SOIL COMPACTING IMPACTS OF GRAZING IN MIXED PRAIRIE AND FESCUE GRASSLAND ECOSYSTEMS OF ALBERTA

M. A. NAETH[1], D. J. PLUTH[1], D. S. CHANASYK[1], A. W. BAILEY[2], and A. W. FEDKENHEUER[3]

[1]Department of Soil Science and [2]Department of Plant Science, University of Alberta, Edmonton, Alberta, Canada T6G 2E3; and [3]NOVA Corporation of Alberta, Calgary, Alberta, Canada T2P 2N6. *Received 29 May 1989, accepted 21 Nov. 1989.*

NAETH, M. A., PLUTH, D. J., CHANASYK, D. S., BAILEY, A. W. AND FEDKENHEUER, A. W. 1990. Soil compacting impacts of grazing in mixed prairie and fescue grassland ecosystems of Alberta. Can. J. Soil Sci. **70**: 157–167.

The impacts of long-term grazing on compaction were assessed in mixed prairie and fescue grassland ecosystems of Alberta. Grazing regimes were of light to very heavy intensities, grazed early, late, and continuously during the growing season. Bulk density was measured with a surface moisture/density gauge and a combination moisture/density probe to 65 cm. Penetration resistance to 30 cm was measured with a cone penetrometer. Solonetzic soils were less sensitive to compaction under grazing than Chernozemic soils. Heavy intensity and/or early season grazing had greater impacts on compaction than light intensity and/or late season grazing. Under the former grazing regimes, bulk density increased to 7.5 cm at Kinsella and 65 cm at Stavely; penetration resistance increased to depths of 2.5 cm at Brooks, 15 cm at Kinsella, and 30 cm at Stavely. Heavy trampling versus regular grazing increased penetration resistance to depths of 30 and 10 cm under heavy intensity and/or early season and light intensity and/or late season grazing, respectively. Late season grazing at Brooks and light to moderate grazing at Stavely may be used as management models to reduce compaction under grazing. Trends were not as clear at Kinsella, but light June and autumn grazing had the least compacting effect.

Key words: Compaction, grazing, rangelands, penetration resistance, bulk density

[Effets du pâturage sur le compactage du sol dans les prairies mixtes et les champs de fétuque de l'Alberta.]
Titre abrégé: Effets de compactage provoqué par le pâturage dans les grands parcours de l'Alberta.
Nous avons évalué les effets du pâturage à long terme sur le compactage du sol dans les prairies mixtes et les champs herbagers de fétuque de l'Alberta. Les régimes de pâturage durant la saison de croissance ont varié de léger à très intense, ou de précoce, tardif ou continu. La densité apparente a été mesurée à l'aide d'un indicateur de l'humidité volumique et d'une combinaison humidimètre/densimètre à une profondeur de 65 cm. La résistance à la pénétration à 30 cm a été mesurée à l'aide d'un pénétromètre à cône. Les sols solonetziques se sont avérés moins sensibles au compactage provoqué par le pâturage que les sols chernozémiques. Par ailleurs, les modes de pâturage de forte intensité ou précoce ont provoqué un plus grand effet de compactage que les régimes de faible intensité ou tardif. Dans les premier cas, la densité apparente a augmenté à 7,5 cm à Kinsella et à 65 cm à Stavely; par ailleurs, la résistance à la pénétration a augmenté à des profondeurs de 2,5 cm à Brooks, de 15 cm à Kinsella et de 30 cm à Stavely. Le piétinement intensif par opposition au pâturage ordinaire a accru la résistance à pénétration à des profondeurs de 30 et 10 cm, sous l'effet respectivement d'un régime de pâturage intensif ou hâtif et d'un régime de faible intensité ou tardif. Le régime de pâturage tardif à Brooks, ainsi que les modes de pâturage d'une

intensité variant de faible à modérée à Stavely, pourraient servir de modèles de gestion pour réduire l'effet de compactage provoqué par le pâturage. Aucune tendance aussi évidente n'a été observée à Kinsella; l'effet de compactage a toutefois été le plus faible avec les modes de pâturage légers pratiqués en juin et à l'automne.

