Long-term Grazing Effects on *Stipa-Bouteloua* Prairie Soils[1]

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Highlight

The effects of grazing on *Stipa-Bouteloua* prairie soils in Alberta were evaluated after 19 years of continuous summer use by sheep at three stocking intensities. Analysis of the soils under the heavy grazing treatment showed lower values for pH and percent spring moisture but higher values for total carbon (C), alcohol/benzene-extractable C, alkaline-soluble C, polysaccharides, and belowground plant material than the soil under light or no grazing. The results were attributed to changes in amounts and kinds of roots due to species changes caused by grazing and to increased amounts of manure deposited by sheep on fields grazed at a higher intensity. Shallow-rooted species replaced the deeper-rooted ones on the drier environment induced by heavy grazing.

Grazing studies have emphasized plant-animal relationships and have usually considered range soils only in relation to damage by erosion. But the kind of vegetation affects and modifies the soil on which it grows (Humphrey, 1962). Hence, changes in vegetation caused by grazing animals should affect and modify soil of grazed fields.

Results of a study of long-term grazing effects on fescue grassland soils (Johnston et al., 1971) showed that very heavy grazing by cattle of range that previously had been lightly grazed changed the color of the Ah horizon from black to dark brown and the pH from 5.7 to 6.2, reduced percent organic matter, decreased percent soil moisture, reduced percent total P but increased available P, and increased soil temperature. We suggested that the results reflected increased use of vegetation by cattle and, hence, increased erosion from the more heavily grazed fields.

The purpose of this study was to assess long-term effects of grazing by sheep on *Stipa-Bouteloua* prairie soils.

Materials and Methods

The study site was at the Canada Department of Agriculture Research Substation, Manyberries, Alberta, where the vegetation is that of the mixed prairie (Coupland, 1961), the climate is semiarid, and the annual precipitation averages about 31 cm. The soil is a member of the Brown Subgroup of the Solod Great Group of the Solonetzic Order. It has a leached Ae horizon and a strongly columnar B horizon. Numerous shallow, eroded pits are present throughout the area. Profile description is:

Ah	0–10 cm	Brown (10YR 4/3–5/3, dry), loam to sandy loam, weak platy to granular.
Ae	10–14 cm	Grayish to pale brown (10YR 5/2–6/3, dry), loam, platy.
Bnt	14–27 cm	Pale brown (10YR 6/3, dry), clay loam to sandy clay loam, round-topped columnar.
Cca	At 27 cm	Light brownish gray (10YR 6/2, dry), massive.

In 1950 the study site was divided into three fields. Prior to 1950 the area was lightly grazed by sheep. From 1951 these fields were grazed by ewes with lambs from about May 1 to November 1 each year. The grazing treatments were: light, 2.5 hectares per animal unit month (AUM); moderate, 2.0 ha/AUM; and heavy, 1.7 ha/AUM. A nearby exclosure, protected since 1928, served as an ungrazed control. Percentage basal area of vegetation was determined by the vertical point method in August 1950 and 1969.

In April 1970, 10 random core samples (10 cm diameter) were obtained from the Ah horizon of the soil profile from each grazed field and from the ungrazed exclosure. After the samples were air-dried and ground to pass a 1-mm screen, their dry colors were rated according to the Munsell (1954) notation. Moisture content was determined at time of sampling. Moisture retention, expressed as percent of air-dry basis (U.S. Salinity Laboratory Staff, 1954), was determined at 1, 5, and 15 bar, and at 100, 200, 300, and 500 mbar. (Moisture retention at 15 bar and at 200 mbar was taken as an index of permanent wilting percentage and field capacity, respectively.) Neutral NH_4OAc was used for the displacement of exchangeable cations and NaOAc solution at pH 8.2 for the determination of the cation exchange capacity (U.S. Salinity Laboratory Staff, 1954). Exchange acidity was determined with $BaCl_2$ triethanolamine at pH 8.1 (Black, 1965b). Soil pH was measured in 0.01 M $CaCl_2$. Total carbon (C), nitrogen (N), nitrates (NO_3) phosphorus (P), and $NaHCO_3$-soluble P were determined as outlined by Black (1965b). Polysaccharide content was determined using anthrone (Brink et al., 1960). Two separate fractions of organic matter, one that is soluble in alcohol:benzene (1:1 EtOH: C_6H_6) and one that is soluble in alkaline solution (0.1 N NaOH), were determined. The first fraction, which included the fats, resins, waxes, and humic substances, is, henceforth, referred to as alcohol/benzene-extractable C and the second fraction as the alkaline-soluble C. An additional 10 samples per field were analyzed for bulk density (U.S. Salinity Laboratory Staff, 1954) and particle size (Black, 1965a).

