Stocking rate effect on soil carbon and nitrogen in degraded soils

K.N. Potter, J.A. Daniel, W. Altom , and H.A. Torbert

ABSTRACT: Stocking rate (SR) effects on soil organic carbon (OC) and nitrogen content resulting from 10 year continuous management were determined. Treatments were rotational grazing with four SR levels: light, moderate, heavy and non grazed. Two soils, a Durant loam (Udertic Argiustolls) and a Teller silt loam (Udic Argiustolls) located within common paddocks were sampled. Total OC mass in the surface 60 cm of the Durant soil, averaged across treatments, was 95.7 t ha^{-1} compared to 56.7 t ha^{-1} in the Teller soil. In the Durant soil, OC decreased as SR increased, with the non grazed exclosure having the greatest amount of soil OC. In contrast, the Teller soil had similar amounts of OC in the soil profile with all grazing treatments, but less without grazing. Total soil nitrogen followed similar trends as the soil OC. Soil properties should be considered to accurately assess the potential of grazing lands to sequester carbon.

Keywords: Grazing, organic carbon, sequestration

Increasing carbon storage in soils has been proposed as a method to reduce atmospheric carbon levels and reduce 'greenhouse gas' effects on global climatic conditions. Reclamation of degraded cropland by establishment of permanent grasses has been suggested as a method to sequester carbon in soils (Lal et al. 1998). For example, soils in central Texas, which were previously tilled and then returned to grass, accumulated carbon at a rate of 475 kg ha^{-1} yr^{-1} for periods up to 60 yr in the absence of grazing (Potter et al. 1999). However, it is unclear how grazing would have affected this rate of carbon accumulation.

Grazing provides income while possibly sequestering carbon in soils. However, grazing has a number of effects on soil and vegetative properties that may impact carbon sequestration potential. Changes in soil carbon content resulting from extended grazing have often been related to changes in plant species or species diversity. For example, Smoliak et al., (1972) reported total soil carbon concentration increased in the Ah horizon of a *Stipa-Bouteloua* soil after 19 yr of grazing by sheep to levels greater than those found in ungrazed exclosures. This was attributed to the fact that shallow rooted grass species had replaced deeper rooted species under grazing. However, a recent review by Milchunas and Laurenroth (1993) reported that differences in soil organic matter or C were nearly equally divided between positive and negative as a function of species diversity. Thus, species diversity appears to be a poor indicator of the effect of grazing on soil carbon sequestration.

Few studies have considered the interaction of soil properties and grazing on soil carbon content. Most previous studies have been on a range site or have included only one soil series. Dormaar and Smolak (1985) found that after 55 yr under moderate grazing in southeast Alberta, soil organic matter was lower for abandoned farmland than that of native range. Schuman et al. (1999) reported that 12 yr of grazing a native mixed grass prairie did not change the total mass of carbon and nitrogen in the root zone (0–60 cm) of Ascalon and Altvan *(Aridic Argiustoll)* soils. The distribution of the carbon and nitrogen was changed, however, with an increased concentration and mass of carbon and nitrogen in the surface 30 cm of grazed compared to non grazed pastures.

Frank et al. (1995) found that soil carbon varied among grazing treatments after 78 years on a Temvik Silt Loam *(Typic Haplorborolls)* in North Dakota. Moderate grazing reduced soil carbon compared to a nongrazed exclosure, while heavy grazing did not change the soil carbon content. It was noted that heavy grazing resulted in a species composition change from mixed prairie to predominately blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex Griffiths]. The change in species may have compensated for soil carbon losses resulting from grazing native grasslands.

Bauer et al. (1987) determined soil organic carbon content after 75 yr of grazing on native grassland and nongrazed virgin grasslands for three soil textural classes: moderately coarse, medium, and fine textured soils in North Dakota. The organic carbon content to 46 cm of the soils was consistently larger in nongrazed than in the grazed soils. The largest difference in organic C content between the grazed and nongrazed soils in the surface 7.6 cm occurred in the medium textured soils and the smallest difference in the fine textured. At depths from 7.5–46 cm, the largest differences occurred in the sandy soils and the least in the medium textures.

The objective of our study was to determine the effect of 10 yr stocking rate differences on carbon and nitrogen contents of two degraded soils in southern Oklahoma. Both soils occurred within a common range site for this region, Loamy Prairie (Maxwell and Reasoner 1966).