Mots clés: compactage, pâturage, parcours naturels, résistance à la pénétration, densité apparente

Researchers have documented soil compaction by grazing animals in various ecosystems of the world. In the Canadian Northern Great Plains, grazing causes compaction on sand, loam, silt loam, and clay-textured soils in Saskatchewan mixed prairie (Lodge 1954; Martens 1979) but not on sandy loam and loam-textured soils in Alberta mixed prairie grazed by sheep (Smoliak et al. 1972). Grazing intensity affects compaction, with heavy grazing compacting soils to a 10-cm depth but light and moderate grazing having no effect on bulk density (Lodge 1954).

On rangelands in the United States, susceptibility of a soil to compaction is affected by vegetative cover (Wood and Blackburn 1984), and plant roots (Gifford et al. 1977). Compaction is higher, and to a greater depth on coarse-textured soils, but there is often no effect on fine-textured soils (Van Haveren 1983). Degree of compaction is affected by soil water content (Gifford et al. 1977) and is maximum between wilting point and field capacity (Orr 1960). Soil compaction increases as stocking rate increases (Reed and Peterson 1961). In most studies, grazing effects on soil bulk density are manifested in the top 6 cm. Studying compaction in range ecosystems is complex because factors other than trampling, such as vegetation mass and type, plant rooting depth, freeze-thaw and wetting-drying cycles, organic matter content, soil structure, and soil water holding capacity, affect soil bulk density and penetration resistance.

It was hypothesized that heavy grazing would compact the soil, especially in treatments where vegetation was most affected and in heavily utilized areas such as cattle paths. It was also hypothesized that defoliation without trampling could lead to higher bulk densities than occurred in areas that were not defoliated or trampled since grazing can reduce root activity, which can affect soil bulk density and penetration resistance. The objective of this study was to determine the effect of season and intensity of grazing on soil bulk density and penetration resistence in mixed prairie and fescue grassland ecosystems of Alberta. A further objective was to determine the magnitude of compaction from heavy trampling, light trampling, and no trampling within a given grazing treatment.

MATERIALS AND METHODS

Study Sites

Three study sites representing major rangeland ecosystems of southern and central Alberta were selected. Each study site had long-term grazing treatments, ungrazed controls, grass-dominated vegetation that had never been cultivated, and slopes of less than 2% (Naeth 1988). Moss (1983) was used as the botanical authority unless otherwise noted.

The Brooks study site was located in mixed prairie approximately 225 km east of Calgary (approximately 51°N latitude and 112°W longitude). The area has a continental climate and semiarid moisture regime. Mean annual precipitation is 355 mm with an average annual moisture deficit of 227 mm. Mean annual temperature is 4°C, with a July mean of 19°C and a January mean of −14°C. Elevation averages 745 m above sea level with slopes of less than 2%. Soils are Brown Solodized Solonetz and Brown Solod developed on till (Kjearsgaard et al. 1982). Soil is loam-textured for the upper 30 cm and clay loam below (Naeth 1988). Vegetation is of the Blue grama-Spear grass-Wheat grass (*Bouteloua-Stipa-Agropyron*) faciation dominated by blue grama (*Bouteloua gracilis*), spear grass (*Stipa comata*), western, and northern wheat grasses (*Agropyron smithii* and *A. dasystachyum*) (Coupland 1961). Pasture sage (*Artemisia frigida*) and little club-moss (*Selaginella densa*) are common forbs. A short grass disclimax dominated by blue grama is common as a result of heavy long-term grazing.

