

Impacts of rotational grazing on mixed prairie soils and vegetation

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Abstract

In this study the impact of a rotation grazing system on the soil and vegetation of a *Stipa-Bouteloua-Agroropyron* community in the mixed prairie ecoregion was compared with the ungrazed treatment in exclosures. At a low stocking rate, grazing had no effect on the vegetation but did alter soil quality. Grazing pressure was so light in the rotational grazing treatment that recovery of productivity, as measured by standing crop and litter, was not significantly different from the ungrazed treatment. Conversely, the species distribution was unchanged but was indicative of a lower seral state for this mixed prairie. The effect of grazing on this community was indirect, possibly by altering the microenvironment. The relationships observed among forage production, soil chemistry, and species composition raise questions on the importance of any one variable expressing range condition on the mixed prairie.

Key Words: rest rotation, deferred rotational grazing, soil analysis (chemical), soil transformation, reclamation, monosaccharides

Livestock producers and land managers in the Northern Great Plains of Alberta, Canada, are interested in practices that restore range productivity. This interest has been stimulated with an increase in our understanding of the effects of grazing on the environment and with increasing concern for sustaining the range resources.

Grazing systems are tools for improving range condition. They distribute the grazing impact chronologically and spatially among 2 or more paddocks according to a prescription designed to achieve resource management goals. Most earlier studies have examined the effects of the grazing system on the plant community and animal (Clarke et al. 1947, Hubbard 1951, Smoliak 1960) while more recent studies focused on the effects on physical (Wood and Blackburn 1981, Warren et al. 1986, Abdel-Magid et al. 1987) and chemical (Dormaar et al. 1989, Dormaar et al. 1994, Frank et al. 1995) properties of soil.

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Resumen

En este estudio se comparó el impacto en el suelo y la vegetación de la comunidad *Estipa-Bouteloua-Agropiro* en la ecoregión de las praderas mixtas de un sistema de pastoreo rotativo con el tratamiento sin pastoreo. Con una baja carga animal, el pastoreo no afectó la vegetación pero sí alteró la calidad del suelo. El efecto del pastoreo fue tan bajo en el tratamiento del pastoreo rotativo que la recuperación de producción, medida por la cantidad de material en pie y los residuos vegetales acumulados en el suelo, no fue significativamente diferente del tratamiento sin pastoreo. En forma similar, la distribución de las especies no cambió pero sirvió como indicación de un estado que no era el ideal para esta mezcla de pastos. El efecto del pastoreo en esta comunidad fue indirecto, posiblemente debido a la alteración del micro medio ambiente. La relación observada entre la producción de forrajes, la química del suelo y la composición de las especies muestra la importancia de cualquiera de estas variables para definir el estado del pastizal en la pradera mixta.

The interest in the effect of grazing on soil is at least partly because of its vulnerability to degradation and the long-term impact this has on production. The character of the soil is a function of the vegetation and climate and, as such, tends to follow trends in those variables. It is also a function of the direct impact of grazing animals on the soil through trampling and fouling without noticeably altering the plant community. Therefore, an assessment of only the plant community will not accurately reflect animal impact on the ecosystem.

The period of rest from grazing incorporated into rotational grazing systems is designed to provide partial or a full year's rest over 2 or more years. They are implemented assuming they will improve range condition while allowing grazing; however, impacts of such a system on soil parameters indicative of grazing pressure have not been examined. In this study, impact of a rotational grazing system on soil and vegetation was compared with an ungrazed treatment on range that was recovering from overgrazing. Therefore, the hypothesis tested was that rotational grazing, when stocked at levels designed to remove about 50% of standing crop, has no detrimental effect on soil and vegetation recovery of a mixed prairie community.

Materials and Methods

Site Description

The study site was at the Antelope Creek Ranch (50°37'N Lat, 112°10'W Long) 15 km west of Brooks, Alberta, Canada (Adams et al. 1994). The vegetation represents the *Stipa-Bouteloua-Agropyron* community of the mixed prairie ecoregion (Clarke et al. 1947; Coupland 1961). Annual precipitation averaged 335 mm with April to August precipitation averaging 206 mm. The soils identified on the study site were 2 closely related series differentiated mainly by slope position and included a Hemaruka Brown Solodized Solonetz (Aridic Natriboroll) clay loam to loam and a Cecil Solonetzic (Typic Haploboroll) clay loam to loam (Kjearsgaard et al. 1983). Around 30% of the area had eroded pits (i.e., areas of these soils often have patchy microrelief due to differential erosion, and the B horizon is exposed in some eroded pits; plant growth is usually very sparse) and the parent material is till.