Table 1. Basal area (%) of vegetation on study areas at Manyberries, 1950 and 1969.*

Species	Study area in 1950	Study areas in 1969 by grazing treatments			
		Ungrazed	Light	Moderate	Heavy
Blue grama	2.0	0.3	2.4	2.8	3.6
Needle-and-thread	0.6	2.2	1.3	1.2	0.5
Western wheatgrass	1.4	1.3	1.7	1.2	0.7
Other grasses	1.3	1.4	1.6	1.5	1.1
Low sedge	0.9	0.4	0.5	0.8	1.1
Forbs and shrubs	0.5	0.4	0.7	0.9	0.4
Little club moss	7.1	9.6	18.7	22.6	26.0

* Each value is the mean of 4200 points.

A respiratory study was conducted[2] on soils from the heavily-grazed and ungrazed fields. Duplicate 100 g samples of soil were placed in a respiration apparatus and incubated at 28 C with moisture maintained at 200 mbar or about 18%. Evolved CO_2 was absorbed in approximately 1 N NaOH, and amounts were determined by differential titration using a Beckman automatic titrator. Glucose, equivalent to 2000 ppm C, was added to half of the samples. The general procedure is described by Chandra and Bollen (1960) and by Bollen and Ku (1961). Results were plotted as accumulative difference in C released (mg/100 g) as CO_2 from glucose-treated and untreated soil.

Ten soil cores, 6.5×60 cm, were obtained from each field, and amounts of belowground plant material by 15 cm increments were measured. Hot-water-soluble carbohydrate content of belowground plant parts from the upper 15 cm increment of the soil profile was determined (Deriaz, 1961) .

Results

Vegetation

Species composition of the vegetation changed as a result of grazing. Percentage basal area of blue grama (*Bouteloua gracilis* (HBK.)

Lag.), low sedge (*Carex eleocharis* Bailey), and little club-moss (*Selaginella densa* Rydb.) increased with increased grazing pressure whereas that of needle-and-thread (*Stipa comata* Trin. and Rupr.) and western wheatgrass (*Agropyron smithii* Rydb.) decreased (Table 1).

Weight of belowground plant parts in the upper 15 cm and in the 0–60 cm increments of the soil profile increased significantly as grazing pressure increased, did not differ significantly in the 15–30 and 30–45 cm depths, but decreased significantly at the 45–60 cm depth (Table 2). Water-soluble carbohydrate content of belowground plant parts from the upper 15 cm increment was significantly greater under light or no grazing than under moderate or heavy grazing.

Soil

Percentage total C, alcohol/benzene-extractable C, alkaline-soluble C, exchangeable acidity, and the C/N ratio increased whereas percent soil moisture, soil pH, and exchangeable calcium (Ca) and sodium (Na) decreased with increased grazing intensity (P < .05, Table 3). There were no significant differences in color, texture, moisture tension, bulk density, N, total and available P, exchangeable potassium (K), and cation exchange capacity (CEC).