The Kinsella study site was located in aspen parkland approximately 150 km southeast of Edmonton (approximately 53°N latitude and 111°W longitude). The climate is dry subhumid. Mean annual precipitation is 380 mm; mean annual evapotranspiration is 381 mm. Mean annual temperature is 2°C, with a July mean of 17°C and a January mean of −17°C. Elevation averages 685 m above sea level with gently rolling to hilly topography (Howitt 1988). Orthic Black Chernozems on glacial till dominate the grasslands. Soil texture is sandy clay loam in the upper 5 cm and loam to sandy loam below (Naeth 1988). Vegetation consists of grass and shrub communities with aspen groves (*Populus tremuloides*) occurring at irregular intervals. Plains rough fescue [(*Festuca hallii*) (Vasey) Piper] (Pavlick and Looman 1984) dominates open undisturbed grasslands and western porcupine grass (*Stipa curtiseta*) codominates on grazed areas (Wheeler 1976). Various forbs are a common component of the vegetation.

The Stavely study site was located in foothills fescue grassland approximately 100 km south-southwest of Calgary (approximately 50°N latitude and 114°W longitude). The climate is subhumid without marked deficiency of precipitation. Mean annual precipitation is 550 mm. Mean annual temperature is 5°C, with a July mean of 18°C and a January mean of −10°C. Elevation averages 1350 m above sea level and topography is gently rolling to hilly. Soils are Orthic Black Chernozems developed on till (Johnston et al. 1971). Soil is clay loam textured in the upper 30 cm and loam to clay loam below (Naeth 1988). Vegetation is of the fescue grassland association (Looman 1969) with rough fescue (*Festuca campestris* Rydb.) dominating in undisturbed and lightly grazed areas. Parry's oat grass (*Danthonia parryi*) and bluebunch fescue (*Festuca idahoensis*) are codominants in grazed areas. With heavy grazing, rough fescue is replaced by annual invaders and bluegrass (*Poa*) species.

Grazing Treatments

At Brooks, three grazing treatments were studied within a community pasture established in 1964 (B. Shanks, pers. commun. 1984): (1) early season grazing from May through July; (2) late season grazing from August through October; and (3) a control that had not been grazed since the late 1930s. The 0.9 animal unit months (AUM) ha^{-1} stocking rate was considered heavy for the area.

At Kinsella, five grazing treatments established in 1973 on the University of Alberta ranch were studied: (1) light June grazing from 1 to 30 June at 1.5 AUM ha^{-1}; (2) heavy June grazing from 1 to 30 at 4.4 AUM ha^{-1}; (3) heavy autumn grazing from 15 Sept. to 15 Oct. at 4.4 AUM ha^{-1}; (4) light autumn grazing from 15 Sept. to 15 Oct. at 1.5 AUM ha^{-1}; and (5) a control ungrazed since 1942 (Bailey et al. 1987). Two randomly located permanent exclosures in each treatment were also studied.

At Stavely, five grazing treatments established in 1949 on the Agriculture Canada Range Research Substation and grazed from May through September were studied: (1) very heavy grazing at 4.8 AUM ha^{-1}; (2) heavy grazing at 2.4 AUM ha^{-1}; (3) moderate grazing at 1.6 AUM ha^{-1}; (4) light grazing at 1.2 AUM ha^{-1}; and (5) a control comprised of permanent exclosures in each grazing treatment (Johnston et al. 1971).

Experimental Design and Statistical Analyses

The experimental design within each site was a hierarchical arrangement (Steel and Torrie 1980). Within each treatment, three 0.1-ha replicates were randomly established. Measurement points were randomly selected within each replicate.

Statistical analyses were conducted using variation among replicates as an appropriate measure of error variation for testing the significance of treatments. Data were tested for homogeneity of variance using Cochran and Bartlett-Box tests. The W test was used to test data for normality of distribution (Shapiro and Wilk 1965). Analysis of variance was used to test for treatment effects. Data with significant *F* values were further analyzed to separate the means using the Student-Newman-Keul (SNK) test at the 5% probability level (Steel and Torrie 1980).

