Impacts of grazing systems on soil compaction and pasture production in Alberta

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[1]*Department of Renewable Resources, University of Alberta, Edmonton, Alberta, Canada T6G 2H1;* [2]*Department of Agricultural, Food and Nutritional Science, University of Alberta, Edmonton, Alberta, Canada T6G 2P5.* *Received 9 March 2001, accepted 12 September 2001.*

Donkor, N. T., Gedir, J. V., Hudson, R. J., Bork, E. W., Chanasyk, D. S. and Naeth, M. A. 2002. **Impacts of grazing systems on soil compaction and pasture production in Alberta**. Can. J. Soil Sci. **82**: 1–8. Livestock trampling impacts have been assessed in many Alberta grassland ecosystems, but the impacts of animal trampling on Aspen Boreal ecosystems have not been documented. This study compared the effects of high intensity [4.16 **animal unit month per ha** (**AUM**) ha^{-1}] **short-duration grazing** (**SDG**) versus moderate intensity (2.08 AUM ha^{-1}) **continuous grazing** (**CG**) by wapiti (*Cervus elaphus canadensis*) on soil compaction as measured by **bulk density at field moist condition** (**Db$_f$**) and **penetration resistance** (**PR**). Herbage phytomass was also measured on grazed pastures and compared to an **ungrazed control** (**UNG**). The study was conducted at Edmonton, Alberta, on a Dark Gray Luvisolic soil of loam texture. Sampling was conducted in the spring and fall of 1997 and 1998. Soil cores were collected at 2.5-cm intervals to a depth of 15-cm for measurement of bulk density (Db$_f$) and moisture content. Penetration resistance to 15 cm at 2.5-cm intervals was measured with a hand-pushed cone penetrometer. The Db$_f$ and PR of the top 10-cm of soil were significantly ($P \leq 0.05$) greater by 15 and 17% under SDG than CG, respectively, by wapiti. Generally, Db$_f$ in both grazing treatments decreased over winter at the 0–7.5 cm and 12.5–15 cm depths, suggesting that freeze-thaw cycles over the winter alleviated compaction. Soil water content under SDG was significantly ($P < 0.05$) lower than CG. Total standing crop and fallen litter were significantly ($P \leq 0.05$) greater in CG treatment than the SDG. The SDG treatment had significantly ($P \leq 0.05$) less pasture herbage than CG areas in the spring (16%) and fall (26%) of 1997, and in the spring (22%) and fall (24%) of 1998, respectively. The SDG did not show any advantage over CG in improving soil physical characteristics and herbage production.

Key words: Bulk density, *Cervus elaphus*, moisture content, penetration resistance, pasture production

Donkor, N. T., Gedir, J. V., Hudson, R. J., Bork, E. W., Chanasyk, D. S. et Naeth, M. A. 2002. **Conséquences des régimes de paissance sur le compactage du sol et la production de pâturages en Alberta**. Can. J. Soil Sci. **82**: 1–8. Les conséquences du piétinement sur de nombreux écosystèmes de graminées de l'Alberta ont déjà fait l'objet d'une évaluation, mais on ne sait pas grand-chose des répercussions d'un tel compactage sur les prairies-parcs boréales de trembles. Les auteurs ont comparé les effets d'une paissance de courte durée (PCD), à forte intensité (4,16 unités animales-mois par hectare), sur le compactage du sol à ceux d'une paissance continue (PC) d'intensité moyenne (2,08 UAM par hectare) par les wapitis (*Cervus elaphus canadensis*). Le compactage a été établi d'après le poids volumique apparent dans les champs humides (Db$_f$) et la résistance à la pénétration (RP). Les auteurs ont aussi mesuré la phytomasse des herbages dans les parcelles pâturées et les parcelles intactes servant de témoin. L'étude s'est déroulée à Edmonton (Alberta) sur des luvisols gris foncés à texture loameuse. L'échantillonnage a eu lieu au printemps et à l'automne 1997 et 1998. Pour cela, les auteurs ont prélevé des carottes de sol jusqu'à une profondeur de 15 cm, à intervalles de 2,5 cm, et en ont établi le poids volumique apparent (Db$_f$) et la teneur en eau. Ils ont mesuré la résistance à la pénétration à la même profondeur, également à intervalles de 2,5 cm, avec un pénétromètre manuel à pointe conique. Dans la couche supérieure de 10 cm, le Db$_f$ et la RP sont sensiblement plus élevés ($P \leq 0,05$) avec la PCD que la PC par les wapitis (de 15 % et de 17 %, respectivement). En général, aux profondeurs de 0 à 7,5 cm et de 12,5 à 15 cm, le Db$_f$ diminue pendant l'hiver pour les deux régimes, signe que la succession de gels et de dégels durant cette période atténue le compactage. En régime PCD, le sol renferme sensiblement moins d'eau ($P < 0,05$) qu'avec la PC. Au total, les peuplements sur pied et les débris végétaux au sol sont sensiblement plus nombreux ($P \leq 0,05$) avec la PC que la PCD. La quantité d'herbages sur les parcelles PCD était sensiblement plus faible ($P \leq 0,05$) que sur les parcelles PC au printemps (16 %) et à l'automne (26 %) de 1997, ainsi qu'au printemps (22 %) et à l'automne (24 %) de 1998. La PCD ne semble procurer aucun avantage sur la PC pour ce qui est d'améliorer les propriétés physiques du sol et la production d'herbages.

