a conversion from a colorimetric endpoint to a millivolt endpoint (Raveh and Avnimelech). Soil organic C was determined on a subsample of the soil ground to 0.50 mm (0.02 in).

Data analysis. Soil organic C and N concentration, for each transect and by depth increment, were converted to a mass basis (kg/ha) using the mean bulk density of the two soil cores obtained from each line transect. The bulk density data in Table 1 are presented for assessing C and N changes on a concentration basis because of the debate surrounding data presentation on a mass basis. Analysis of variance was used to evaluate treatment effects on soil organic C and N and least-significant-difference (LSD) procedures were used for mean separation (Steel and Torrie). All statistical analyses were evaluated at $P \leq 0.10$.

Results and discussion

Soil organic C and N in the surface 7.6 cm (3 in) of soil were significantly lower in the exclosure compared to all of the grazing management strategies (Figures 2 and 3). No differences existed between any of the grazing strategies, except that in the 3.8-7.6 cm (1.5-3 in) soil depth the organic C was significantly lower under the continuous-light grazing strategy than

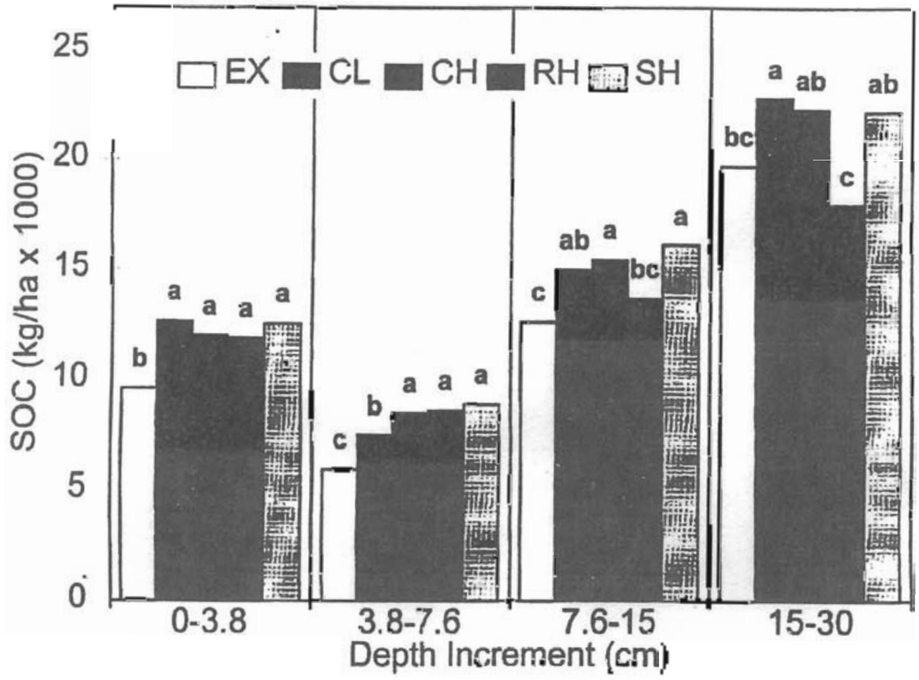

Figure 2. Soil organic carbon as affected by various grazing strategies (exclosure, continuous-light, continuous-heavy, rotationally-deferred heavy, and short-duration rotation heavy grazing), 0-30 cm soil depth

Bars within a soil depth increment with the same letter are not significantly different, $P < 0.10$