Statistical analyses within each study year (April to November) by treatment combination indicated variation among replicates was not significantly different from sampling point variation; therefore in all future analyses replicate and sampling point variations were pooled. If statistical analyses within treatment using the pooled error term indicated significant differences between study years, data were analyzed on a within-year basis. Otherwise data from all years were pooled and means presented. Sources of variation in the final statistical analysis were treatments and error within treatments.

Soil Analyses and Field Measurements

Three neutron probe access tubes were installed with a hydraulic coring unit at random points in all replicates (nine tubes per treatment). Soil bulk density and soil water measurements were made with a Campbell Pacific Nuclear 501 combination moisture/density probe in late July 1985, 1986, and 1987. Two 15-s readings were taken at each depth, starting at 15 cm and proceeding in 10-cm increments to 65 cm. Two surface bulk density (0–10 cm) readings were taken adjacent to each access tube with a Campbell Pacific Nuclear MC1-12 surface moisture/density gauge.

Penetration resistance was measured with a hand-pushed CN-973 penetrometer with a 30° cone, a 3.23-cm^2 base area, and a 0–2070 kPa range. Measurements were made in 10 randomly selected locations per replicate at the soil surface and at depths of 2.5,5,10,15, and 30 cm in late July 1986 and 1987. Bulk density and penetration resistance measurements were taken in July, corresponding to mid-growing season and lowest soil water.

To assess the combined effect of defoliation and trampling on soil compaction, bulk density and penetration resistance were measured on cattle paths where heavy trampling occurred, in the grazing treatment under normal animal traffic, in the exclosure where vegetation was neither trampled nor defoliated, and just within the exclosure fence where no trampling occurred but vegetation was defoliated from cattle reaching under the fence. Bulk density and soil water were measured with the surface moisture/density gauge and penetration resistance with the penetrometer in 10 randomly selected points per replicate. These measurements could not be made at Brooks where there were no grazing exclosures adjacent to treatments.

Table 1. Near-surface (0–7.5 cm) soil water (mm) during penetration resistance measurements

Treatment	1986	1987
Brooks		
Early	9*a*	11*ab*
Late	9*a*	9*b*
Control	11*a*	12*a*
Kinsella		
Light June	29*a*	32*a*
Heavy June	27*ab*	32*a*
Heavy autumn	25*ab*	32*a*
Light autumn	24*b*	27*b*
Control	14*c*	22*c*
Stavely		
Very heavy	13*a*	12*ab*
Heavy	9*b*	12*ab*
Moderate	7*b*	15*a*
Light	7*b*	11*ab*
Control	5*b*	9*b*

a-c Within a given site and year, treatment means with the same letters are not significantly different ($P<0.05$).

RESULTS

Near-surface (0–7.5 cm) soil water at the time of penetration resistance measurements generally differed among treatments for a given year in all three study sites (Table 1).

Brooks: Mixed Prairie

Treatment had no significant effect on soil bulk density at any depth (Table 2). Penetration resistance in the upper 2.5 cm was affected by season of grazing, being lowest in the control and highest under early season grazing (Table 3). Penetration resistance at depths greater than 5 cm exceeded the range of the penetrometer.

Kinsella: Parkland Fescue

Significant treatment effects on soil bulk density were evident in the upper 7.5 cm and between 35 and 55 cm, inclusive (Table 2). Near-surface bulk density was lowest in the control and highest under heavy June grazing. Bulk density at 35–55 cm was lowest under light autumn grazing.

Penetration resistances from 0 to 15 cm were lower in the control than in one or more grazing treatment (Fig. 1). Penetration resistances at 5 and 10 cm, inclusive, were higher in the heavy autumn treatment than in the control or June treatments. Values at 15 cm were higher in the heavy autumn treatment than in the heavy June treatment.

Bulk density in the upper 7.5 cm was not affected by defoliation without trampling but was higher in grazed areas and cattle paths than in exclosures or defoliated, untrampled areas (Table 4). Under light intensity grazing, bulk density in grazed areas was lower than that on cattle paths, whereas under heavy intensity grazing it was the same in the grazed areas and paths.