Methods and Materials

The study site was located on the Noble Foundation Coffey Demonstration Ranch near Marietta, Oklahoma. This area receives 842 mm rain yr^{-1} and has a mean daily temperature of 17°C. The soils had been tilled and farmed for an extended period prior to being abandoned in 1950 and reverting to grazing land. The Coffey ranch was grazed continuously for 37 yr from 1950–1987. During that time the annual stocking rate declined to about 20% of the original carrying capacity for the ranch as a whole. The ranch also experienced a considerable amount of soil erosion and gully formation. The Noble Foundation obtained control of the ranch in 1987 and has conducted stocking rate studies from 1988–1997 using a rotational grazing system. A single cattle herd, with an average cow weight of 500 kg, was used to graze paddocks of approximately 2.25 ha ('heavy' stocking rate of 22.5 Mg cattle ha^{-1}), 4.5 ha ('moderate' stocking rate of 11.2 Mg cattle ha^{-1}), and 9.0 ha ('light' stocking rate of 5.6 Mg cattle ha^{-1}). Graze periods ranged from 8–72 hr with an average time of 12 hr for heavy, 24 hr for

Kenneth N. Potter is a soil scientist with the U.S. Department of Agriculture, Agricultural Research Service at the Soil and Water Research Laboratory in Temple, Texas. J.A. Daniel is a geologist with the U.S. Department of Agriculture, Agricultural-Research Service at the Grazing lands Research Laboratory in El Reno, Oklahoma. W. Altom is an agronomist with the Samuel R. Noble Foundation in Ardmore, Oklahoma. H.A. Torbert is a soil scientist scientist with the U.S. Department of Agriculture, Agriculture Research Service at the Grassland, Soil and Water Research Laboratory, Temple, Texas.

moderate and 36–48 hr for light intensity grazing. At the initiation of the study, low seral plant groups, predominately ragweed *(Ambrosia artemisiifolia)*, dominated the pasture. After ten years, mid and high seral plant groups, predominately native grasses, had increased on all treatments, including the exclosure (Aljoe 1999).

Two soils within the paddocks were identified by an experienced Natural Resources Conservation Service soil scientist and selected for study. The finer textured soil was a Durant soil (Fine, smectitic, thermic Udertic Argiustolls). The coarser textured soil was a Teller soil (Fine-loamy, mixed, active, thermic Udic Argiustolls). Adjacent nongrazed enclosures (1987–1998) of each soil series were also studied. Six soil cores, 4.1 cm diameter by 60 cm length, were taken from each soil/grazing treatment at 10 m intervals and segmented to determine bulk density and soil organic carbon and total nitrogen distribution. Segment increments were 0–5, 5–10, 10–15, 15–20, 20–30, 30–40, 40–50, and 50–60 cm. Soil segment wet weight was determined. The soil core was then split lengthways. Half the soil core segment was weighed, oven dried at 105°C for 48 hr and the dry weight recorded.

The soil water content was determined and used to correct the segment weight for calculating soil bulk density. The other half of the soil core was air dried until it easily crumbled and easily identified plant material such as roots, stems, leaves, and plant crowns was removed. The remaining soil was crushed to pass through a 2 mm sieve. A subsample of the cleaned sample was ground in a rolling grinder (Kelley 1994) in preparation of organic carbon and total nitrogen analysis. The ground sample was oven dried for three hours at 65°C immediately before burning.

Soil organic carbon was measured using a Leco CR412 Carbon Determinator (Leco Corporation, St. Joseph, Missouri). Soil samples were burned at 575°C and CO_2 concentration in the airflow was determined with a solid state infrared detector. The combustion temperature was such that organic carbon was oxidized but inorganic carbon (i.e., CO_3) was not (Chichester and Chaison 1992; Rabenhorst 1988; Merry and Spouncer 1988). The CO_2 concentration was integrated over the duration of the burn to determine the sample organic carbon concentration. Soil samples were analyzed for total nitrogen on a FISON NA 1500 Nitrogen and Carbon Determinator (Fison Instruments, Inc., Dearborn, Michigan). Organic carbon and total nitrogen content (t ha^{-1}) were determined by multiplying concentrations and soil bulk density for individual samples.

Soil textural analysis was determined on selected soil samples using the hydrometer method (Day 1965). Data were analyzed using an ANOVA and Protected LSD to determine significant differences among treatments at each depth increment.

Results and Discussion

Soil physical properties. Soil texture varied between the two soils (Table 1). The Durant is finer textured, classified as a loam at the surface grading into a clay loam at depths below 35 cm and clay below 45 cm. The Teller soil is coarser textured and classified as a silt loam at the surface, grading into a loam below 10 cm, and a clay loam below 40 cm. Soil clay content in the Teller soil exclosure treatment was lower compared to that occurring in the grazed treatments (Table 1).