Grazing Management

In 1987, 1,793 ha were cross-fenced to create 4 paddocks of approximately equal area. A single enclosure (50 × 50 m) was constructed in each paddock on sites modal to Cecil soils without eroded pits and within the *Stipa-Bouteloua-Agropyron* community. The soil and vegetation, on which the enclosures were constructed, were representative of about 65% of each paddock.

The initial grazing management program was inaugurated to demonstrate range improvement practices and involved a rest rotation grazing system with only 3 paddocks grazed in any year. This allowed each paddock to be rested 1 year in every 4 years. Grazing of the 3 paddocks followed a deferred rotational sequence with each grazed for 1 month beginning in mid-July. Because forage production increased, a deferred rotation grazing sequence was adopted in 1992 in which all 4 paddocks were grazed each year. The stocking rates averaged 0.32 animal-unit-months (AUM) ha⁻¹ until 1991 and 0.39 AUM ha⁻¹ in 1991 and 1992. The grazing pressure was light to moderate as the recommended stocking rate on poor range is 0.37 AUM ha⁻¹ (Wroe et al. 1988). Prior to 1982, the whole area was grazed continuously at moderate stocking rates. From 1982 to 1986 grazing coincided with severe drought conditions resulting in heavy grazing pressure. Although the species mix did not change, plant vigour decreased and litter was eliminated.

Vegetation Effects

Prior to establishing the experiment in 1987, the range condition was scored according to Wroe et al. (1988) and all areas subsequently utilized were similar (Adams, unpublished data). Vegetation was sampled inside and outside each enclosure in 1988, 1990, and 1992. The basal area of vegetation was determined at each location with point sampling using a 30-pin frame placed on 40 selected positions along each of 2 transects. A "hit" was recorded when the point of a pin touched plant material at ground level or the ground surface within the periphery of the plant crown. Basal area was expressed as a percent of hits using the formula:

$$\frac{\text{no. hits}}{\text{total no. pins}} \times 100, \text{ for each species.}$$

Standing crop was estimated each year of the study. Ten, 0.5-

m² plots were randomly located on the Cecil soil series inside and outside each enclosure. The soils had a fairly uniform texture. Generally they were clay loams while some were sandy clay loams. Portable enclosure cages (1.5 × 1.5 m) were used to protect plots on grazed areas until August when they were harvested. This allowed the measurement of growth in grazed paddocks after 1 season of protection. Litter, consisting mostly of standing dead and fallen weathered herbage produced the previous years, was removed by hand and the standing crop was harvested near ground-level using hand-held shears. The material was oven-dried at 60°C and weighed.

Soil Effects

On 25 November, 1987, and 24 September, 1992, the Ah(= A1) horizon was sampled to a depth of 15 cm in 4 subplots inside and outside the enclosures. Samples from outside the enclosures were obtained 8 m from the fence, outside the zone of abnormal live-stock impact.

Samples were hand-sieved through a 2-mm sieve the day they were collected. A portion of each sieved sample was stored in sealed, double polyethylene bags at 40°C; the remainder was dried and ground to pass a 0.5-mm sieve. At the time of sieving, roots and other debris were removed from the soil and discarded. Biological analyses were conducted on a moist soil. All other analyses were conducted on air-dried soils.

Soil Analyses

Enzymes accumulated in soil have biological significance (Dormaar et al. 1984) as they assist in the cycling of elements and thus play an important role in the initial phases of organic residue decomposition. Urease activity, which is important in urea decomposition, was determined at pH 9.0 by incubating 5 g soil with tris (hydroxymethyl)-aminomethane (THAM) buffer (0.05M), urea solution, and toluene at 37°C for 2 hours, and measuring the ammonium (NH₄-N) released after steam distillation (Tabatabai and Bremner 1972).

The size distribution of individual particles in the soil samples was established on a portion of the dried samples by the hydrometer method as outlined by Gee and Bauder (1986). Soil pH was measured in 0.01M CaCl₂ (solution:soil ratio of 2:1). Mineralizable-N, as an index of biological N availability and autoclaveable-N, as an index of chemical-N availability, were determined as described by Keeney (1982). Total C and N were determined by dry combustion in a Carlo Erba NA 1500 Analyzer. Nitrate-nitrogen (NO₃-N) and NH₄-N were determined by KCl extraction and steam distillation as per Keeney and Nelson (1982). NaHCO₃-soluble phosphorus (available P) was determined as described by Olsen et al. (1954).