Mots clés: Poids volumique apparent, *Cervus elaphus*, teneur en eau, résistance à la pénétration, production de pâturages

Wapiti and other diversified ruminant livestock are raised in pasture-based systems and provide the opportunity to enhance the efficient and sustainable use of these areas. Determining an optimal grazing rotation to ensure sustainable pasture use goes beyond the simple examination of vegetation removal. Modification of soil physical properties by hoof action, in concert with reduced vegetation cover, often results in increased bulk density and penetration resistance of soils (Wood and Blackburn 1981; Blackburn 1984).

Several studies (e.g., Heydon et al. 1993) have demonstrated significant differences in forage intake rates between

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deer grazing on pastures with high and low forage availability, whereas others have shown little difference (e.g., Niezen et al. 1993; Gedir and Hudson 2000). The disparity in foraging behavior could ultimately affect pasture regrowth because treading is a key factor in pasture damage (Brown and Evans 1973). Consequently, modifying foraging behavior and forage availability (Abdel-Magid et al. 1987) could minimize pasture soil damage.

Short-duration grazing is a system that enables control of animal distribution with the use of many smaller pastures, thus concentrating livestock and permitting time-controlled grazing (Dormaar et al. 1989). Recently, short-duration grazing systems have been proposed as alternatives to grazing continuously over the entire growing season. It has been speculated that these systems will help reduce, or perhaps eliminate, the deleterious effects of grazing on soil properties. However, research indicates that the use of heavy stocking rates under rotational grazing have consistently shown no significant hydrologic and carrying capacity improvement over continuously grazed pastures (Wood and Blackburn 1981; Blackburn 1984; Abdel-Magid et al. 1987; Heitschmidt et al. 1987; Dormaar et al. 1989; Chanasyk and Naeth 1995). The negative effect of continuous season-long grazing on soil physical properties has also received considerable attention (e.g., McCarty and Mazurak 1976; Thurow et al. 1986). Grazing animals may compact soil, mechanically disrupt soil aggregates and reduce soil aggregate stability (Willatt and Pullar 1983).

The degree of compaction is affected by soil water content at the time of compaction (Gifford et al. 1977; Van Haveren 1983). In some rangelands, soil water in the Ah horizon decreased with increased grazing intensity (Johnston 1961; Johnston et al. 1971; Smoliak et al. 1972), whereas in others there was no effect (Lodge 1954). Reductions in soil water through grazing are attributed to increased runoff and decreased infiltration. Less infiltration has been attributed to soil compaction and sealing by animal trampling and reduced litter cover (Naeth et al. 1991). Increased soil water with removal of herbage through grazing is attributed to reduced evapotranspiration (Naeth and Chanasyk 1995). Despite numerous studies on the effects of cattle grazing on soil physical properties (e.g., Naeth et al. 1990; Mulholland and Fullen 1991; Mapfumo et al. 1999), little information is available on the effect of farmed wapiti and other wildlife on soil properties. We expect differences in the effect of cattle versus wild ruminants on soil physical properties because the grazing season in the latter is longer than in the former. Wild ruminants have strong seasonal cycles of feed intake are able to forage through snow (Gates and Hudson 1983). Moreover, animal trampling impacts on Dark Gray Luvisolic soils in the Aspen Boreal forest ecosystems in Alberta have received little attention.

