Vegetation and soil responses to short-duration grazing on fescue grasslands

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Abstract

The effects of animal impact on soil chemical and physical properties as well as range condition were measured over a 5-year period to test the hypothesis that animal impact can improve the nutrient and water status of the soil and promote grassland succession. A seventeen-pasture short-duration grazing system was established in 1981 on 972 ha. The pastures were stocked on average with 278 cows with calves from 1982 to 1986, which was about twice to triple the recommended rate of 0.8 AUM/ha. Increased grazing pressure reduced range condition as reflected by a loss of desirable species such as rough fescue (*Festuca scabrella* Torr.). Soil moisture was always higher in soils of ungrazed exclosures. Soil bulk density increased while hydraulic conductivity decreased with grazing. Litter was not significantly incorporated into the soil with hoof action. Chitin-N, as a measure of fungal biomass, decreased significantly under the increased grazing pressure. The hypothesis that animal impact would improve range condition was rejected since impact, in the manner applied during the study, resulted in retrogression of the grasslands.

Key Words: forage production, soil physical properties, soil chemical properties, range condition, rough fescue

The primary objective of most grazing management practices is to maximize livestock production per unit area of rangeland while maintaining a sustained forage resource (Heitschmidt and Walker 1983). Short-duration grazing is a system that enables more rigid control of animal distribution with the use of numerous smaller pastures, thus concentrating livestock and permitting time-controlled grazing. It has been proposed that short-duration grazing will allow conventional stocking rates to be doubled or tripled regardless of range condition at the time of implementation (Savory 1983). Improved carrying capacity is, presumably, obtained through a positive impact of animal activity on water, nutrient, and energy cycles and, ultimately, increased forage production through advanced plant succession. Conversely, the hypothesis predicts range deterioration in the absence of animal impact.

Soil formation may be regarded as a function of, among others, vegetation and organisms (Jenny 1980). Any change in any of the components of the biotic factor may affect the soil. Range soils, as found by the European settlers in the late 19th century, were in relative equilibrium with the existing soil-forming processes. The introduction of livestock domestic grazing changed not only the vegetation but also the soil component of the ecosystem (Johnston et al. 1971, Smoliak et al. 1972).

The purpose of this study was to test the hypothesis that animal impact and time-controlled grazing can improve the chemical and physical properties of the soil and promote grassland succession. The objectives were to measure the effects of animal impact on the soil as well as range condition over a 5-year period.

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Site Description

The study was conducted on the Shipwheel Ranch northwest of Fort Macleod on the edge of the Porcupine Hills (49°47'N Lat, 113°39'W Long), Alberta, Canada. The plant communities represent the interface of the Rough Fescue Grassland and the Mixed Prairie with the former being on the upper slopes and the latter at lower elevations. These grasslands have been described by Moss and Campbell (1947) and their response to grazing was reported by Looman (1969). About 70% of the grassland on the ranch was in fair to poor range condition in 1981 when the grazing system was implemented (Wroe 1984). The recommended stocking rate was about 0.8 animal unit months (AUM) per ha (Wroe et al. 1981).

The soils are of the Orthic Black Subgroup of the Chernozemic order (Udic Haploboroll) and developed on Laurentide till overlying sandstone. The Ah horizon consisted of 46% sand and 27% clay. The climate is dry and subhumid, and although the annual precipitation averages about 450 mm, it was 408, 322, 367, 423, and 435 mm from 1982 to 1986, respectively.

Materials and Methods

A 17-pasture short-duration grazing system was established in 1981 on 972 ha. The pastures radiated from a central cell which was a single source for water and the location of gates for transfer among pastures.

Cattle were put onto the range in early May of each year and, following 3 grazing rotations interspersed with 2 rest periods, were removed in late October. The pastures were stocked with 350, 320, 236, 235, and 250 cows with calves from 1982 to 1986, which was about twice to triple the recommended stocking rate (Wroe et al. 1981), respectively. Calves were weaned in September. Cattle movement between pastures was timed to prevent heavy use during periods of rapid forage growth and to allow recovery following grazing. Consequently, the grazing periods during rotation 1 averaged about 2.5 days followed by rest periods of about 40 days. As forages senesced, the grazing and rest periods became longer. In rotation 3, the grazing periods averaged about 4.5 days.

Five pastures were randomly selected for observations. In 1982 a permanent exclosure, measuring 10 × 30 m, was established in each study pasture at a location sufficiently removed from the center cell to avoid impeding animal movement. Paired observations were made inside and outside the exclosures to compare the differential effects of no grazing vs. intensive short-duration grazing. Sampling outside of the exclosure was outside the zone of potentially excessive fenceline traffic.