Penetration resistances were generally lower in exclosures than in grazed areas or on cattle paths by 250–750 kPa (Table 5). Trends in penetration resistance were similar across depths for a given location, lowest at the surface, generally constant at depths of 2.5–15 cm, and highest at 30 cm. Penetration resistance at the soil surface was higher on cattle paths by approximately 250 kPa than in grazed areas in autumn treatments but not

Table 2. Soil bulk density (Mg m^{-3}) with depth at Brooks, Kinsella, and Stavely

Treatment	Depth (cm) 0-7.5	15	25	35	45	55	65
				Brooks			
Early	1.07*a*	1.32*a*	1.39*a*	1.35*a*	1.44*a*	1.50*a*	1.49*a*
Late	1.02*a*	1.30*a*	1.32*a*	1.44*a*	1.52*a*	1.55*a*	1.58*a*
Control	1.07*a*	1.31*a*	1.35*a*	1.49*a*	1.57*a*	1.55*a*	1.54*a*
				Kinsella			
Light June	0.96*b*	1.24*a*	1.41*a*	1.52*a*	1.50*a*	1.55*a*	1.69*a*
Heavy June	1.07*a*	1.11*a*	1.37*a*	1.47*a*	1.45*a*	1.39*ab*	1.54*a*
Heavy autumn	0.99*b*	1.17*a*	1.35*a*	1.47*a*	1.49*a*	1.55*a*	1.57*a*
Light autumn	0.95*b*	1.12*a*	1.30*a*	1.34*b*	1.35*b*	1.34*b*	1.41*a*
Control	0.89*c*	1.26*a*	1.34*a*	1.46*a*	1.52*a*	1.55*a*	1.58*a*
				Stavely			
Very heavy	0.90*a*	0.70*a*	0.99*a*	1.16*a*	1.40*a*	1.62*a*	1.68*a*
Heavy	0.83*b*	0.48*bc*	0.86*a*	1.20*a*	1.39*a*	1.59*a*	1.66*a*
Moderate	0.80*b*	0.40*c*	0.66*b*	1.09*a*	1.19*b*	1.41*b*	1.48*b*
Light	0.83*b*	0.58*b*	0.82*a*	1.11*a*	1.29*ab*	1.41*b*	1.51*b*
Control	0.75*c*	0.51*b*	0.90*a*	1.16*a*	1.34*a*	1.43*b*	1.50*b*

a-c At a given site and depth, treatment means with the same letters are not significantly different ($P<0.05$).

Table 3. Penetration resistance (kPa) with depth at Brooks

Depth (cm)	Treatment: Early season	Late season	Control
Surface	1648*a*	1455*b*	648*c*
2.5	2013*a*	1807*b*	1448*c*
5.0	2069*a*	1979*a*	1875*a*

a-c At a given depth, treatment means with the same letters are not significantly different ($P<0.05$)

in June treatments. These two areas had significantly different values at 2.5 cm in all but the heavy June treatment but differences diminished with depth.

Stavely: Foothills Fescue

Soil bulk density was affected by grazing at all depths to 65 cm, with the exception of 35 cm (Table 2). Bulk density in the surface 7.5 cm was lowest in the control and highest under very heavy grazing. Bulk density at 15 cm was highest in the very heavy treatment and at 55 and 65 cm was higher in the heavy and very heavy treatments than in the other three treatments.

Penetration resistance at the soil surface increased under grazing (Fig. 2). Lowest penetration resistances with depth were in the control and highest were in very heavy and/or heavy treatments. Penetration resistances at and below 15 cm did not differ among light, moderate, and control treatments.

Higher near-surface bulk densities were found in grazed areas and on cattle paths than in untrampled areas (Table 4). Bulk densities in defoliated areas and exclosures were not significantly different. Only under very heavy grazing was near-surface bulk density higher on cattle paths than in the regular grazing treatment.