Bulk density was significantly different among grazing intensity treatments in the surface 10 cm in the Durant soil (Table 2). The exclosure had a lower bulk density than the grazed treatments in the surface 10 cm. Bulk density was similar among treatments at depths greater than 10 cm. In the Teller soil, bulk density was not significantly different among stocking rate treatments.

Soil organic carbon. Carbon concentration was lower at all depths in the coarser textured Teller soil compared to the finer textured Durant soil (Table 3). Stocking rate effects on soil organic carbon were also different on the two contrasting soils. Carbon concentrations were not significantly different among stocking rate treatments in the Teller soil. On the finer textured Durant soil, the exclosure had a greater concentration of C than the grazed paddocks at depths of 5–10, 15–20 and 20–30 cm. Low and moderate stocking rates resulted in a greater carbon concentration than the high stocking rate at 5–10 cm depths. The low stocking rate had a greater carbon concentration than the moderate and high stocking rates at 15–30 cm depths.

Total organic carbon content in the surface 60 cm of the Durant soil, averaged across stocking rate treatments, was 95.7 t ha^{-1} compared to 56.7 t ha^{-1} in the Teller soil (Figure 1). Management effects were quite different between the two soils. The exclosure had the greatest cumulative organic carbon content in the Durant soil profile (Figure 1). Low and moderate stocking rate treatments were similar in carbon content, while the high stocking rate treatment had the lowest carbon content. In the Teller soil, the exclosure had a lower cumulative carbon content as compared to the stocking rate treatments (Figure 1). This may have been associated more with the lower clay

Table 1. Average soil texture from all treatments.

	Exclosure			Low			Moderate			High		
Depth cm	Clay %	Silt %	Sand %	Clay %	Silt %	Sand %	Clay %	Silt %	Sand %	Clay %	Silt %	Sand %
					Teller soil							
0–5	8.8	49.3	41.9	11.4	54.0	34.6	12.9	52.5	34.6	11.7	55.6	32.7
5–10	10.7	45.6	43.6	12.3	54.3	33.5	20.2	46.9	32.8	13.4	56.5	30.0
10–15	12.6	44.6	42.8	19.3	51.3	29.4	21.8	42.9	35.2	17.6	52.5	29.9
15–20	14.5	43.6	41.9	20.6	51.8	27.5	22.5	44.8	32.6	19.9	50.5	29.5
20–30	18.9	42.3	38.7	23.7	49.2	27.0	24.0	45.4	30.6	23.1	48.9	27.9
30–40	21.4	40.6	38.0	27.2	48.5	24.3	27.8	41.7	30.4	25.9	47.5	26.4
40–50	21.6	35.9	42.5	28.5	47.2	24.4	29.2	41.9	28.8	27.2	46.5	26.3
50–60	22.5	40.9	36.5	26.6	47.7	25.7	32.4	39.5	28.1	27.3	46.5	26.2
					Durant soil							
0–5	20.5	47.9	31.6	24.7	45.5	29.7	24.2	49.0	26.7	23.2	41.5	35.3
5–10	24.1	46.1	29.8	29.4	42.9	27.7	27.4	46.8	25.8	25.8	39.5	34.7
10–15	26.9	45.4	27.7	33.2	42.2	24.7	29.0	47.2	23.8	28.4	36.6	34.9
15–20	29.6	45.2	25.2	35.7	42.0	22.2	32.2	44.4	23.4	35.7	42.0	22.2
20–30	35.1	42.3	22.6	38.3	40.8	20.8	36.3	42.4	21.3	32.3	38.7	28.9
30–40	40.6	38.5	20.8	40.6	39.2	20.2	39.6	41.0	19.4	40.1	39.2	20.7
40–50	44.2	35.2	20.6	42.9	37.4	19.6	40.8	40.4	18.8	43.7	36.0	20.2
50–60	46.2	35.1	18.8	44.9	34.3	20.8	43.8	38.9	17.3	44.8	33.7	21.4

Table 2. Mean soil bulk density values (Mg/H³).