The purpose of this study was to investigate the effects of wapiti (*Cervus elaphus canadensis*) grazing on soil physical properties as well as *Bromus–Poa* pasture production in an Aspen Boreal forest ecosystem. This was achieved by measuring soil bulk density, penetration resistance (soil strength) and soil water, as well as pasture phytomass production in an intensive short-duration and continuous grazing system. Specific objectives included testing of the following hypotheses: (1) Grazing would compact the soil by increasing both bulk density and penetration resistance and that these impacts would be related to grazing systems (short-duration and continuous); (2) Herbage production would vary under short-duration and continuous grazing systems.

MATERIALS AND METHODS

Study Site

The study was conducted at the Ministik Wildlife Research Station, located 50 km southeast of Edmonton, Alberta, Canada (53°18′N, 114°35′W). Vegetation of the area is classified as Boreal Mixed-Wood forest (Strong 1992), although homesteading (logging and clearing) in the early 1900s created characteristics more similar to those of Aspen Parkland. Major vegetation types include balsam poplar (*Populus balsamifera*) and trembling aspen (*P. tremuloides*) forests, *Carex* wetlands, and grasslands primarily composed of Kentucky bluegrass (*Poa pratensis*), smooth brome (*Bromus inermis*), Dutch white clover (*Trifolium repens*), and dandelion (*Taraxacum officinale*).

The climate is continental, typical of northern boreal forest regions. Ambient temperatures are characterized by seasonal extremes, ranging from a minimum of –49°C in winter to temperatures exceeding 32°C in summer (Olson 1985). Snow cover is usually established in late November, and normally remains into April. The growing season typically extends from May until September. Total precipitation between April and September for 1997 and 1998 was 420 mm and 343 mm, respectively, compared to the 1961–1990 average of 334 mm.

The Ministik area is underlain by the Edmonton Formation, an Upper Cretaceous bedrock of shales, sandstones, and coal interbedding (Bayrock 1972). The area exhibits gently rolling hills and shallow depressions, typical of hummocky dead-ice moraine. Numerous sloughs are characteristic of the area. Soils are generally imperfectly to moderately well drained Dark Gray Luvisols with occasional Gray Solodized Solonetz with a common horizon sequence of Ah (0–6 cm), Ahe (6–10 cm), Ae (10–20 cm), Bntl (20–41 cm), Bnt2 (41–76 cm), Ck (at 76 cm), C (at 101 cm) (Bowser et al. 1962). On average, the Ah/Ae horizon contained 25% clay, 33% silt, 42% sand and 2.1% organic matter. Particle size distribution was determined using the hydrometer method (Sheldrick and Wang 1993). The soil pH was 5.5; determined by glass electrode in 1:2 ratio of soil to 0.01 M $CaCl_2$ (Sheldrick 1984).

Experimental Procedures

Study plots were located in an area that had been continuously grazed in summer by wapiti until the end of 1996, but subsequently rested for 1 yr prior to this study. The previous stocking rate was near 2.0 AUM ha^{-1} (with approximately 50% herbage utilized), which is considered moderate for wapiti hinds under yearlong continuous grazing at the station. Grazing trials were established in 1997 and run for 2 yr from early May 1997 to late September 1999. The grazing treatments studied were: continuous grazing (CG) stocked at a moderate rate of 2.08 AUM ha^{-1}; and short-duration grazing (SDG) stocked at a high rate of 4.16 AUM ha^{-1} (with approximately 75% herbage utilized). Both treatments were stocked with wapiti hinds that weighed an average of 290 kg. The two CG replicate pastures, each 2.2 ha in size, were stocked with five wapiti hinds while the two 1.5-ha SDG pasture replicates were rotationally grazed by 15 wapiti hinds. Animal movement between SDG pastures was timed to prevent excessive use during periods of rapid forage growth and to allow recovery following grazing. Grazing periods in the SDG pastures varied from 7 to 10 d, with 30 to 40 d of rest between grazing periods. There were only two paddocks in the SDG because of logistic constraints and conflict of interests from concurrent research being carried out at the station. This management restriction limited replication in the study. During the rest periods, the 15 animals were moved to other pastures for concurrent behavioral studies. All pastures were considered to be nearly equal in carrying capacity when the trial began, and the overall range condition was considered good.

Immediately after every grazing period (within 1–2 ds), ten 40 × 40-cm plots were clipped at ground level in the SDG treatment. Vegetation in the CG treatment and in the UNG area (about 4.0 ha in size) adjacent to the grazed pastures was sampled in an identical manner. Data from May to June sampling dates (10 May, 20 May, 19 June and 29 June) were pooled into (spring), while those from August to September (3 August, 13 August, 17 September and 28 September) were pooled into (fall) estimates. Herbage was hand-sorted into components of green herbage, standing dead and fallen litter, dried at 60°C, and weighed.