Basal areas of forage species were determined with a point frame having 35 points spaced at 2.5-cm intervals. In each pasture, 2,100 points were sampled systematically along a transect on both the grazed and protected treatments for a total of 10,500 points on each treatment. Sampling was done in July 1982 and again in June 1986. Percent composition was determined for major species and plant forms. These values were also used to determine range condition (Wroe et al. 1981) after applying a weighting factor by species

(Lodge and Campbell 1965) to convert basal area to a dry weight basis.

The Ah soil horizon was sampled, in 3 subplots each paired within and adjacent to each of the 5 exclosures, on 7 May and 15 Oct. 1985, and on 30 Apr. and 30 Sep. 1986. Samples were hand-sieved through a 2-mm screen, and stored in sealed, double polyethylene bags at 4° C. At the time of sieving, roots and other debris were removed from the soil and discarded. Moisture content of the soil was determined gravimetrically. Enzymes accumulated in soil have biological significance (Dormaar et al. 1984) as they participate in the cycling of elements and thus play a very important role in the initial phases of the decomposition of organic residues. Specifically, dehydrogenase activity in soils provides correlating information on the biological activity and microbial populations while phosphatase activity is thought to be directly related to the level of organic phosphorus in the soil. Dehydrogenase and phosphatase activities were determined on the fresh, moist soil within 24 and 48 hours, respectively, after its collection from the field to avoid changes in the activities.

Dehydrogenase activity was determined at pH 7.6 by measuring the triphenylformazan (formazan) produced by reduction of 2, 3, 5-triphenyltetrazolium chloride when soil was incubated with 2-amino-2-(hydroxymethyl)propane-1:3-diol buffer (0.5 M) at 30° C for 5 hours (Ross 1971). Phosphatase activity was determined at pH 6.5 by measuring the p-nitrophenol produced when soil was incubated with buffered sodium p-nitrophenyl phosphate solution (0.115 M) and toluene at 37° C for 1 hour (Tabatabai and Bremner 1969).

Following the enzyme analyses, the soils were dried and the subplot samples were combined and mixed. Dry soil colors were rated according to the Munsell (1954) notation. Subsamples were ground to pass a 0.5-mm sieve.

At the time of sampling, undisturbed core samples, 55 mm diam. and 30 mm deep, were taken with a drop-hammer type sampler at 0- to 3-cm and 3- to 6-cm depths at each subplot. The core samples were refrigerated at 4° C until needed. Saturated hydraulic conductivity was determined using the Tempe Cell method (Sommerfeldt et al. 1984). The cores were then oven-dried, their mass obtained, and the bulk densities calculated.

It has been shown (Johnston et al. 1971, Dormaar et al. 1984, Willms et al. 1988) that grazing affects a number of soil chemical parameters such as total organic carbon (C), total nitrogen (N), nitrate-N (NO_3-N), and available phosphorus (P). Chitin is a polymer of N-acetyl-2-amino-2-deoxyglucose linked in a β-1,4 sequence. It occurs in fungal cell walls and arthropod exoskeletons (Gould et al. 1981). Since more permanent aggregation is the result of the development of a network of fungal mycelia (Cheshire 1979), it was hypothesized that chitin values are sensitive enough to be used as a measure of potential aggregation as affected by grazing.

Total organic C was determined by dry combustion at 900° C for 15 minutes; the evolved and scrubbed CO_2 was collected and weighed. Total N was estimated using a macrokjeldahl procedure, and NO_3-N was determined by steam distillation (Bremner 1965). The analysis for available P was carried out according to Olsen et al. (1954). Chitin N was determined and corrections were made for extraction efficiency and ammonium-N as outlined by Gould et al. (1981).

The light organic matter fraction was obtained as outlined by Spycher et al. (1983). An increase in the light organic matter fraction could be indicative of litter incorporated into the soil by hoof action. However, nonhumified materials also contain a more rapidly decomposable fraction and thus a source of available nutrients.

Although fungal mycelia aid more permanent aggregation, initial development of structure largely depends on organic matter which is most readily decomposed (Cheshire 1979). Monosaccharides represent the latter. Hence, the monosaccharide distribution in hydrolysates of the soil samples was determined as outlined by Dormaar (1984) except that the hydrolysis step was modified with the elimination of the 2-hour 72% H_2SO_4 pretreatment (Dormaar 1987). The quantitative analyses of the alditol acetates were done with a Hewlett Packard gas chromatograph 5840 A.