Amounts of polysaccharides in the Ah horizon of soil of the fields increased significantly with grazing intensity and paralleled the amounts of manure deposited by sheep during the study. The amounts of polysaccharides were 201, 219, 229, and 262 mg/100 g of soil from the ungrazed, lightly grazed, moderately grazed, and heavily grazed fields, respectively. Estimated amounts of manure deposited were 3,100, 3,800, and 4,400 kg/ha on the light, moderate, and heavily grazed fields, respectively. Analysis of soil outside and inside the holding pens showed that polysaccharides totalled 240 and 532, 293 and 533, and 400 and 706 mg/100 g of soil from the lightly grazed, moderately grazed, and heavily grazed fields, respectively.

Table 2. Weight and water-soluble carbohydrate content of belowground plant parts of study areas grazed at various rates for the previous 19 years at Manyberries, 1970.*

Measurement and depth	Grazing treatments			
	Ungrazed	Light	Moderate	Heavy
Belowground plant biomass (kg/ha)				
0–15 cm	14,955 a	16,163 ab	18,946 b	24,038 b
15–30 cm	2,681 a	2,663 a	2,413 a	2,529 a
30–45 cm	2,120 a	2,495 a	1,877 a	2,299 a
45–60 cm	1,330 a	861 b	457 b	599 b
Total	21,086 a	22,182 a	23,693 a	29,465 b
Water-soluble carbohydrate content of roots (mg/g)				
0–15 cm	22.0 a	21.4 a	17.6 b	14.8 b

* Each value is the mean of two determinations on each of ten samples. Means in the same row followed by the same letter do not differ significantly at the 5% level (Duncan's multiple range test).

**Table 3. Characteristics of Ah horizon of soil from the study areas grazed at various rates for the previous 19 years at Manyberries, 1970.*

Characteristic	Grazing treatments							
	Ungrazed		Light		Moderate		Heavy	
Color (dry)	10YR 4/3		10YR 5/3		10YR 5/3		10YR 5/3	
Texture								
sand (%)	53	a	51	a	51	a	52	a
clay (%)	17	a	16	a	15	a	15	a
Soil moisture								
April 1970 (%)	19.0	a	15.1	b	15.0	b	11.1	c
200 mbar tension (%)	18.4	a	17.4	a	17.2	a	17.0	a
15 bar tension (%)	7.3	a	6.7	a	6.1	a	6.5	a
Bulk density (g/cm³)	1.27	a	1.25	a	1.28	a	1.28	a
Total C (%)	1.10	a	1.15	ab	1.16	ab	1.38	b
Total N (%)	0.12	a	0.12	a	0.11	a	0.12	a
NO_3-N (µg/g)	0.53	a	0.68	a	0.78	a	1.00	a
C/N ratio	9.1	a	9.9	b	10.4	b	10.3	b
Alcohol/benzene- extractable C (%)	0.054	a	0.065	a	0.078	b	0.079	b
Alkaline-soluble C (% of total C)	15.5	a	17.2	b	18.0	bc	19.5	c
Total P (%)	0.035	a	0.035	a	0.032	a	0.035	a
Available P (µg/g)	2.5	a	2.6	a	2.5	a	2.3	a
Soil pH ($CaCl_2$)	6.4	a	6.3	ab	6.0	b	5.8	b
Exchangeable cations								
Ca (meq/100 g)	8.57	a	5.84	b	5.04	b	4.75	b
K (meq/100 g)	0.70	a	0.74	a	0.65	a	0.68	a
Na (meq/100 g)	0.31	a	0.22	b	0.23	b	0.20	b
Exchangeable acidity (pH 8.1 (meq/100 g)	2.60	a	2.72	a	2.92	a	3.40	b
CEC (meq/100 g)	15.1	a	13.7	a	13.7	a	13.2	a

* Values are means of two determinations on each of ten samples. Means in the same row followed by the same letter do not differ significantly at the 5% level (Duncan's multiple range test).

The accumulative difference between the CO_2 released by the glucose-treated and the untreated soil was greater for soil samples from the heavily grazed than from the ungrazed fields after 10 days (Fig. 1).

With few exceptions, correlation coefficients among various soil factors were highly significant (Table 4).