To evaluate the combined effect of defoliation and trampling on soil compaction, bulk density and penetration resistance were measured in the treatment areas at the end of each grazing period. A 7.5-cm-diameter hand-driven Uhland core sampler was used to collect ten 15-cm-long samples in each sampling event from each grazing treatment for bulk density measurements. Each sample was sectioned into six segments of 2.5-cm depth intervals. Moist soil samples were immediately weighed and later oven dried at 105°C to determine dry bulk density and gravimetric water content. Around each sample site (clipped area), penetration resistance was measured to a 15-cm depth at 2.5-cm intervals using a small hand-pushed cone penetrometer (30° angle and basal area of 3.2 cm^2). The same soil parameters were measured in the UNG pasture. The soil water contents, bulk densities and penetration resistances measured in the UNG pasture (averaged data) were then compared with corresponding values obtained in the grazed treatments.

Statistical Analyses

Statistical analyses were conducted using the SAS generalized linear models procedure (SAS Institute, Inc. 1989) to compare bulk density, penetration resistance, soil water and herbage production among the three treatments. Thus, a general linear model showing the factors affecting the response of dependent variables is represented by:

$$\gamma_{ijk} = \mu + \tau_i + \alpha_j + \beta_k + \varepsilon_{ijk}$$

where $\gamma = Db_f$, PR etc.; μ = overall mean; τ = grazing intensity; α = stocking rate; β = sampling time; ε = error. Post-hoc mean comparisons were done on all significant treatment means using Tukey's method ($P \le 0.05$). To compare bulk densities between spring and fall for each depth interval, the Student's *t*-test for paired samples (Snedecor and Cochran 1989) was used.

RESULTS

Bulk Density

Regardless of the type of grazing system (e.g., CG or SDG), grazing by wapiti increased soil bulk density at field moist condition (Db_f). These differences were most pronounced at soil depths less than 10 cm, but also varied temporally, with the most pronounced difference in fall of 1998, followed by spring of 1998, fall of 1997, and finally spring of 1997 (Table 1).

Comparison of the two grazing systems indicates that SDG generally had greater Db_f than the CG pastures. These differences were most evident at the soil depths down to 7.5 cm in spring of 1997, 10 cm in fall of 1997, 5 cm in spring of 1998, and 12.5 cm in the fall of 1998 (Table 1). Relative to SDG, the CG pastures were much more similar to the UNG treatment, with only occasional increases in Db_f (e.g., 0–2.5 and 7.5–10 cm in fall of 1997, and 0–2.5 cm depth in spring of 1998, and 0–5 cm in fall of 1998) (Table 1).

Bulk densities in the 0 to 7.5-cm and 12.5 to 15-cm depth intervals were significantly ($P \le 0.05$) lower in the spring of 1998 than in the fall of 1997 (Table 2). For the 7.5- to 12.5-cm interval, Db_f were similar between the two times.

Over-winter change in Db_f between fall 1997 and spring 1998 was significantly greater for SDG than that for CG and UNG for the surface 2.5-cm (Table 3). At depths between 2.5- and 15-cm, the changes in Db_f were similar between all three grazing treatments. Changes in Db_f below 7.5 cm soil depth were generally small (Table 3).

Penetration Resistance

Generally, differences in PR occurred between grazing treatments (SDG > CG ≥ UNG) and between seasons (fall 1998 > fall 1997 > spring 1998 > spring 1997). Comparison of the two grazing systems indicates that SDG generally had greater PR than the CG pastures. These differences were most evident at the soil depths down to 5 cm in spring 1997, 7.5 cm in fall 1997, 5 cm in spring 1998, and 10 cm in fall 1998 (Table 4). Relative to SDG, the CG was much more similar to the ungrazed treatment at the surface, with a significant increase of PR in the spring of 1998 (Table 4).

In general, the PR measured in spring and fall 1997 were lower than spring and fall 1998. In the fall of both years, PR values at depths greater than 2.5-cm were greater than 2 MPa, while PR values in spring of both years were generally less than 2 MPa.