Acid hydrolysis of the samples was carried out essentially as outlined by Cheshire and Mundie (1966) and Cheshire (1979) except that the samples were first treated with 12M H₂SO₄ for 16 hours at room temperature, then diluted to 0.5M H₂SO₄ and held at 100°C for 1 hour (Dormaar 1984). Monosaccharides were reduced and acetylated as described by Blakeney et al. (1983). D-allose was added as the internal standard. The alditol acetates were identified with a Hewlett Packard GC 5890 Series IIPlus equipped with a hydrogen flame ionization detector and a 30-m glass capillary column (0.25 mm i.d.) wall-coated with OV-225 (50% cyanopropyl-50% methylphenylpolysiloxane) with helium as the carrier gas at a linear flow rate of 21 cm sec⁻¹. Reference alditol acetates of rhamnose, fucose, ribose, arabinose, xylose,

allose, mannose, galactose, and glucose were used as standards and prepared as outlined by Blakeney et al. (1983). Polysaccharides were considered to be of plant origin if they contained substantial quantities of arabinose and xylose and of microbial origin if they contained mainly galactose and mannose.

Statistical Analyses

The grazing and year effects were analyzed by the GLM procedure (SAS Institute Inc. 1989) for a split plot design with "years" as the secondary effect while paired comparisons of "years" were made using a single degree of freedom contrast (Steel and Torrie 1980). Individual paddocks were the replicates. Percentage data (plus 0.5) were subjected to the square-root transformation before analysis. The experimental error for the grazing effect was represented by the interaction of replicate (paddock) × grazing treatment (exclosure vs grazed areas), while the error for the year effect was represented by the interaction of replicate × grazing × year. For most tests of soil variables, the interaction between year and grazing treatment was significant ($P < 0.05$), therefore, each year was analyzed separately.

The rotational system consisted of 4 paddocks containing a single exclosure each. The exclosure and associated grazed area represents a block with 2 treatments (grazed and ungrazed). The fact that the blocks were treated at different times does not negate their value as replicates, but, at the worst, would increase the experimental error in some unknown manner that is irrelevant to this study.

Relationships of standing crop to year since implementing the grazing system and to precipitation (April to August, Table 1) were evaluated separately with linear regression analyses. Regression analysis is clearly the correct analysis considering the important effect that litter has on production (Willms et al. 1993). Furthermore, the effect is linear within the range of litter quantity found on the mixed prairie. Regression analyses were also used to

Table 1. Estimates of standing crop and precipitation at the Antelope Creek Ranch, from 1988 to 1992, on ungrazed areas within exclosures and on grazed areas that were protected by cages for 1 year and harvested at the end of the growing season. (Precipitation data taken from: Alberta Environment 1988, and Alberta Agriculture, Food, and Rural Development 1993).

	Rotation system				Precipitation (April to August)
	Ungrazed ¹		Grazed		
	Standing crop	Litter	Standing crop	Litter	
	----- (kg ha ⁻¹ ± 1SD) -----				-- (mm) --
1988	314 ±70	53 ±14	247 ±86	59 ±26	165
1989	369 ±82	68 ±44	479 ±87	59 ±23	161
1990	383 ±86	81 ±21	396 ±54	96 ±36	151
1991	323 ±87	100 ±29	407 ±22	112 ±86	294
1992	489 ±58	363 ±124	534 ±129	153 ±94	220
Average	376	133	413	96	198

¹The overall effects of the rotation grazing system on the standing crop and litter do not differ ($P > 0.05$) and the effect was similar among years. Standing crop and litter differed significantly ($P < 0.05$) between 1988 and 1992 and between 1991 and 1992. All other paired comparisons were equivalent ($P > 0.05$).

Table 2. Average area of major species, and total "hits" on live vegetation, at the Antelope Creek Ranch study site.

Species	Rotation			Year effect (P)
	1988	1990	1992	
	----- (% basal area) -----			
<i>Bouteloua gracilis</i>	1.2a ¹	1.2a	4.0b	
<0.001 <i>Stipa comata</i>	3.4a	4.5b	3.7a	0.001
<i>Koeleria macrantha</i>	1.4b	1.8b	0.9a	0.025
<i>Agropyron dasystachyum</i>				
<i>A. smithii</i>	1.2a	1.0a	1.8b	0.001
<i>Poa sandbergii</i>	0.0a	0.2b	0.1b	0.011
<i>Carex</i> spp.	0.7a	3.2b	2.7b	<0.001
<i>Artemisia frigida</i>	1.3b	0.8b	0.2a	0.002
<i>Phlox hoodii</i>	0.3b	0.2ab	0.1a	0.099
<i>Selaginella densa</i>	1.1a	13.8b	15.1b	<0.001
	----- (no. "hits") -----			
Total (maximum = 2,400)	289a	654b	721c	<0.001

¹Means in row having the same letter do not differ significantly ($P > 0.05$) according to a single degree of freedom contrast test. The effect of grazing or its interaction with year were not significant ($P > 0.05$) for any species. The statistical tests were made on transformed data (square root) but the means are calculated from unconverted data.

assess the relationship of litter quantity with year and the relationship between standing crop and litter quantity.