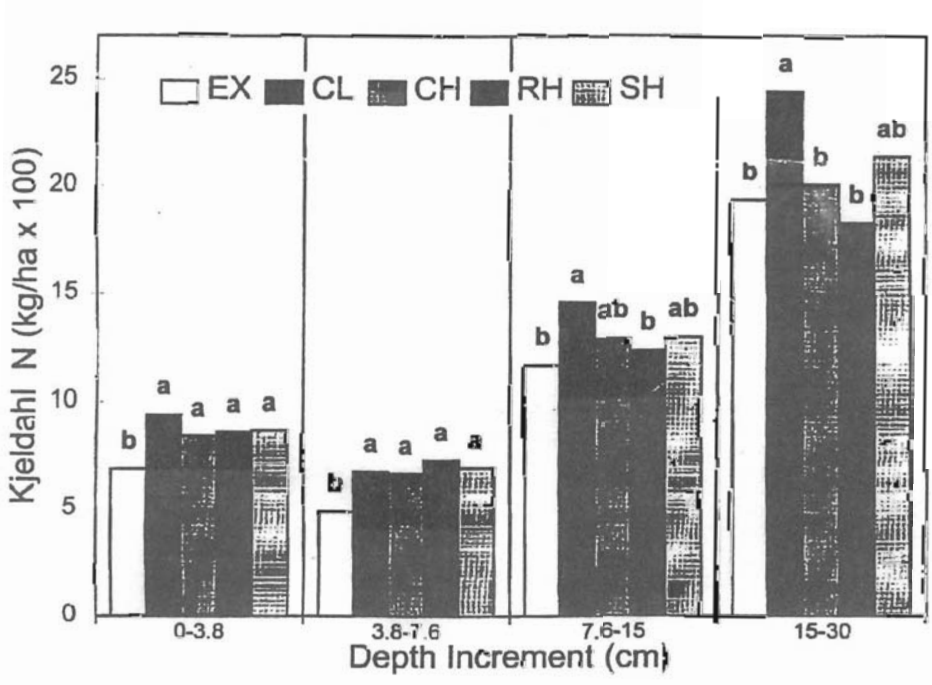

Figure 3. Soil organic nitrogen as affected by various grazing strategies (exclosure, continuous-light, continuous-heavy, rotationally-deferred heavy, and short-duration rotation heavy grazing), 0-30 cm soil depth

Bars within a soil depth increment with the same letter are not significantly different, $P < 0.10$

under any heavily grazed management, but was still significantly greater than in the exclosure. In the 7.6-30 cm (3-12 in) soil depth, differences in soil organic C and N contents among grazing strategies were more varied, but C and N contents in the exclosure remained lower than, or at best comparable to, C and N under the various grazing treatments. These data exhibit the importance of the surface few centimeters of soil as it relates to C and N dynamics under a grassland. Seventy to 90% of the root biomass is present in the surface 30 cm (12 in) of the soil in this type of grassland system (Dormaar et al. 1984); therefore, nutrient availability in this zone is very important. In the 30-91 cm (12-36 in) depth, soil organic C and N contents were not significantly different among ungrazed and grazed treatments (Figure 4). Soil organic C and N concentrations were quite low and variable at this depth in the soil. Only a small percentage of the root system is present in this soil depth increment; therefore, it is not surprising that grazing for 11 years had no affect on the lower portion of the soil profile.

The higher levels of soil organic C and N in the surface soil of the grazed rangeland may be due in part to the effects of grazing on litter and standing dead components of the above-ground biomass. Although grass roots are the primary source of organic matter in rangeland soils, above-ground litter provides a secondary source (Aandahl). The grazing treatments essentially eliminated the standing dead component and greatly reduced the surface litter component. Animal traffic may be enhancing physical breakdown and soil incorporation of this residual plant material. In comparison, 70% of the above-ground phytomass in the exclosures was in the form of litter and standing dead plant material. We estimate that this large component of recalcitrant material immobilized about 35 kg N/ha (31 lb N/ac) and 1550 kg C/ha (1,383 lb C/ac) above-ground in the exclosures[1]. Species composition shifts within a plant community can also result in C changes as discussed earlier (Smoliak et al.). However, our research did not show an increase in blue grama (Hart et al.) nor did it show a significant below-ground biomass response to grazing[2].

In general, defoliation is thought to stimulate an increase in allocation of C and N to regrowing leaves and a decrease in allocation of C to roots (Detling et al.), resulting in reduced root biomass (Dormaar et al. 1990; Johnston) and reduced root exudate contributions to soil organic matter. Thus researchers have predicted losses rather than gains, of soil organic C and N with grazing (Holland et al.). However, multiple harvests (simulated grazing) taken throughout the growing season have been shown to result in greater plant production than a single estimate obtained at peak standing crop (Mutz and Drawe). Dodd and Hopkins found that clipping

[1] G.E. Schuman. 1994. unpublished data.
[2] R.H. Hart. 1994. unpublished data.