Available forage was sampled around each exclosure. Seven permanent sampling sites in fields A to D and 5 sites in field E were randomly located within the area and single 0.5-m² plots were clipped to determine forage removal on the grazed treatments, at each location before and after each grazing rotation. Utilized forage was calculated as the difference between the first and second harvest. Total utilization over the grazing season was calculated as the difference between total available forage and residual.

Total available forage was $H_{11} + (H_{21} - H_{12}) + (H_{31} - H_{22})$ where H_{ij} is the harvest at rotation i (1, 2, or 3) and time j before (1) or after (2) grazing.

The data were subjected to an analysis of variance using a split plot model. The fields were regarded as replicates, the grazing treatment as the whole plot, and the repeat measurements (over seasons, years) on each whole plot as subplot treatments. For the soils data, analyses were carried out for each variable for each year separately and over the years. Since the whole plot error (Error A) was generally smaller than the subplot error (Error B), another analysis was carried out with these errors pooled. The analyses of the hydraulic conductivity at depths 1 and 2 and the vegetation data, including estimates of range condition, were carried out on log-transformed data to meet assumptions of normal distribution (Steel and Torrie 1980).

Results

Forage production and utilization averaged 509 and 425 kg/ha, respectively, from 1983 to 1986 (Table 1). Percent utilization of available forage, over the same period, averaged 22, 42, and 58 for rotations, 1, 2, and 3, respectively.

Table 1. Average stocking rates over 5 fields and annual production and utilization ($\bar{x} \pm$ 1SD) in the vicinity of the study sites from 1983 to 1986.

	1983	1984	1985	1986	1983–86
Stocking rates (AUM/ha)	3.0	2.3	2.5	2.7	2.6
Forage production (kg/ha)	570 (338)	337 (186)	347 (137)	784 (451)	509 (353)
Residual (kg/ha)	90 (88)	97 (52)	58 (34)	94 (81)	85 (61)
Utilization:					
Actual (kg/ha)	481 (336)	240 (170)	228 (122)	690 (424)	425 (338)
Proportion (%)					
Total	82 (16)	67 (18)	83 (8)	87 (10)	80 (15)
Rotation 1	26 (32)	34 (25)	14 (20)	13 (25)	22 (26)
Rotation 2	52 (27)	45 (28)	56 (20)	17 (22)	42 (28)
Rotation 3	61 (26)	41 (24)	46 (28)	82 (14)	58 (28)

It is clear from the data in Table 2 and their statistical treatment by treatment and season within and between years in Table 3 that, in spite of sometimes significant interactions among treatments (i.e., grazed vs. ungrazed range) and time of sampling within years or among treatment and time and year of sampling, the grazing management practiced over a 5-year period on fescue grassland had a most pronounced effect on many physical and chemical properties.

Physical Properties

In 1986 the color of the soil of the exclosures was black (5YR 2/1, dry); around the exclosures it was dark reddish brown (5YR 2/2-3/2, dry). This suggests either a loss of organic matter or

Table 2. Physical and chemical properties of Black Chernozemic soil under short-duration grazing (Sdg) and ungrazed (Excl) Fescue Grassland at Fort Macleod, Alberta (average of 5 samples).

	1985				1986			
	May 7		Oct. 15		Apr. 30		Sep. 30	
	Sdg	Excl	Sdg	Excl	Sdg	Excl	Sdg	Excl
Moisture (%)	16.1	20.2	27.5	29.2	13.4	17.1	22.7	28.0
Bulk density: 0-3 cm	0.97	0.81	0.94	0.82	0.92	0.84	0.94	0.83
(Mg/m³) 3-6 cm	1.09	0.98	1.02	0.99	1.00	0.96	1.04	0.97
Hydraulic conductivity: 0-3 cm	4.61	6.29	1.96	4.51	4.31	5.34	1.79	4.69
(cm/hour) 3-6 cm	3.29	4.50	2.95	2.54	3.15	4.24	2.66	3.12
Phosphatase activity[1]	921	1144	708	913	904	1084	738	879
Dehydrogenase activity[2]	89	138	177	242	81	114	186	264
Carbon (%)	4.27	4.52	3.51	4.23	4.02	4.52	4.27	4.90
Light fraction C as % of total C	13.6	16.8	14.9	17.0	17.4	20.8	12.7	15.0
Nitrogen (%)	0.39	0.43	0.39	0.42	0.42	0.46	0.41	0.45
C:N ratio	11.0	10.5	8.9	9.7	9.6	9.7	10.4	10.8
NO_3-N (μg/g)	10.2	12.6	10.3	8.4	5.6	10.0	8.3	5.9
Chitin (mg N/g soil)	0.55	0.61	0.64	0.78	0.58	0.66	0.71	0.81
Available P (μg/g)	9.35	7.00	5.90	7.13	4.95	4.02	4.32	4.98
Monosaccharides (g/kg)	5.04	7.66	5.46	6.45	3.89	7.07	5.06	5.70
galactose + mannose / arabinose + xylose	0.58	0.86	0.60	0.56	0.60	0.78	0.74	0.68