Soil Water

Generally, grazing reduced soil water up to a depth of 15 cm in fall and 7.5 cm depth in spring (Table 5). In addition, soil

Table 1. Mean soil bulk densities at different depth intervals for *Bromus-Poa* pasture under short-duration and continuous grazing by wapiti versus ungrazed pasture at Ministik Wildlife Research Station, Alberta

Sampling time	Grazing system	Soil bulk density (Mg m^{-3}) at depth intervals (cm)					
		0–2.5	2.5–5	5–7.5	7.5–10	10–12.5	12.5–15
Spring (May – June) 1997							
	Short duration	1.05*a*	1.07*a*	1.10*a*	1.15*a*	1.18*a*	1.21*a*
	Continuous	0.75*b*	0.90*b*	0.85*b*	1.16*a*	1.20*a*	1.22*a*
	Ungrazed	0.85*b*	0.90*b*	0.90*b*	1.02*a*	1.15*a*	1.07*a*
Fall (August – September) 1997							
	Short duration	1.41*a*	1.41*a*	1.37*a*	1.26*a*	1.25*a*	1.27*a*
	Continuous	1.10*b*	1.21*b*	1.18*b*	1.19*b*	1.22*a*	1.23*a*
	Ungrazed	0.95*c*	1.15*b*	1.11*b*	1.08*c*	1.10*a*	1.14*a*
Spring (May – June) 1998							
	Short duration	1.05*a*	1.08*a*	1.12*a*	1.16*a*	1.18*a*	1.20*a*
	Continuous	0.98*b*	0.91*b*	0.95*ab*	1.14*ab*	1.16*a*	1.17*a*
	Ungrazed	0.81*c*	0.87*b*	0.90*b*	1.05*b*	1.11*a*	1.10*a*
Fall (August – September) 1998							
	Short duration	1.38*a*	1.37*a*	1.35*a*	1.30*a*	1.24*a*	1.20*a*
	Continuous	1.24*b*	1.21*b*	1.17*b*	1.19*ab*	1.14*b*	1.13*a*
	Ungrazed	0.96*c*	1.07*c*	1.11*b*	1.05*b*	1.09*b*	1.04*b*

a–c Within each sampling time and depth interval, means followed by the same letter are not significantly different ($P \le 0.05$).

Table 2. Average soil bulk densities in spring and fall at each depth interval averaged across grazing intensity, and the significance levels obtained using Student's *t*-test

Depth interval (cm)	Bulk density (Mg m^{-3}) Fall 1997	Bulk density (Mg m^{-3}) Spring 1998	Significance level (α)
0–2.5	1.15 (0.14)[z]	0.95 (0.08)	0.014
2.5–5	1.26 (0.08)	0.95 (0.06)	0.002
5–7.5	1.22 (0.08)	0.99 (0.07)	0.003
7.5–10	1.18 (0.06)	1.12 (0.03)	0.102
10–12.5	1.19 (0.05)	1.15 (0.02)	0.253
12.5–15	1.21 (0.04)	1.16 (0.03)	0.023

[z]Standard error of the means in parentheses.

water content under SDG was significantly ($P < 0.05$) lower than CG. This trend occurred in the top 5 cm of soil regardless of sampling time, but extended to between 7.5 and 15 cm in spring of 1997. By the fall of 1998, the SDG treatment remained lower in soil water at all depths sampled.

Herbage Available under Grazing

Live green, standing dead, fallen litter phytomass and total herbage production was generally greater in the CG than the SDG treatment (Table 6). Grazing under SDG resulted in less herbage on the pastures than that of CG by 16 and 26%, respectively, in spring and fall 1997 (Table 6). The same trend was observed in spring and fall 1998; a decrease of 22 and 24%, respectively. Herbage available on pastures was generally greater in 1997 than 1998, likely because of high precipitation in 1997. As expected, grazing treatments reduced herbage on grazed pastures compared to UNG pasture. Herbage reduction was evident in all three herbage pools (green herbage, standing dead and fallen litter). In the absence of grazing, there was a trend towards increased standing dead and litter accumulation (Table 6).

DISCUSSION

Grazing Impacts on Soil Physical Properties

Short-duration grazing is a relatively new concept for western Canada and controlled studies are few (Dormaar et al. 1989). From the standpoint of livestock distribution and production, the grazing system is encouraging. Nevertheless, the hypothesis of potential benefit to soil physical properties from intensive livestock activity at high stocking rates is questionable (Heitschmidt et al. 1987; Dormaar et al. 1989).