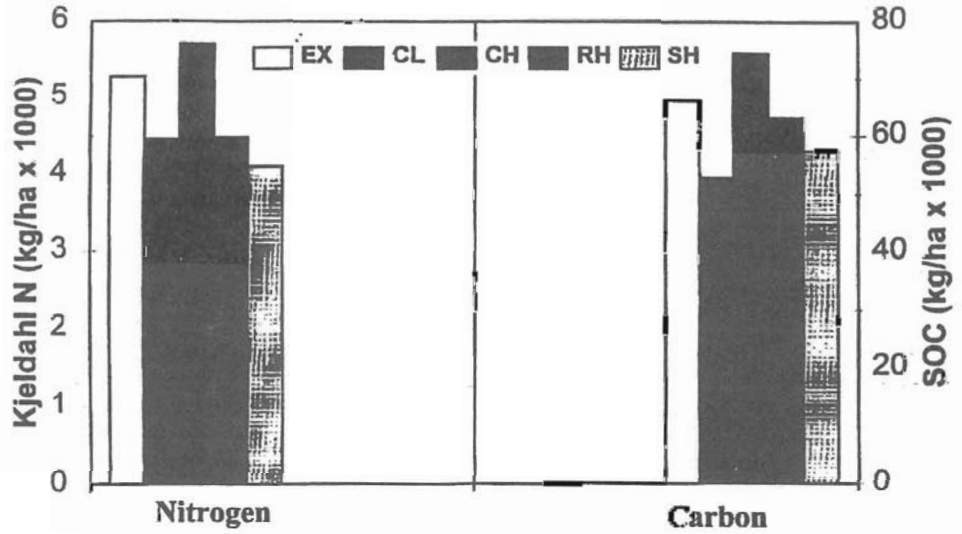

Figure 4. Soil organic nitrogen and carbon as affected by various grazing strategies (exclosure, continuous-light, continuous-heavy, rotationally-deferred heavy, short-duration rotation heavy grazing), 30-91 cm soil depth

No significant differences between grazing treatments within a parameter were observed, $F \leq 0.10$.

blue grama five times gave greater production than clipping three or four times, indicating that this species would respond to grazing defoliation and produce greater aboveground biomass. Grazing also stimulates tillering (Floate) and rhizome production (Schuman et al. 1973). Thus, if plant growth is stimulated by grazing, then greater CO_2 sequestration would occur, which could result in greater C allocation to below-ground portions of the system. Dyer and Bokhari (Dyer and Bokhari) inferred that blue grama responded to defoliation by rapidly translocating material to the crowns and roots and by increasing root respiration and/or root exudation rates. Ruess and McNaughton (Ruess and McNaughton) suggested that grazing accelerates the rate of nutrient cycling by stimulating primary production and net nutrient flux, thereby increasing the percentage of the system's nutrients that are available and which cycle rapidly near the soil surface.

The results of this study indicate that responsible grazing strategies implemented 11 years earlier did not detrimentally affect soil organic C and N levels in the active and important upper 30 cm (12 in) of the soil profile under native mixed-grass rangeland. In fact, the data indicate that grazing enhanced the overall soil quality as assessed by these parameters, and that plant production should be sustainable.

REFERENCES CITED

Aandahl, A.R. 1981. Soils of the Great Plains: Land Use, Crops and Grasses. University of Nebraska Press, Lincoln, NE.

Ashby, M.M., R.H. Hart, and J.R. Forwood. 1993. Plant community and cattle responses to fifty years of grazing on shortgrass prairie. USDA-Agricultural Research Service, Rangeland Resources Research Unit, RRRU-1, Cheyenne, WY.

Bauer, A., C.V. Cole, and A.L. Black. 1987. Soil property comparisons in virgin grasslands between grazed and nongrazed management systems. Soil Science Society of America Journal 51:176-182.

Blake, G.R., and K.H. Hartge. 1986. Bulk density-core method. In: A. Klute (ed.) Methods of soil analysis, Part 1, 2nd ed., Agronomy Monograph No. 9, American Society of Agronomy, Madison, WI.

Charley, J.L. 1977. Mineral cycling in rangeland ecosystems. In: R.E. Sosebee et al. (eds.) Rangeland Plant Physiology. Range Science Series 4:214-256.

Detling, J.K., M.I. Dyer, and D.T. Winn. 1979. Net photosynthesis, root respiration and regrowth of Bouteloua gracilis following simulated grazing. Oecologia 41:127-134.

Dodd, J.D., and H.H. Hopkins. 1958. Yield and carbohydrate content of blue grama as affected by clipping. Transactions of the Kansas Academy of Science 61:280-287.

Dormaar, J.F., A. Johnston, and S. Smoliak. 1984. Seasonal changes in carbon content, and dehydrogenase, phosphatase, and urease activities in mixed prairie and fescue grassland Ah horizons. Journal of Range Management 37:31-35.

Dormaar, J.F., A. Johnston, and S. Smoliak. 1977. Seasonal variation in chemical characteristics of soil organic matter of grazed and ungrazed mixed prairie and fescue grassland. Journal of Range Management 30:195-198.

Dormaar, J.F., S. Smoliak, and W.D. Willms. 1990. Distribution of nitrogen fractions in grazed and ungrazed fescue grassland Ah horizons. Journal of Range Management 43:6-9.

Dormaar, J.F., and W.D. Willms. 1990a. Effect of grazing and cultivation on some chemical properties of soils in the mixed prairie. Journal of Range Management 43:456-460.

Dormaar, J.F., and W.D. Willms. 1990b. Sustainable production from the rough fescue prairie. Journal of Soil and Water Conservation 45:137-140.