Depth (cm)	Exclosure	Low	Moderate	High	LSD*
			Durant		
2.5	1.23	1.44	1.34	1.42	NS
7.5	1.42	1.54	1.49	1.55	0.05
12.5	1.48	1.53	1.51	1.54	NS
17.5	1.51	1.52	1.54	1.51	NS
25	1.54	1.56	1.61	1.55	NS
35	1.60	1.60	1.66	1.58	NS
45	1.60	1.61	1.64	1.59	NS
55	1.65	1.68	1.59	1.53	NS
			Teller		
2.5	1.23	1.32	1.44	1.25	NS
7.5	1.49	1.52	1.54	1.54	NS
12.5	1.58	1.49	1.52	1.53	NS
17.5	1.57	1.47	1.52	1.49	NS
25	1.57	1.50	1.53	1.52	NS
35	1.56	1.52	1.57	1.53	NS
45	1.59	1.56	1.59	1.57	NS
55	1.63	1.60	1.59	1.56	NS

* Least significant difference (P = 0.05). NS refers to non significant differences.

Table 3. Soil organic carbon concentration percentage.

Depth (cm)	Exclosure	Low	Moderate	High	LSD*
			Durant		
2.5	2.71	2.11	2.44	1.87	NS
7.5	1.83	1.38	1.44	1.13	0.21
12.5	1.59	1.31	1.15	1.08	NS
17.5	1.46	1.16	1.00	0.96	0.10
25	1.19	1.03	0.85	0.82	0.16
35	0.99	0.91	0.72	0.70	NS
45	0.84	0.76	0.67	0.58	NS
55	0.69	0.76	0.66	0.52	NS
			Teller		
2.5	1.10	1.43	1.60	1.77	NS
7.5	0.53	0.72	0.82	0.87	NS
12.5	0.47	0.65	0.71	0.67	NS
17.5	0.49	0.74	0.68	0.67	NS
25	0.51	0.70	0.61	0.52	NS
35	0.44	0.62	0.57	0.49	NS
45	0.45	0.54	0.54	0.44	NS
55	0.39	0.49	0.44	0.40	NS

* Least significant difference (P = 0.05). NS refers to non significant differences.

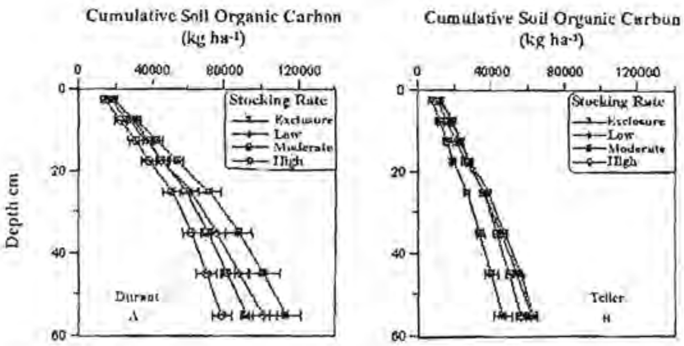

Figure 1. Cumulative organic carbon content with depth in two soils. Horizontal bars represent ± one standard deviation.

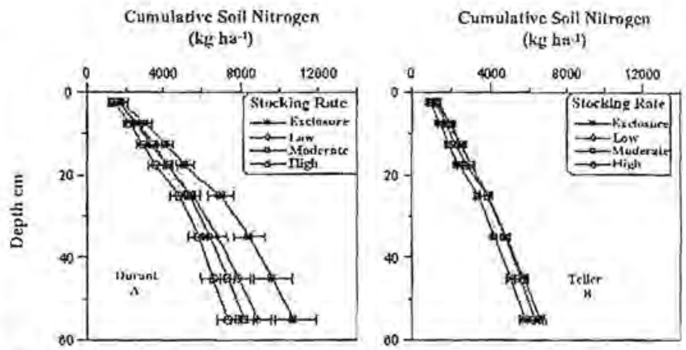

Figure 2. Cumulative total soil nitrogen content with depth. Horizontal bars represent ± one standard deviation.

Table 4. Total soil nitrogen concentration percentage.

Depth (cm)	Exclosure	Low	Moderate	High	LSD*
			Durant		
2.5	0.27	0.20	0.21	0.17	NS
7.5	0.18	0.12	0.13	0.11	0.02
12.5	0.15	0.11	0.11	0.09	NS
17.5	0.14	0.10	0.10	0.09	0.01
25	0.12	0.09	0.07	0.08	0.016
35	0.09	0.08	0.06	0.06	NS
45	0.08	0.07	0.06	0.05	NS
55	0.08	0.01	0.03	0.05	NS
			Teller		
2.5	0.13	0.15	0.16	0.18	NS
7.5	0.06	0.07	0.09	0.09	NS
12.5	0.06	0.07	0.07	0.07	NS
17.5	0.06	0.07	0.07	0.07	NS
25	0.06	0.07	0.06	0.06	NS
35	0.06	0.07	0.06	0.06	NS
45	0.06	0.06	0.06	0.05	NS
55	0.06	0.03	0.07	0.02	NS

* Least significant difference (P = 0.05). NS refers to non significant differences.