Results

Vegetation

The basal area of each species was similar ($P > 0.05$) inside and outside the exclosure and the response was the same each year the vegetation was sampled (Table 2). Only year had a significant ($P < 0.05$) effect on the major species tested (Table 2). The standing crop was greater on the grazed than the ungrazed treatments (Table 1). The standing crop on the grazed area varied from 247 kg ha⁻¹ in 1988 to 534 kg ha⁻¹ in 1992. Litter reserve levels have gradually increased over time in the grazed area (Table 1).

The relationships of standing crop to years since implementing the grazing system, precipitation (April to August), and litter can be expressed by regression equations (Table 3). Litter quantity and standing crop were both significantly related to years since implementing the grazing system, while standing crop was also significantly related to precipitation (Table 3).

Soils

At the start of the grazing experiment in 1987, soil variables were similar ($P > 0.05$) inside and outside the exclosures. By 1992, soils had increased in total C, total N, biological index, chemical index, and hexoses; and decreased in NH₄-N, NO₃-N, urease activity, available P, monosaccharides, and pentoses ($P < 0.05$; Table 4).

Table 3. Relationships of standing crop (kg ha⁻¹) to years since implementing the grazing system, precipitation (mm April to August), and litter quantity (kg ha⁻¹).

y	x	Regression	r ²	P	n
Standing crop	Years	y = 273 + 40x	0.46	0.03	10
Standing crop	Precipitation	y = 358 + 0.18x	0.75	0.01	10
Standing crop	Litter	y = 335 + 0.52x	0.30	0.10	10
Litter	Years	y = -20 + 45x	0.52	0.02	10

In 1992, grazed areas had less ($P < 0.05$) total C, total N, biological index, and chemical index, but more ($P < 0.05$) $\text{NH}_4\text{-N}$, $\text{NO}_3\text{-N}$, urease activity, available P, and monosaccharides than the ungrazed exclosures. The grazing effect was modified ($P < 0.05$) by year as would be expected because grazing was comparable across treatments in 1987 when the exclosures were constructed.

Discussion

Grazing had no effect on species composition of the plant community but changed soil chemical properties. Therefore, changes in productivity of certain species among years were either the result of differences in weather or resulted from the inability to detect low-lying ground cover of blue grama [*Bouteloua gracilis* (HBK.) Lag.] or club moss (*Selaginella densa* Rydb.) (Table 2). The latter explanation is more likely since plants of these perennial species do not expand their basal areas very rapidly.

The *Stipa-Bouteloua-Agropyron* community was resilient to changes in grazing impacts at these stocking rates over this 5-year period. This could be expected, because in another study (Willms et al. 1990) removing about 80% available standing crop in the same type of plant community showed only small changes in range condition after 5 years and no significant ($P > 0.05$) effect on basal areas of blue grama or needle-and-thread (*Stipa comata* Trin. & Rupr.). A lack of response over a short period supports the hypothesis that the grazing effect on the *Stipa-Bouteloua-Agropyron* community is indirect, possibly by altering the growing environment as a result of changes in litter quantity and plant vigour (Smoliak et al. 1972).

The plant microclimate is affected by litter through soil temperature buffering and soil moisture conservation. Where blue grama and needle-and-thread coexist, changes in the moisture status and temperature regime will affect their competitive relationship since blue grama has a C_4 carbon pathway while needle-and-thread has a C_3 pathway. Even though litter increased from 1988 to 1992, the average basal area of little club moss also increased. Conversely, applying 67 Mg straw ha^{-1} to a *Stipa-Bouteloua* com-

munity in southeastern Alberta reduced the basal area of little club moss from 8.0 to 0.2% after 8 years (Smoliak 1965) but had no significant ($P > 0.05$) effect on either blue grama or needle-and-thread.

Despite the apparent absence of species change from 1988 to 1992, forage production on the grazed treatment increased significantly. Since precipitation during the growing season did not account for these increases, other factors must have affected production. These factors may include increased plant vigor, as measured by standing crop, or an altered soil environment caused by litter accumulation. Litter quantity, which also increased over years, explained about 30% of variation in the standing crop yield (Table 3). Although the relationship suggests that each unit of litter accounts for about one-half unit of standing crop, the relationship is affected by soil moisture available for growth (Willms et al. 1993).

