6 Carbon Dynamics and Sequestration of a Mixed-Grass Prairie as Influenced by Grazing

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ABSTRACT

Grazing rangelands can influence plant community structure, soil chemical and physical properties, and the distribution and cycling of nutrients within the plant-soil system. Studies at the High Plains Grasslands Research Station near Cheyenne, Wyoming, have shown that after 12 yr of season-long grazing, the total C mass of the plant-soil (0–60 cm) system was not affected when compared to a nongrazed treatment. However, significant increases in the mass of C in the primary root zone (0–30 cm) of the soil were evident in the grazed treatments. A gas-exchange chamber used to assess CO_2 exchange rates (CER) of these grazing treatments exhibited as much as two times greater CER from mid-April through the end of June for the grazed treatments compared to the nongrazed treatment. This increase in CER was best related to a green vegetation index, hence the grazed pastures exhibited a more vigorous system. We hypothesize that grazing removes and/or prevents the accumulation of dead plant material, and reduces litter, thereby resulting in a warmer soil and enhancing the illumination of green shoots in the spring. This results in earlier spring green-up and greater CER compared to the nongrazed treatment. These data indicate that grazing does not have any detrimental affects on the C balance of the ecosystem and may enhance soil C and the potential for soil C-sequestration on rangelands if managed appropriately.

The effects of grazing on soil organic C dynamics in rangeland have been variable and inconsistent among the ecosystems studied (Milchunas & Lauenroth, 1993; Smoliak et al., 1972; Bauer et al., 1987; Frank et al., 1995). Studies have shown that grazing affects the soil organic C levels, either through changes in plant community (Coupland et al., 1960; Coupland, 1992; Dormaar & Willms 1990), or by other more subtle and less discernable responses such as changes in the chemical composition of organic matter, amount and quality of root exudates, increased root

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biomass, and more rapid cycling of C (Smoliak et al., 1972; Christie, 1979; Naeth et al., 1991; Shariff et al., 1994; Detling et al., 1979; Schuster, 1964; Davidson, 1978; Holland & Detling, 1990; Dyer & Bokhari, 1976).

Research conducted at the High Plains Grasslands Research Station near Cheyenne, Wyoming, on a northern mixed-grass prairie evaluated the effects of three grazing intensities on the soil organic C, plant-soil system C balance (Schuman et al., 1999), soil respiration and photosynthesis (LeCain et al., 1999). The general objective of these studies was to better understand the role of grazing on C cycling and its impact on sustainability of the grassland ecosystem. This chapter summarizes the overall findings of this research and relates them to the effects of grazing management on the potential for C sequestration by a mixed-grass ecosystem.

SITE DESCRIPTION AND METHODS

The research was conducted on a native northern mixed-grass rangeland, near Cheyenne, Wyoming (41°11′ N lat, 104°54′ W long), with rolling topography, elevations ranging from 1910 to 1950 m, a 127-d growing season, and an average annual precipitation of 384 mm, of which 70% occurs from April 1 through September 30 (NOAA, 1994). Soils are Ascalon sandy loams (mixed, mesic, Aridic Argiustolls) (Stevenson et al., 1984). Vegetation is predominately grasses [55% cool-season (C_3) species and 23% warm-season (C_4) species], forbs, sedges and half-shrubs. Dominant grasses are: C_3, western wheatgrass [*Pascopyrum smithii* (Rydb.) A. Love] and needleandthread (*Stipa comata* Trin & Rupr.); and C_4, blue grama [*Bouteloua gracilis* (H.B.K.) Lag. Ex Steud.]. This study area had not been grazed by domestic livestock for over 40 yr prior to establishment of the grazing treatments in 1982.

Three treatments were imposed: (i) nongrazed 0.2-ha exclosures, EX; (ii) continuous season-long light grazing (0.16–0.23 steers ha^{-1}), CL; and (iii) continuous, season-long heavy grazing (0.56 steers ha^{-1}), CH. The CL and CH pastures were 41 and 9 ha, respectively. The experiment was organized in a randomized block design with two replicate blocks (pastures). The heavy stocking rate utilized about 45% of the annual production. Details of the grazing treatments and pasture design are given in Hart et al. (1988).