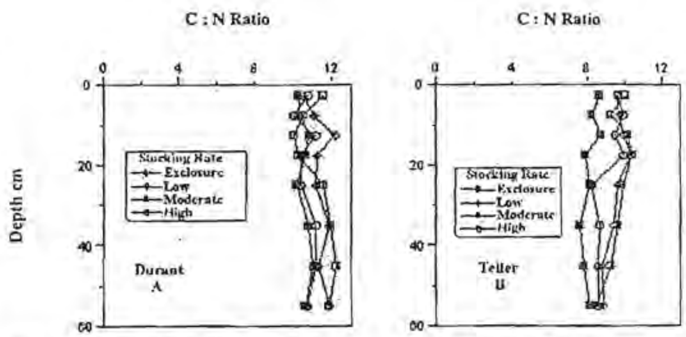

Figure 3. C : N ratios for two soils and four levels of grazing intensity.

content occurring in the exclosure than with the lack of grazing. With grazing, stocking rate had no significant effect on the carbon content in the Teller soil (Figure 1B).

Total Soil Nitrogen. Total soil nitrogen concentration of the Durant soil was greater in the exclosure than in the grazed paddocks at depths of 5–10 and 15–30 cm (Table 4). Differences among stocking rate treatments were relatively small and did not show any consistent trends with stocking rate. Total soil nitrogen concentration of the Teller soil was reduced compared to that of the Durant soil, especially in the surface 30 cm (Table 4). In the Teller soil, total soil nitrogen concentration was similar among all stocking rate treatments (Table 4). Nitrogen concentration effects were not significantly different among stocking rate treatments in the Teller soil.

Total soil nitrogen content in the surface 60 cm of the Durant soil was greatest in the exclosure, 10.7 t ha^{-1}, and lowest in the high stocking rate treatment, 7.3 t ha^{-1} (Figure 2). The low and moderate stocking intensities resulted in lower nitrogen content than the exclosure but greater than the high stocking rate treatment. Results were quite different in the Teller soil, where nitrogen content in the surface 60 cm of the exclosure was significantly less, 5.7 t ha^{-1}, than that in the grazed paddocks, which averaged of 6.4 t ha^{-1} (Figure 2). Differences in nitrogen content among grazed paddocks were not significant in the Teller soil.

C:N ratios. Carbon-Nitrogen (C:N) ratios were relatively uniform within a given soil. On the Durant soil, C:N ratios were generally between 10 and 12 (Figure 3). There were no consistent trends with stocking rate treatments and the ratio did not vary greatly with depth to 60 cm. On the Teller soil, C:N ratios tended to be lower, ranging between 8–10 (Figure 3). The exclosure had a significantly lower C:N ratio than that occurring in the grazed paddocks in the surface 20 cm. The C:N ratio of the grazed paddocks tended to decrease slightly at depths below 30 cm.

Summary and Conclusion

Prior periodic sampling of the paddocks (every three to four years over the 10-year time period of the stocking rate trial) had not shown consistent results or trends in organic matter content (Altom 1998). This was probably because the paddocks had been sampled as a single entity without regard to segregating soils. Nine or more soil samples were obtained at random within the paddock and composited before analysis. The blending of the soils masked the differences that were apparently developing between the two soils. The random sampling within the paddocks is not an unusual practice for range studies, which are often based upon range sites.

In this study, however, when the soils were sampled separately, several trends regarding soil carbon sequestration became apparent. The effect of stocking rate on soil carbon and nitrogen status was apparently altered by differences in soil properties, especially soil clay content. Clay is believed to alter carbon retention by bonding with the carbon and forming stable microaggregates which physically protect the organic carbon from oxidation (Follett 2000). Between the two soils, the finer textured Durant soil contained much more carbon than the coarser textured Teller soil across all stocking rate treatments. This is in agreement with the results of Nichols (1984) who reported that organic carbon generally increased with an increase in clay content in soils in the southern Great Plains. However, clay content affects may be dependent upon climatic conditions as clay content was found to have little correlation to soil organic carbon content in the northern Great Plains (Sims and Nielsen 1986).