Soil bulk densities were significantly greater up to 10-cm depth (in the A horizon) in the SDG pastures than those in the CG pastures and UNG pasture due to trampling. Greater amounts of fallen litter, and a lower stocking rate and density in the CG pasture may have reduced trampling effects on the soil. Other studies on Alberta pastures containing Orthic Black Chernozems with horizon sequence of Ah (> 15 cm), Bm_1 (14–35 cm), Bm_2 (35–53 cm), BCk and Ck (60 cm) (Walker et al. 1991) found trampling associated with very heavy grazing caused significantly greater bulk densities in the top 7.5-cm (Naeth et al. 1990; Chanasyk and Naeth 1995) and 2.5–3 cm of soil (Dormaar et al. 1989; Mapfumo et al. 1999). Differences in the depth of compaction in our study and others could be due to differences in soil type. Soil properties such as texture, organic matter, water content and other environmental conditions govern the degree to which compaction occurs (Mapfumo et al. 1999). For example, our soil was Dark Gray Luvisolic with an organic matter content of 2.1% compared to as high as 9.5% in the study area of Mapfumo et al. (1999). These characteristics, combined with a greater clay content (25% compared to 15% in others) may have resulted in greater soil water and greater potential for compaction in general. Hence, the variation of these factors makes it difficult to compare results of grazing impacts on actual Db_f values among sites.

Table 3. Changes in average soil bulk densities over winter (Fall 1998 vs. Spring 1998) at different depths for *Bromus-Poa* pasture under short-duration and continuous grazing by wapiti versus ungrazed pasture at Ministik Wildlife Research Station, Alberta

Grazing intensity	Change in soil bulk density[z] (Mg m^{-3}) for depth intervals (cm)					
	0–2.5	2.5–5	5–7.5	7.5–10	10–12.5	12.5–15
Short duration	–0.36*a*	–0.33*a*	–0.25*a*	–0.10*a*	–0.07*a*	–0.07*a*
Continuous	–0.12*b*	–0.30*a*	–0.23*a*	–0.05*a*	–0.06*a*	–0.06*a*
Ungrazed	–0.10*b*	–0.20*a*	–0.21*a*	–0.03*a*	+0.01*a*	–0.04*a*

[z]Change in bulk density = spring bulk density – previous fall bulk density for a given depth interval; over winter decreases in bulk density have minus (–) signs.
a, *b* Within columns, means followed by the same letter are not significantly different from each other at 0.05 probability level.

Table 4. Mean penetration resistance at various soil depths for *Bromus-Poa* pasture under short-duration and continuous grazing by wapiti versus ungrazed pastures at Ministik Wildlife Research Station, Alberta

Grazing time	Grazing system	Soil penetration resistance (MPa) at depth intervals (cm)						
		Surface	2.5	5	7.5	10	12.5	15
Spring (May – June) 1997								
Short duration		1.27*a*	1.64*a*	1.78*a*	1.77*a*	1.84*a*	1.92*a*	1.95*a*
Continuous		0.92*b*	1.42*b*	1.54*b*	1.41*a*	1.50*a*	1.68*a*	1.75*a*
Ungrazed		0.85*b*	1.29*c*	1.47*b*	1.32*a*	1.31*b*	1.41*b*	1.55*b*
Fall (August – September) 1997								
Short duration		1.61*a*	3.40*a*	2.98*a*	2.70*a*	2.85*a*	3.00*a*	3.35*a*
Continuous		1.45*b*	2.66*b*	2.50*b*	2.45*b*	2.90*a*	3.18*a*	3.10*a*
Ungrazed		1.35*b*	1.97*b*	1.81*c*	1.97*c*	1.90*b*	1.95*b*	1.91*b*
Spring (May – June) 1998								
Short duration		1.56*a*	2.60*a*	2.14*a*	1.96*a*	2.05*a*	2.00*a*	1.86*a*
Continuous		1.20*b*	2.18*b*	1.74*b*	1.52*a*	1.55*ab*	1.60*ab*	1.46*a*
Ungrazed		1.11*c*	1.58*c*	1.52*c*	1.42*a*	1.41*b*	1.44*b*	1.45*a*
Fall (August – September) 1998								
Short duration		1.95*a*	3.58*a*	3.86*a*	3.93*a*	4.02*a*	3.54*a*	3.45*a*
Continuous		1.42*b*	2.56*b*	3.18*b*	2.98*b*	3.06*b*	3.02*a*	3.20*a*
Ungrazed		1.36*b*	1.98*c*	1.95*c*	1.91*c*	1.99*c*	1.99*b*	1.98*b*

a–c Within each sampling time and depth interval, means followed by the same letter are not significantly different ($P \leq 0.05$).