Vegetation field transects (50 m) were established in each replicate pasture on near-level sites of the Ascalon soil map unit. Depth of the A horizon and solum of the Ascalon soil is 15 cm ±2 and 100 cm ±7, respectively. In July 1993, soil and plant samples were collected at 10-m intervals along the transects to assess the C content of the various components of the plant-soil system. Soil samples were collected to a depth of 60 cm and segregated into the following depth increments: 0 to 3.8, 3.8 to 7.6, 7.6 to 15, 15 to 30, 30 to 45, and 45 to 60 cm. Separate soil cores were obtained for root biomass and C assessment. Bulk density data also were obtained and used to convert the soil C concentrations determined on a mass concentration basis (mg kg^{-1}) to mass of C on a land area basis (kg ha^{-1}). Bulk density was obtained using a 3.2-cm diam. core 3.8 cm long for the first two depth increments and 7.6 cm long for the lower four depths (Blake & Hartge 1986). Root biomass was obtained using a washing and screening technique described by

Lauenroth and Whittman (1971). Surface litter and standing dead plant biomass were estimated at 10-m increments along the transects within a 0.18-m^2 quadrat. Estimates of annual production were obtained from duplicate 0.18-m^2 quadrats clipped from three 1.5- by 1.5-m temporary exclosures located throughout each of the grazed pastures; in the exclosures five 0.18-m^2 quadrats were sampled along the 50-m transects.

Soil organic C was determined using the Walkley-Black dichromate oxidation procedure (Nelson & Sommers 1982) and plant component C was determined with an automated combustion analyzer.

In 1995, five 1-m^2 angle iron metal frames were driven into the soil about 3 m from and parallel to each 50-m transect for assessing canopy CER, a measure of photosynthetic activity and soil respiration. The CER measurements were only made on one replicate pasture. The carbon dioxide exchange rate was measured with a 40 cm high by 100 by 100 cm Lexan (Regal Plastics, Littleton, CO[1]) chamber. The air in the chamber was circulated by small fans and a sample of the air pumped to a portable infrared analyzer that assessed the CO_2 depletion within the chamber during a 2- to 3-min period. The CER measurements were taken from 1000 to 1300 h (Mountain Standard Time) approximately every 3 wk during the growing seasons in 1995 to 1997. Measurements made on this site showed that maximum daily photosynthesis, as measured by CER, occurred during this period of the day which agrees with Detling et al. (1979). Each time CER measurements were made, a 10-pin point frame was used to determine the relative photosynthetic surface area (green vegetation index, GVI) within each of the CER frames (Warren-Wilson 1963). Green leaves, stems, and sheaths were reccorded by the point frame since all three are significant contributors to photosynthesis (Caldwell et al., 1981). Standard methods of assessing leaf area index would not work on a plant canopy of this short stature, and destructive sampling was unacceptable to achieve repeated sampling over time on the same areas. Soil respiration was measured on small plots (82 cm^2) adjacent to each CER frame in which all vegetation had been removed; all CER data were adjusted for soil respiration by subtracting the CO_2 contributed by soil respiration from the CO_2 depletion measured (PP Systems, SRC-1, Hertfordshire, UK[1]). The CER and soil respiration data were calculated on a ground surface area basis.

Greater detail of these studies are reported by Schuman et al. (1999) and LeCain et al. (1999).

RESULTS AND DISCUSSION

Grazing of these pastures at the heavy stocking rate decreased the peak standing crop (PSC), Table 6–1, and shifted plant composition. Western wheatgrass represented 45% of the PSC (weight basis) in the CL and only 21% in the CH grazing treatments, while the percentage of blue grama increased from 17% under CL to 27% under the CH treatment (Schuman et al., 1999). Even though the PSC was similar for the EX and CL treatments, plant composition was quite different. Forbs were the dominant species group in the EX (33%) but only accounted for 16 and

[1] Brand names and company identification are made for the benefit of the reader only and in no way imply endorsement by USDA or the Agricultural Research Service.

Table 6–1. Total above and below ground vegetation biomass as affected by grazing, 1993 (modified from Schuman et al., 1999).