[1]P-nitrophenol released, μg/g dry soil/hour.
[2]Formazan released, nmol/g dry soil/hour.

differential rates of organic matter accumulation and/or decomposition between grazed and rested treatments.

Moisture was always significantly higher in the soils of the exclosures. Bulk densities did not vary over the seasons or years, but increased significantly with grazing. Hydraulic conductivity at the 0-3 cm depth was negatively affected by the grazing regime.

Enzyme Activities

Phosphatase activity decreased over the summer and returned to the previous year levels the following spring. Conversely, dehydrogenase activity doubled from spring to autumn.

Table 3. Significant effects at $P \leq 0.05$ (*) and $P \leq 0.01$ (**) of physical and chemical characteristics of Black Chernozemic soil after short-duration grazing (Sdg) and sampled at different seasons (Seas) and years (Year).

	1985		1986		1985 + 1986		
	Sdg	Seas	Sdg	Seas	Sdg	Seas	Year
Moisture (%)	**	*	*	**	**	*	*
Bulk density: 0-3 cm	**		**		**		
(Mg/m³) 3-6 cm	*		**		**		
Hydraulic conductivity: 0-3 cm	**	**	**	**3	**	**	3
(cm/hour) 3-6 cm		**3	**	**	**	**	3
Phosphatase activity[1]	**	**	**	**	**	**	
Dehydrogenase activity[2]	**	**	**	**	**	**	3,4
Carbon (%)	**	**	**	**	**		4
Light fraction C as % of total C	**	*	**	**	**	**	4
Nitrogen (%)	**		**		**		**
C:N ratio		**3		**		**	4
NO_3-N (μg/g)		**3					** 3
Chitin (mg N/g soil)	**	**	**	**	**	**	**
Available P (μg/g)	*	**3			*	**	** 3,4
Monosaccharides (g/kg)	**		**	3	**		** 3
galactose + mannose / arabinose + xylose	*	*3					

[1]P-nitrophenol released, μg/g dry soil/hour.
[2]Formazan released, nmol/g dry soil/hour.
[3]Sdg × seas interaction significant.
[4]Seas × year interaction significant.

Chemical Properties

The grazing treatment showed significantly lower C and N contents of the soil. There was a significant difference over the season for the C content as well. Conversely, the N content remained the same within the years with only a slight shift over winter.

The light fraction C as percent of total C represented one form of compartmentalizing the soil organic matter. The autumn samples did have more light fraction C as percent of total C than the spring ones, which could represent increased fine roots over the growing season. Litter was not significantly incorporated into the soil by hoof action, regardless of year, as indicated by the light organic matter fraction data.

Chitin was measured to give an indication of fungal biomass and thus of aggregation potential. All comparisons were highly significant. Autumn samples had higher chitin levels than spring samples. Nitrate N behaved differently under the grazing regimes over the season. The same was true for available P.

Since polysaccharides containing substantial quantities of arabinose and xylose are considered to be of plant origin and those containing galactose and mannose to be predominantly of microbial origin (Oades 1984), the ratio galactose + mannose/arabinose + xylose should be low (<0.5) for plant polysaccharides and high (>2.0) for microbial polysaccharides. The soils of the grazed areas thus seem to have more polysaccharides of plant than of microbial origin. Changes due to the grazing treatment were significant for the 1984 season only.

Grazing significantly reduced range condition and protection resulted in improvement (Table 4). Of the plant species examined individually or as a group, only rough fescue showed a significant trend corresponding to the shift in range condition.

Discussion

Short-duration grazing is a relatively new concept for western Canada and controlled research studies are few and recent. From the standpoint of livestock production, the grazing philosophy is encouraging. However, the hypothesis of potential benefit to soil physical and chemical properties and to range condition resulting from intensive livestock activity at high stocking rates is questionable. Prior to settlement of the prairies, extensive flashfloods often

Table 4. Range condition (% of climax) and composition (%) of plant species or types in relation to time and grazing treatment on Fescue Grassland near Ft. Macleod (means back-transformed from the logarithmic means).