Table 5. Mean moisture content at different depth intervals for *Bromus-Poa* pasture under short-duration and continuous grazing by wapiti versus ungrazed pasture at Ministik Wildlife Research Station, Alberta

Sampling time	Grazing system	Soil moisture content (cm^3 cm^{-3} × 100) at depth intervals (cm)					
		0–2.5	2.5–5	5–7.5	7.5–10	10–12.5	12.5–15
Spring (May – June) 1997							
Short duration		19.8*c*	23.6*c*	26.7*a*	28.2*b*	28.1*b*	27.6*b*
Continuous		23.9*b*	24.8*b*	23.5*b*	31.2*a*	30.6*a*	29.2*a*
Ungrazed		26.6*a*	27.5*a*	26.7*a*	28.9*b*	31.2*a*	27.0*b*
Fall (August – September) 1997							
Short duration		16.3*b*	21.1*b*	22.1*a*	19.3*a*	19.0*b*	18.8*b*
Continuous		19.3*a*	22.3*a*	19.5*b*	19.5*a*	19.4*b*	19.3*b*
Ungrazed		17.6*b*	20.7*b*	19.1*b*	19.1*a*	20.1*a*	20.5*a*
Spring (May – June) 1998							
Short duration		23.6*b*	23.9*b*	26.7*a*	28.2*a*	27.5*a*	26.6*a*
Continuous		25.5*a*	25.1*a*	24.9*b*	27.4*a*	26.7*a*	26.7*a*
Ungrazed		24.3*a*	23.9*a*	25.7*a*	27.3*a*	26.8*a*	25.3*a*
Fall (August – September) 1998							
Short duration		15.6*b*	17.5*b*	18.0*b*	17.3*b*	16.1*c*	15.2*c*
Continuous		17.5*a*	19.0*a*	19.3*a*	19.1*a*	18.2*b*	17.9*b*
Ungrazed		14.4*c*	17.9*b*	19.1*a*	18.4*a*	19.7*a*	19.1*a*

a–c Within each sampling time and depth, means followed by the same letter are not significantly different ($P \leq 0.05$).

The speculation that benefit can be derived from short-term, high-intensity physical impact of livestock is the principal foundation upon which many proponents of SDG base their support. The physical impact is believed to chip or churn the soil and break up surface crusting without compacting the soil (Savory and Parsons 1980). However, tram-

Table 6. Herbage availability on *Bromus-Poa* pasture under short-duration and continuous grazing by wapiti versus ungrazed at Ministik Wildlife Research Station, Alberta

Sampling time	Grazing intensity	Herbage component ($g\ m^{-2}$)		
		Green herbage	Standing dead	Fallen litter
Spring (May – June) 1997				
Short duration		60*c*	46*c*	16*b*
Continuous		71*b*	55*b*	19*b*
Ungrazed		90*a*	70*a*	55*a*
Fall (August – September) 1997				
Short duration		68*c*	77*c*	23*c*
Continuous		89*b*	103*b*	35*b*
Ungrazed		105*a*	134*a*	85*a*
Spring (May – June) 1998				
Short duration		51*c*	33*c*	12*b*
Continuous		65*b*	42*b*	16*b*
Ungrazed		81*a*	79*a*	65*a*
Fall (August – September) 1998				
Short duration		55*c*	61*b*	21*b*
Continuous		74*b*	73*b*	33*b*
Ungrazed		90*a*	117*a*	93*a*

a–c For each sampling time and within each column, means followed by the same letter are not significantly different ($P \leq 0.05$).

pling due to SDG on Orthic Black Chernozems in Alberta (Dormaar et al. 1989; Chanasyk and Naeth 1995) and this study conducted on Dark Gray Luvisolic soil had no clear advantage for breaking up surface crusting and improving soil properties that are normally correlated to water infiltration. Trampling a dry soil did, indeed, chip and churn the soil surface in other studies (e.g. Warren et al. 1986). However, the hoof action reduced the size of naturally occurring soil aggregates and increased density of the surface soil layer.

The observed decrease in Db_f in the top 7.5 cm and 12.5 to 15 cm over winter is consistent with the study by Mapfumo et al. (1999) in central Alberta on Orthic Black Chernozemic soil. They found a decrease in Db_f over winter in the top 2.5-cm. The most likely explanation for this pattern is that bulk density, as a soil characteristic, is actually a function rather than a single value (United States Department of Agriculture 1996) and sensitive to variation of soil moisture due to contrasting precipitation between 1997 and 1998. Also, these observations support the assertion that freeze-thaw activities can alleviate the effect of animal trampling on soils (Abdel-Magid et al. 1987), and is likely a very important mitigator of soil compaction in central Alberta where moisture is abundant and winters are long and cold.