Dyer, M.I., and U.G. Bokhari. 1976. Plant-animal interactions: Studies of the effects of grasshopper grazing on blue grama grass. Ecology 57:762-772.

Floate, M.J.S. 1981. Effects of grazing by large herbivores on nitrogen cycling in agricultural ecosystems. In: F.E. Clark and T. Rosswall (eds.) Terrestrial Nitrogen Cycles. Ecological Bulletin 33:585-601.

Hart, R.H., M.J. Samuel, P.S. Test, and M.A. Smith. 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. Journal of Range Management 41:282-286.

Holland, E.A., W.J. Parton, J.K. Detling, and D.L. Coppock. 1992. Physiological responses of plant populations to herbivory and their consequences for ecosystem nutrient flow. The American Naturalist 140:685-706.

Johnston, A. 1961. Comparison of lightly grazed and ungrazed range in the fescue grassland of southwestern Alberta. Canadian Journal of Plant Science 41:615-622.

Kieft, T.L. 1994. Grazing and plant-canopy effects on semiarid soil microbial biomass and respiration. Biol. Fert. Soils. 18:155-162.

Mathews, B.W., L.E. Sollenberger, V.D. Nair, and C.R. Staples. 1994. Impact of grazing management on soil nitrogen, phosphorus, potassium and sulfur distribution. Journal of Environmental Quality 23:1006-1013.

Milchunas, D.G., and W.K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63: 327-366.

Mutz, J.L., and D.L. Drawe. 1983. Clipping frequency and fertilization influence herbage yield and crude protein content of 4 grasses in South Texas. Journal of Range Management 36:582-585.

Naeth, M.A., A.W. Bailey, D.J. Pluth, D.S. Chanasyk, and R.T. Hardon. 1991. Grazing impacts on litter and soil organic matter in mixed prairie and fescue grassland ecosystems in Alberta. Journal of Range Management 44:7-12.

Nelson, D.W., and L.E. Sommers. 1982. Total carbon, organic carbon, and organic matter. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.) Methods of soil analysis, part 2, 2nd ed., Agron Monograph No. 9, American Society of Agronomy, Madison, WI.

Parton, W.J., D.S. Schimel, C.V. Cole, and D.S. Ojima. 1987. Analysis of factors controlling soil organic matter levels in Great Plains Grasslands. Soil Science Society of America Journal 51:1173-1179.

Pluhar, J.J., R.W. Knight, and R.K. Heitschmidt. 1987. Infiltration rates and sediment production as influenced by grazing systems in the Texas rolling plains. Journal of Range Management 40:240-243.

Ravels, A., and Y. Avnimelech. 1972. Potentiometric determination of soil organic matter. Soil Science Society of America Proceedings 36:967.

Ruess, R.W., and S.J. McNaughton. 1987. Grazing and the dynamics of nutrient and energy regulated microbial processes in the Serengeti grasslands. Oikos 49:101-110.

Schuman, G.E., M.A. Stanley, and D. Knudsen. 1973. Automated total nitrogen analysis of soil and plant samples. Soil Science Society of America Proceedings 37:480-481.

Schuman, G.E., D.T. Booth, and J.W. Waggoner. 1990. Grazing reclaimed mined land seeded to native grasses in Wyoming. Journal of Soil and Water Conservation 45:653-657.

Shariff, A.R., M.E. Biondini, and C.E. Grygiel. 1994. Grazing intensity effects on litter decomposition and soil nitrogen mineralization. Journal of Range Management 47:444-449.

Simpson, J.R., S.M. Bromfield, and O.L. Jones. 1974. Effects of management on soil fertility under pasture. 3. Changes in total soil nitrogen, carbon, phosphorus, and exchangeable cations. Australian Journal of Experimental Agriculture and Animal Husbandry 14:487-494.

Skene, J.K.M. 1966. Errors in accretion studies of soil organic matter. Journal of the Australian Institute Agricultural Science 32:208-209.

Smoliak, S., J.F. Dormaar, and A. Johnston. 1972. Long-term grazing effects on Stipa-Bouteloua prairie soils. Journal of Range Management 25:246-250.

Steel, R.G.D., and J.H. Torrie. 1980. Principles and procedures of statistics; a biometrical approach. 2nd ed., MaGraw-Hill Book Co., New York, NY.

Stevenson, A., R.E. Baumgartner, and G.E. Schuman. 1984. High Plains Grasslands Research Station, Detailed Soil Survey. USDA-Agricultural Research Service, Cheyenne, WY and USDA-Soil Conservation Service, Casper, WY; and Wyoming Agricultural Experiment Station, Laramie. 1-84/1C/3.62.

Technicon TRAACS 800. 1987. Crude protein in feeds. Industrial Method No. 825-87t. Technicon Industrial Systems, Tarrytown, NY.