	Protected		Grazed		Contrasts			
	1982	1986	1982	1986	1 vs 2	3 vs 4	2 vs 4	Year × treatment
	1	2	3	4	Probabilities			
Range condition	51.6	56.2	50.0	39.2	0.360	0.018	0.002	0.023
Graminoids	58.1	65.7	64.4	65.7	0.094	0.798	0.951	0.292
Festuca scabrella	1.6	6.0	1.3	0.7	<0.001	0.163	<0.001	0.001
Carex spp.	16.2	19.1	16.8	21.9	0.413	0.145	0.362	0.625
Stipa spp.	8.9	8.5	5.7	5.1	0.225	0.174	0.761	0.908
Agropyron spp.	8.7	11.7	12.3	10.1	0.184	0.359	0.495	0.121
Koeleria/Bouteloua/Poa	11.3	14.9	15.1	21.2	0.223	0.139	0.127	0.835
Forbs	39.4	31.2	33.8	32.8	0.136	0.836	0.734	0.346
Artemisia frigida	5.0	3.6	4.3	4.4	0.635	0.959	0.761	0.709
Shrubs	0.9	0.2	0.6	0.4	0.084	0.509	0.597	0.411

led to quick inundation of lowlands. This was blamed on the vast herds of bison that trampled the ground until it was impervious to water (Connell 1984). Indeed, more recently, Warren et al. (1986) showed that the use of heavy stocking rates under rotation grazing, with its repeated high intensity of trampling, reduced infiltration rates and increased erosion.

The short-duration grazing management of the present study may not be as drastic as a vast herd of bison; nevertheless forage utilization was high and within a few years there was already significant impact on the vegetation, range condition, and soil. Effects of twice the recommended stocking rates have been shown by Johnston et al. (1977). Although the grassland was already in fair to poor condition (Wroe 1984) at the start of this study, it continued to deteriorate with a reduction of range condition reflected by a loss of desirable species such as rough fescue.

The dominant status of rough fescue in this community is indicated by its rapid expansion within the exclosures. However, it is readily damaged by defoliation during the growing season (Willms, unpublished) and, in the present study, decreased with grazing. The hypothetical positive effects of animal impact (Savory and Parsons 1980), whether by trampling, defecation, or time grazing, did not ameliorate the negative effects of defoliation on the plant.

The effects of animal impact were also detected within the soil. Either the exclosures improved, or the short-duration grazing management further aggravated the soil, or both occurred, thereby widening the gap to significant differences. Thus, with the increase in bulk density and the reduction in hydraulic conductivity, coupled with the loss of vegetation, there is an increased potential for severe run-off and erosion.

Both the decrease in hydraulic conductivity in the exclosure, probably due to increased root growth over the season allowing the roots to force soil particles together (Barber 1984), and the decrease in hydraulic conductivity of the grazed soils from spring to autumn were alleviated overwinter. Shrinking and swelling, and freezing and thawing allowed the soil to resile and ameliorated soil compaction overwinter. The degree of soil compaction, as measured by bulk density and hydraulic conductivity, depends, of course, on the texture as well as the water content and the percentage of organic matter of the soil at the time of trampling (Tanner and Mamaril 1959, Van Havern 1983, Willatt and Pullar 1983).

Soil enzymes play an important role in the functioning of stable and resilient plant-soil systems. Dehydrogenase activity is thought to reflect the total soil biological activity (Skujins 1973). The increase from spring to autumn would thus reflect an increase of both microorganisms and root mass over the summer. The increased phosphatase activity in spring would allow for immediate release of phosphate ions bonded to the organic complex overwinter (Dormaar et al. 1984).

Although the grazing treatment did have an effect on the various parameters representing organic matter, there were no definite trends except for carbon and chitin levels. Indirectly, of course, through the effect of organic matter on the physical parameters measured, as evidenced by increased bulk density, there were definite trends (Tables 2 and 3). It can thus be concluded that the stocking rates used in this short-duration grazing management study significantly affected a number of physical and chemical properties of the soil, causing less desirable soil conditions.

Animal impact, as applied in this study, resulted in a reduction of range condition as evidenced by loss of seral species. These trends were associated with less soil moisture and increased soil bulk densities indicating reduced infiltration rates. Similarly, soil quality, as determined by percent nitrogen and enzyme activity, was also reduced. Consequently, the hypothesis that animal impact would improve range condition was rejected. Rather, such impact, in the manner applied during the study, resulted in retrogression of the grasslands. The evidence indicates that timed-controlled grazing, with a high herd density in a short duration grazing system, will not negate the effects of high utilization.

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