Amounts of elements removed by animals from soil of the grazing fields were low in relation to total amounts in the profile. The estimated amounts of elements removed annually were 0.3, 0.5, and 0.6 kg/ha N; 0.09, 0.12, and 0.15 kg/ha P; and 0.16, 0.21, and 0.25 kg/ha Ca from the fields grazed at the light, moderate, and heavy intensity, respectively. The estimated amounts of elements contained in the Ah horizon in the ungrazed field were 2,700 kg/ha N, 780 kg/ha P, and 8,700 kg/ha Ca.

Discussion

Increased grazing pressure had little effect on physical characteristics of the soil such as texture, moisture tension, and bulk density (Table 3); or on total and available P and N content. But a number of significant changes did occur. The pH changed from 6.4 under no grazing to 5.8 under heavy grazing. Total C, alcohol/benzene-extractable C, alkaline-soluble C, and polysaccharides all increased with increasing grazing pressure. Most of these soil characteristics were significantly correlated (P < 0.05, Table 4). However, the correlation of total C content with alkaline-soluble C was low and not significant. It was likely that the increase did not occur simultaneously, that is, the total C increased relatively less than did the alkaline-soluble C, when considered as percent in the soil. Usually a negative relationship exists between alkaline-soluble C and exchangeable Ca; however, in this study the relationship was not significant.

Although data obtained in laboratory respirometers, in which soil was wetted and treated with glucose, cannot be extrapolated to field conditions, the effect of different grazing intensities on potential in vitro decomposition rates can be studied using this technique. The greater difference in CO_2 release between untreated and glucose-treated soils in heavily grazed than in ungrazed areas was expected because of the greater amount of total belowground plant biomass (Table 2), total C, NO_3-N (Table 3), and the polysaccharide content of belowground plant materials in the heavily grazed areas than in the ungrazed ones.

Soil compaction on the fields grazed by sheep was not a problem on these generally dry soils. There were no differences in bulk density of soil from grazed or ungrazed fields. Soil compaction by trampling has been reported in other studies (Humphrey, 1962).

The increased weight of belowground plant material on the heavily grazed field at depths to 15 cm reflects changes in the vegetative cover (Table 2 and 1). Deeper-rooted needle-and-thread and western wheatgrass were replaced by shallow-rooted little club-moss and
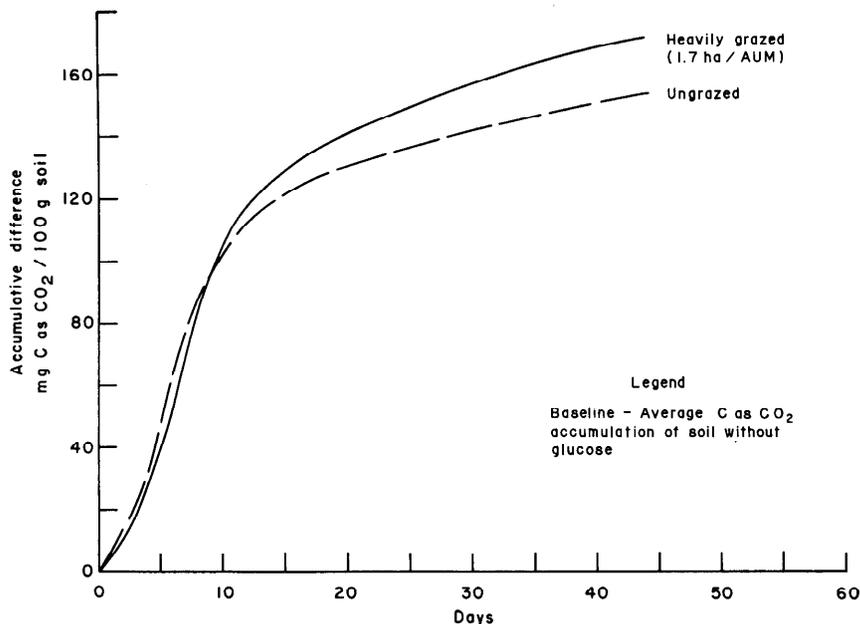
FIG. 1. Potential accumulative decomposition of soil organic matter from the ungrazed enclosure and from a field heavily grazed for the previous 19 years, Manyberries, 1970.