Component	Exclosure (EX)	Continuous light grazing (CL)	Continuous heavy grazing (CH)	$LSD_{(0.10)}$
	kg ha^{-1}			
Above-ground				
Live biomass	1 330	1 224	816	270
Dead biomass	3 344	2 139	1 271	1 054
Total biomass	4 673	3 363	2 087	1 176
Root biomass				
0–15 cm	31 474	21 695	27 319	6 500
15–30 cm	5 516	6 971	5 289	n.s.
30–60 cm	1 618	1 779	1 162	n.s.
Total roots	38 609	30 446	33 770	n.s.
Total plant biomass	43 281	33 809	35 857	n.s.

22% in the CL and CH pastures, respectively (Schuman et al., 1999). Litter and standing dead biomass together accounted for 72, 63, and 61% of the above-ground plant biomass in EX, CL, and CH pastures, respectively. Root biomass in the 0- to 15-cm soil depth was significantly lower in the CL than in the EX and CH treatments but no difference was found between the EX and CH grazing treatments. Coupland et al. (1960) and Dormaar and Willms (1990) found that grazing significantly altered plant community composition and they found that with a change from a cool-season dominated community to warm-season species like blue grama, root biomass in the surface 15 to 30 cm increased. However, our root biomass did not respond like that reported by Dormaar and Willms (1990). The lack of a similar response may be because of less intense grazing or greater variability in the root biomass and/or the grass species involved in our study.

Carbon distribution in the above-ground vegetation components (Table 6–2), as would be expected, responded like the vegetation component biomass (Table 6–1). Heavy grazing significantly reduced live biomass C, while both the CL and CH treatments reduced dead biomass C. Mass of root C in the 0- to 15-cm depth was greater in the EX than for either of the grazing treatments. The greater root C

Table 6–2. C mass of vegetation components as affected by grazing, 1993 (modified from Schuman et al., 1999).

Component	Exclosure (EX)	Continuous light grazing (CL)	Continuous heavy grazing (CH)	$LSD_{(0.10)}$
	kg ha^{-1}			
Above-ground				
Live biomass	587	535	355	119
Dead biomass	1 015	742	394	255
Total above-ground C	1 602	1 277	749	252
Roots				
0–15 cm	7 166	6 011	5 763	1 073
15–30 cm	1 244	1 646	1 312	n.s.
30–60 cm	379	504	346	n.s.
Total root C	8 790	8 160	7 421	n.s.
Total plant C	10 392	9 437	8 170	1 259

Table 6–3. Soil profile C mass and total system C mass of a grazed mixed-grass prairie, 1993 (modified from Schuman et al., 1999).

Soil profile	Exclosure (EX)	Continuous light grazing (CL)	Continuous heavy grazing (CH)	$LSD_{(0.10)}$
	kg ha^{-1}			
Depth increments				
0–3.8 cm	9 595	12 675	12 000	1 309
3.8–7.6 cm	5 906	7 457	8 478	660
7.6–15 cm	12 662	15 009	15 472	1 573
0–15 cm	28 162	35 141	35 950	2 188
15–30 cm	19 761	22 847	22 348	2 485
0–30 cm	47 923	57 998	58 298	2 463
30–45 cm	22 932	20 353	25 281	n.s.
45–60 cm	17 291	13 595	17 689	n.s.
0–60 cm	88 147	91 937	101 267	11 853
Total ecosystem C (includes plant components)				
0–30 cm	58 315	67 425	66 468	4 334
0–60 cm	98 539	101 374	109 437	n.s.