Stocking rate affected the Durant and Teller soils differently. On the finer textured Durant soil, the more intensive the stocking rate, the lower the organic carbon content in the soil profile. In the coarser textured Teller soil, differences in stocking rate did not affect the organic carbon content present in the profile. Grazing apparently increased the soil organic carbon content compared to the exclosure, but this was confounded somewhat by lower clay content in the exclosure soil compared to that in the grazed treatments (Table 1). Grazing effects on soil nitrogen content were similar to the soil organic carbon results. Soil clay content also affected grazing effects in a stocking rate trial conducted in northeastern Colorado (Schuman et al. 2000). These results differ from those reported by Bauer et al. (1987) when comparing grazed and non grazed relict grasslands in central North Dakota. In that study, after 75 years, the greatest difference in organic carbon content between grazed and non grazed soils occurred in coarse textured soils, with the non grazed having the greatest amount. Differences also occurred with medium and finer textured soils, but to a lesser extent. Total soil nitrogen content was greater in the grazed soils than the non grazed soils (Bauer et al. 1987).

Soil properties and climatic interactions should be considered to accurately assess the potential of grazing lands to sequester carbon. Grazing management practices to maximize carbon sequestration apparently vary among soil series, with coarser textured soils less sensitive to stocking rate than finer textured soils in warm climates.

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REFERENCES CITED

Aljoe, H. Conversation with author, November 2, 1999.

Altom, W. Letter communication, May 20, 1998.

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.

Chichester, F.W. and R.F. Chaison, Jr. 1992. Analysis of carbon in calcareous soils using a two temperature dry combustion infrared instrumental procedure. Soil Science 153:237–241.

Day, P.R. 1965. Partial fractionation and particle-size analysis. In: A.L. Page et al. (eds). Methods of soil analysis. Part 2. Agronomy 9:545–567.

Dormaar, J.F. and S. Smoliak. 1985. Recovery of vegetative cover and soil organic matter during revegetation of abandoned farmland in a semi-arid climate. Journal of Range Management 38:487–491.

Frank, A.B., D.L. Tanaka, L. Hofmann, and R.F. Follett. 1995. Soil carbon and nitrogen of Northern Great Plains grasslands as influenced by long-term grazing. Journal of Range Management 48:470–474.

Follett, R.F. 2000. Organic carbon pools in grazing land soils. pp 65–86. In: Follett, R.F., J.M. Kimble, and R. Lal (eds). The potential of U.S. grazing lands to sequester carbon and mitigate the greenhouse effect. New York: Lewis Publishers.

Kelley, K.R. 1994. Conveyor-belt apparatus for fine grinding of soil and plant materials. Soil Science Society of America Journal 58:144–146.

Lal, R., J.M. Kimble, R.F. Follet, and C.V. Cole. 1998. The potential of U.S. cropland to sequester carbon and mitigate the greenhouse effect. Chelsea: Ann Arbor Press.

Maxwell, A.J. and R. Reasoner. 1966. Soil survey of Love County, Oklahoma. Prepared for the Superintendent of Documents., Washington D.C.: U.S. Government Printing Office.

Merry, R.H. and L.R. Spouncer. 1988. The measurement of carbon in soils using a microprocessor controlled resistance furnace. Communications in Soil Science and Plant Analysis 19:707–720.

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

Nichols, J.D. 1984. Relation of organic carbon to soil properties and climate in the southern Great Plains. Soil Science Society of America Journal 48:1382–1384.

Potter, K.N., H.A. Torbert, H.B. Johnson, and C.R. Tischler. 1999. Carbon storage after long-term grass establishment on degraded soils. Soil Science 164:718–725.

Rabenhorst, M.C. 1988. Determination of organic and inorganic carbon in calcareous soils using dry combustion. Soil Science Society of America Journal 52:965–969.

Schuman, G.E., J.E. Herrick, and H.H. Janzen. 2000. The dynamics of soil carbon in rangelands. pp 267–290. In: R.F. Follett, J.M. Kimble, and R. Lal (eds). The potential of U.S. Grazing Lands to sequester carbon and mitigate the greenhouse effect. New York: Lewis Publishers.

Schuman, G.E., J.D. Reeder, J.T. Manley, R.H. Hart, and W.A. Manley. 1999. Impact of grazing management on the carbon and nitrogen balance of a mixed-grass rangeland. Ecological Applications 9:65–71.

Sims, Z.R., and G.A. Nielsen. 1986. Organic carbon in Montana soils as related to clay content and climate. Soil Science Society of America Journal 50:1269–1271.

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.