Penetration resistance is frequently used to measure soil strength. Animal hooves can exert pressure up to 200 kPa, which is considerably greater than the pressure exerted on the soil surface by a tractor, which can range from 30 to 150 kPa (Proffitt et al. 1993). The maximum depth of soil at which changes in PR occurred in this study was 15 cm. The PR was also significantly greater under SDG than CG.

In many studies, root elongation has been linearly related to PR up to 2 MPa, which has been used as the threshold beyond which root growth becomes restricted (Taylor et al. 1966; Graecen 1986; Naeth et al. 1991). If we accept this value as critical for limiting growth, then root growth was most likely affected in the fall of both years at depths of 2.5 to 15 cm for both grazed treatments. Additionally, root growth was less likely affected in the spring of each year because of PR values around 2 MPa. A positive linear relationship between PR and Db_f and a negative linear relationship between PR and Db_f and soil moisture were observed in all experimental periods (not shown). This observation is consistent with other field studies (Malqueen et al. 1977; Ehlers et al. 1983; Busscher et al. 1987; Mapfumo and Chanasyk 1998). These relationships have ramifications to pasture production because this study has also shown that soil water differences explain variation in pasture production in each year.

Because of high precipitation in 1997, especially at the time of sampling, soil water content was generally higher in 1997 than in 1998. The influence of soil water on pasture phytomass production followed the same pattern as that reported by Levitt (1980); aboveground production was reduced with increasing water stress. Soil water was generally reduced at all depths by grazing. This agrees with studies in native rangeland grassland ecosystems in Alberta in which grazing decreased soil water to a 10-cm depth (Smoliak et al. 1972) and to a 30-cm depth (Johnston 1961; Johnston et al. 1971; Naeth et al. 1991). Soil water was greater in ungrazed exclosures compared to short-duration grazed treatments near Fort Macleod, Alberta (Dormaar et al. 1989). Reduced soil water under grazing is generally attributed to reduced infiltration rates as trampling compacts and seals the soil surface (Llacos 1962), a finding backed up by the changes in Db_f and PR. Grazing also reduces litter, which affects soil water through increased evaporation and reduced infiltration (Tomanek 1969; Naeth et al. 1991).

Grazing Impacts on Pasture Production

This study showed differences between grazing treatments (CG > SDG) relative to quantity of standing crop (live green and standing dead) and fallen litter (CG > SDG) and total herbage production (standing crop + fallen litter) (CG > SDG). These results agree with other studies (e.g., Holechek 1980; Heitschmidt et al. 1987) showing that SDG reduced the accumulation of standing dead vegetation and fallen litter. Our study indicated that greater litter was removed by trampling or consumption under SDG than CG. As grazing animals trample and remove live vegetation and litter mass, production is reduced, especially in xeric ecosystems (Johnston et al. 1971; Willms et al. 1986). Though Savory and Parsons (1980) suggest SDG can increase forage production through hoof action, there is abundant literature suggesting that the amount of physical animal impact attained at high stocking rates deters plant succession by reducing the amount of protective plant cover (e.g. Heitschmidt and Walker 1983). Our results, therefore, support the conclusion that high intensity rotational grazing systems do not eliminate the potential hazards commonly associated with excessive rates of stocking on rangelands (Heitschmidt et al. 1987; Dormaar et al. 1989). These results also demonstrate that the dangers of high stocking apply to diversified livestock such as wapiti, and tame pastures as well as native grasslands (e.g., Willms et al. 1986; Dormaar et al. 1989), including Dark Gray Luvisolic soils in the more mesic Boreal Mixed region of Alberta.

CONCLUSIONS

The effects of grazing by wapiti on Db_f and PR were evident in the top 10 cm of the Dark Gray Luvisolic soil examined here. In general, grazing effects on soil properties were more evident in fall than in spring. High intensive SDG compacted the soil more than moderately stocked CG, indicating the former has no advantage over the latter on soil physical properties, at least in the short term. Moreover, SDG removed more green herbage and standing dead material and reduced fallen litter more than that of CG. Long-term evaluation of the effects of grazing systems on soil physical characteristics may help to address seasonal, yearly, and inherent variability in these ecosystems.

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