The most important effect was a trend toward greater production on the rotation-grazed area than on the exclosures (Table 1). This trend was maintained in successive years as total standing crop in 1993 and 1994 on the grazed area was 1,174 and 1,074 kg ha^{-1} , respectively, and on the ungrazed area it was 750 and 1,015 kg ha^{-1} , respectively (Adams, unpublished data). April to August precipitation in these years was 245 and 169 mm, respectively.

How do the measured soil variables reflect quality or grazing impact?

These data may lead one to conclude that the soil quality has improved; however, we do not know the baseline composition of a bison/fire stabilized mixed prairie. Conversely, with increased grazing pressure the composition of the vegetation changes from predominantly needle-and-thread to predominantly blue grama, while the soil carbon increases concomitantly (Smoliak et al. 1972). From a lower seral state, blue grama decreases while needle-and-thread increases after 13 years of rest, while soil carbon decreases (Dormaar et al. 1994).

The relationships among forage production, soil chemistry, and species composition raise questions on the importance of any 1 variable expressing range condition on the mixed prairie. The

Table 4. Effects of grazing and protection on some soil characteristics on a mixed prairie site at the Antelope Creek Ranch, Alberta, Canada.

	Rotation (R)				Comparisons				
	Ungrazed (U)		Grazed (G)		1987	1992	RU vs G		
	1987	(n = 16) 1992	1987	(n = 16) 1992	RU vs RG	RU vs RG	Graze	Year	G x Y
pH	5.5	5.6	5.6	5.6	NS	NS	NS	NS	NS
Total C (%)	2.34	3.34	2.21	2.74	NS	**2	**	**	**
Total N (%)	0.220	0.286	0.219	0.250	NS	**	**	**	*
Mineralizable N (mg kg^{-1})									
Biological index	48.1	67.4	48.5	55.0	NS	**	**	**	**
Chemical index	80.6	110.3	80.9	95.4	NS	**	**	**	**
Exchangeable N (mg kg^{-1})									
$\text{NH}_4\text{-N}$	8.03	3.31	7.90	4.96	NS	**	**	**	**
$\text{NO}_3\text{-N}$	3.99	0.22	3.96	1.22	NS	**	**	**	**
Urease activity ¹	220	15.2	218	166	NS	**	*	**	NS
Available P (mg kg^{-1})	3.17	1.13	3.24	2.32	NS	**	*	**	**
Monosaccharides (mg kg^{-1})	6.06	4.66	5.99	5.03	NS	*	NS	**	NS
Deoxyhexoses (%)	5	5	5	5	NS	NS	NS	NS	NS
Pentoses (%)	45	41	45	40	NS	NS	NS	**	NS
Hexoses (%)	50	54	50	55	NS	NS	NS	**	NS

¹ $\text{NH}_4\text{-N}$ released (mg kg^{-1} of dry soil h^{-1}).

²Level of significance (* = $P < 0.05$, ** = $P < 0.01$, NS = $P > 0.05$).

question arises if one should judge soil quality on its own merits (Manley et al. 1995) or combined with species composition of the vegetation. If the latter, we may have to re-evaluate the concept of "soil improvement", since conclusions will then be based on productivity and not on species composition. For example, decreased grazing pressure did not change species composition but increased C content of the soil (Table 3). Yet, how valid is total C as a soil quality indicator when all we can say is that production has only improved within the same vegetation mix? By 1993 the average composition of the 4 grazed paddocks was 49% needle-and-thread and 17% blue grama; this amount of blue grama represents a seral mixed prairie community (Adams, unpublished data). There will certainly be a lag in the eventual decrease in soil carbon (Dormaar et al. 1994), since it takes time for soil microorganisms to mineralize root mass.

Even though there was little difference in species composition of plant communities between ungrazed and grazed treatments, adding feces and urine to soil will certainly affect its chemistry and, therefore, its quality (e.g., urease activity as per Table 3). In this study, we measured soil quality under 2 grazing regimes, i.e. ungrazed and rotation-grazing management. In addition, there is an ideal bison/fire affected baseline mixed prairie which is no longer available. To truly explore soil quality, other more sensitive parameters, such as organic acids based on differences in chemistry of root exudates between blue grama and needle-and-thread, may have to be selected. This was not possible in this study, because, on the whole, the vegetation did not change.

Soil improvement and soil quality parameters need to be linked with ecological parameters and sustained management. Herrick and Whitford (1994) felt that soil-quality could serve as a useful integrated indicator of overall ecosystem condition. If so, quality and quantity of below ground biomass and root exudates should be included with aboveground composition of biomass. We cannot look at rangeland soil quality responses to grazing in isolation from the prairie vegetation.

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