mass and the greater root biomass at this depth may be due in part to the greater proportion of forbs found in the EX. The forbs have much larger roots and represent greater root biomass than the grass roots. The organic soil C mass in the 0- to 30-cm soil depth was significantly lower in the EX than either of the grazed treatments (Table 6–3). Blue grama has been shown to partition more C below-ground in blue grama-dominated systems (Coupland & Van Dyne 1979) and in mixed-grass prairie (Frank et al., 1995). Even though we could not detect a significant increase in root biomass in the grazed plots, we did observe a slight increase in C/N of the root material from the grazed treatments (CL 27:1, CH 28:1) compared to the 24:1 for the EX. This supports the point that forb roots present in the EX represented less C than the more fibrous root systems present in the CL and CH pastures. Frank et al. (1995) showed a similar, but not significant, increase in the C/N of the soil-root composite under grazing compared to the nongrazed exclosure. Their data also showed that grazing resulted in an increase in blue grama and an increase in the $\delta^{13}C$ that further substantiates an increase in C_4 species contribution to the organic C pool. Dodd and Hopkins (1985) and Mutz and Drawe (1983) showed that simulated grazing stimulated greater above-ground production that resulted in greater root growth. Dyer and Bokhari (1976) also suggested that simulated grazing may stimulate root respiration and root exudation. Increased below-ground C in the grazed treatments was limited to the surface 30 cm where >90% of the root biomass exists in these ecosystems. About 89 to 93% of the ecosystem C was stored in the soil organic matter of the 0- to 60-cm soil depth, with less than 10% found in the vegetation components. The roots accounted for 85 to 91% of the vegetation component C. Therefore, the effect of grazing on the above-ground plant components has limited potential impact on the total C mass of the system. However, any effect it has on plant growth and resource transfer to below-ground components can significantly impact system C distribution. Above-ground vegetation components have a greater potential to photochemically oxidize (Coupland & Van Dyne 1979) and be lost from the system unless grazing breaks down the plant material and encourages soil contact and/or incorporation and decomposition.

Canopy CER, soil respiration rate, and GVI were measured for three growing seasons (1995–1997). The results were similar in all 3 yr (LeCain et al., 1999); therefore for brevity, only the 1997 data are shown here. Early season CER of the plant community in the grazed treatments was as much as two times that exhibited by the plant community of the EX treatment (Fig. 6–1). This grazing induced increased CER was generally observed mid-April through the end of June, and was closely related to the green vegetation index (Fig. 6–1) on the sites. The CER and GVI data illustrate that grazing caused earlier and more vigorous growth that resulted in greater GVI, and hence greater early season photosynthesis. Even though LeCain et al. (1999) showed that the growing season average CER was not signif-