blue grama. Coupland and Johnson (1965) have shown that depth of rooting of blue grama averaged 19 cm less than needle-and-thread and 29 cm less than western wheatgrass. Both blue grama and little clubmoss have roots near the soil surface and, hence, are well adapted to conditions where moisture during the growing season is confined to the upper portion of the soil profile. Under heavy grazing, soil moisture in spring was significantly lower than under no grazing. Beebe and Hoffman (1968) found that where heavy grazing had significantly reduced the vegetation cover both soil surface temperatures and evaporation rates increased. The greater concentration of roots at the 45–60 cm level on the ungrazed site than on the grazed fields shows the effect, noted also by Lorenz and Rogler (1967), of herbage removal by grazing. As intensity of grazing increased, water-soluble carbohydrate content of the roots decreased. Kinsinger and Hopkins (1961), Jameson (1963), and Troughton (1957:56) obtained similar results.

The addition of feces and urine may add growth-promoting substances to the soil and thereby aid root growth (Jameson, 1963). Since these substances would generally be present at shallow depths (Kononova, 1966:340), one would expect the proportion of roots at this depth to increase as intensity of grazing increased (Table 2). Kononova (1966:340) concluded that as manure enriches the soil it increases the content of mobile forms of humic acids in the composition of humus. Also, root production by plants is vigorous in the presence of water-soluble humus substances.

This study indicates that continued heavy grazing of Stipa-Bouteloua prairie not only changes the vegetative cover but also some of the soil properties in the Ah horizon. Part of the changes in the soil were induced through a reduction

Table 4. Correlation coefficients to show relationships among environmental factors, Manyberries, 1970 (n = 40).

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
1. Sand in Ah (%)	1.000											
2. Clay in Ah (%)	-0.628**	1.000										
3. Soil moisture – 200 mbar tension (%)	-0.795**	0.792**	1.000									
4. Soil moisture – 15 bar tension (%)	-0.596**	0.724**	0.865**	1.000								
5. C (%)	-0.741**	0.551**	0.751**	0.672**	1.000							
6. N (%)	-0.633**	0.542**	0.737**	0.692**	0.933**	1.000						
7. Alcohol/benzene-extractable C (%)	-0.671**	0.292	0.560**	0.374*	0.752**	0.604**	1.000					
8. Polysaccharides (mg/100 g)	-0.691**	0.410**	0.689**	0.702**	0.886**	0.841**	0.711**	1.000				
9. Alkaline-soluble C (% of total C)	-0.113	-0.029	-0.020	-0.024	0.122	-0.018	0.243	0.220	1.000			
10. Total P (%)	-0.636**	0.713**	0.810**	0.779**	0.726**	0.776**	0.366*	0.615**	-0.090	1.000		
11. CEC (meq/100 g)	-0.521**	0.576**	0.737**	0.789**	0.713**	0.821**	0.317*	0.689**	-0.066	0.783**	1.000	
12. Exchangeable cations – Ca (meq/100 g)	-0.279	0.603**	0.687**	0.787**	0.341*	0.431**	0.061	0.407**	-0.213	0.581**	0.601**	1.000
13. Exchangeable cations – K (meq/100 g)	-0.702**	0.707**	0.812**	0.885**	0.698**	0.628**	0.503**	0.694**	0.054	0.721**	0.678**	0.615**

* Significant at the 5% level ($P < 0.05$).

** Significant at the 1% level ($P < 0.01$).

in rooting depth resulting from species change in which shallow-rooted species replaced the deep-rooted ones, and part was due to increased amounts of manure deposited by sheep on the more heavily grazed fields.

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