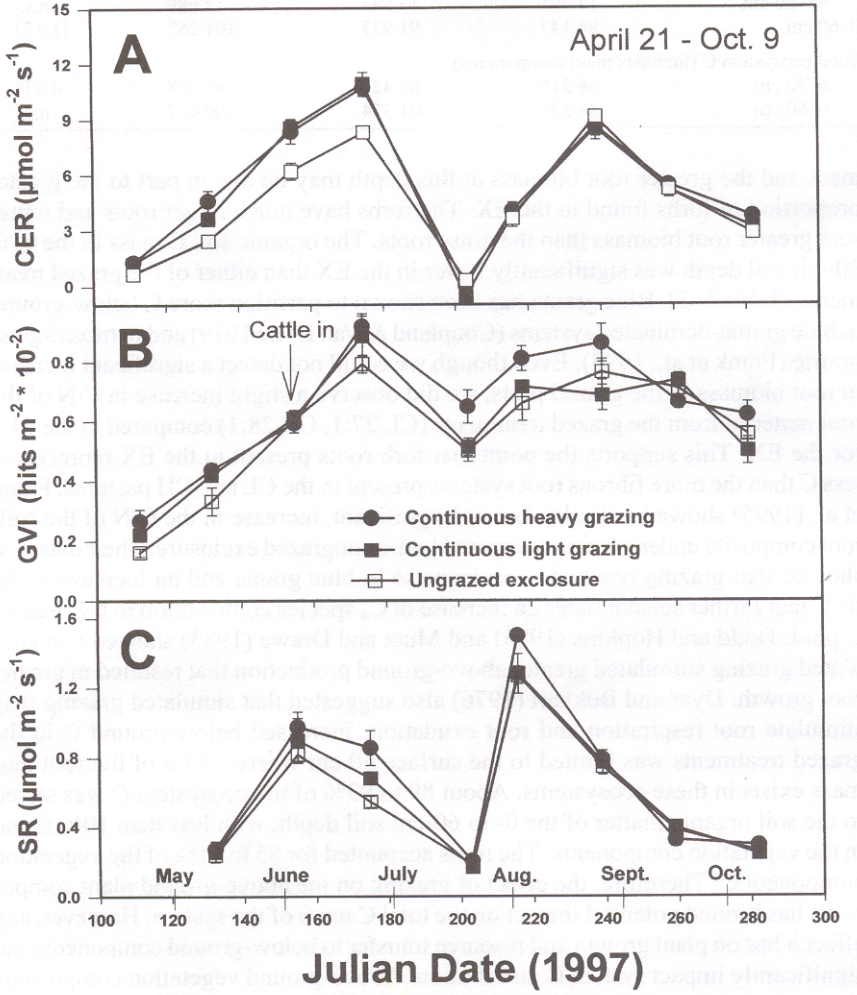

Fig. 6–1. CO_2 exchange rate (CER), green vegetation index (GVI), and soil respiration (SR) of three mixed-grass prairie pastures subjected to different grazing intensities, 1997. Data are means of five replications ± standard error (from LeCain et al., 2000).

icantly different between the grazing treatments, the potential for greater above-ground production is almost always greater during the early part of the growing season, when soil moisture and cool temperatures are more favorable for cool-season, C_3 dominated grasslands than during the latter warmer and typically drier portion of the growing season. Eighty to one-hundred percent of the PSC on the northern mixed prairie in southeastern Wyoming is typically achieved by 30 June (W.S. Johnson, 1984, unpublished data; D. Gasseling, 1998, unpublished data). Assuming that the accrual of new below-ground plant C corresponds to above-ground growth, then one also would assume that production of new below-ground tissues in the spring also dominates seasonal growth rates, and that below-ground production is limited in the latter half of the growing season. However, LeCain et al. (1999) found that substantial photosynthesis can occur in these grasslands in the second half of the growing season, assuming stored soil water does not become depleted. If that is true, then where does the C go when conditions are favorable and mid- to late-season photosynthesis rates are high? LeCain et al. (1999) speculated that much of the C may go to below-ground organs. As perennial plants prepare for winter dormancy, they tend to partition more photosynthate to below-ground storage compounds (Smith, 1973). The same mechanism apparently exists in cool-season grasses like western wheatgrass as they enter the dry, hot days of summer (Morgan et al., 1998). However, rates often are limited by low available soil water so the total amount of photosynthate available for translocation is usually limited. Further, since much of the C that goes below-ground at this time is converted to storage carbohydrates, most of it may be used in the regeneration of above-ground tissues, and so may not reside very long in the soil. For these reasons, we speculate that spring is generally the most important time for the production of plant C that has a significant residence time in the soil. The fact that photosynthesis rates were high in the grazed pastures in the spring could account for a portion of the increased C mass observed in the surface 30 cm of the soil profile.

There also was a trend for greater soil respiration in the grazed compared to the nongrazed treatment early in the season, particularly in the CH pasture, Fig. 6–1. Since the CER data are corrected for soil respiration, this is not a factor in the CER treatment differences. This indeed is another indication of greater biological activity during the early part of the season in the grazed pastures. The reduction of litter and standing dead plant material (Table 6–1) most likely allows better light penetration to the soil, creating warmer soil temperatures and a warmer micro-environment for plant growth and soil microbial activity.

Our research has shown that grazing does not adversely affect the C resources of this system, and in fact shows an increase in the soil C mass associated with the surface 30 cm of soil, which is the most active portion of the soil profile as it relates to root growth and microbial activity. We believe this increase in soil organic C is the result of several things: enhanced incorporation and decomposition of the litter and standing dead through hoof action of the grazing animals, transfer of net primary production to below-ground plant parts, increased plant vigor, improved plant community quality (fewer forbs more perennial grass), and increased plant vigor during early portion of the growing season (exhibited by increased CER and GVI). Increased soil C in the 0- to 30-cm zone has important implications to management and the potential C sequestration by these grasslands. These ecosystems

developed under grazing by large herbivores and removing livestock from this system could over the long-term reduce soil C and the productivity and sustainability of the system (Milchunas et al., 1988).

Several questions require further study. We need to quantify the effects of grazing on root respiration, elongation, and exudation and plant C allocation. These factors have a major impact on the potential sequestration of C and its cycling, since these processes produce soil C that is readily available to the microbial cycling of nutrients.

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