Penetration resistance was lower in exclosures than on cattle paths or grazed areas, most noticeably between 2.5 and 10 cm in the heavy and very heavy treatments where it was lower by 500–1500 kPa (Table 5). The light treatment was the exception, where values at 15 and 30 cm did not differ. Penetration resistance on cattle paths was generally higher than in grazed areas, with the above noted exception and at or below 15 cm in the other treatments. Under very heavy grazing, penetration resistance was not quantifiable on cattle paths below 2.5 cm because values were greater than the 2070 kPa upper limit of the penetrometer.

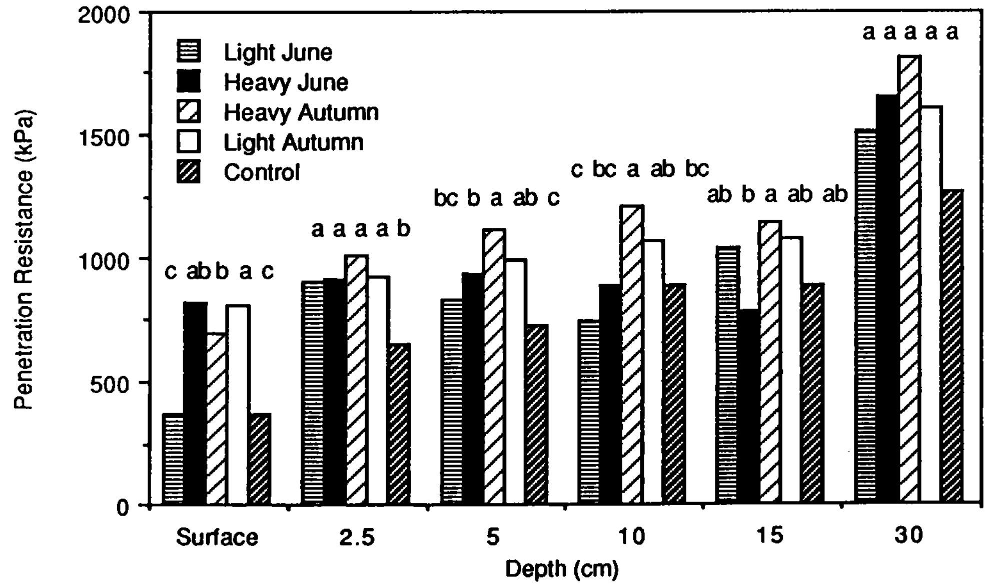

Fig. 1. Penetration resistance at Kinsella. At a given depth, means with the same letters are not significantly different ($P < 0.05$).

Table 4. Surface (0–10 cm) soil bulk density (Mg m^{-3}) at Kinsella and Stavely in the exclosure, in areas defoliated but not trampled, in grazed areas, and in heavily trampled areas

	Location			
Treatment	Path	Grazed	Defoliated	Exclosure
		Kinsella		
Light June	1.01*a*	0.98*b*	0.85*c*	0.81*c*
Heavy June	1.08*a*	1.10*a*	0.95*b*	0.87*b*
Heavy autumn	1.05*a*	1.00*a*	0.82*b*	0.82*b*
Light autumn	1.00*a*	0.97*b*	0.90*c*	0.85*c*
		Stavely		
Very heavy	1.04*a*	0.98*b*	0.81*c*	0.79*c*
Heavy	0.93*a*	0.87*a*	0.63*b*	0.74*b*
Moderate	0.80*a*	0.82*a*	0.74*b*	0.69*b*
Light	0.92*a*	0.89*a*	0.77*b*	0.75*b*

a-c Within site and grazing treatment, location means with the same letters are not significantly different ($P < 0.05$).

DISCUSSION

Grazing Effects

Heavy intensity grazing treatments had the greatest compacting effect as evidenced by higher bulk densities and penetration resistances in treatments compared to controls and lightly grazed treatments. With heavier stocking densities, more surface area was trampled and soil subjected to more loadings. As vegetation is removed by grazing, its cushioning effects are reduced, making the soil more susceptible to compaction. Smaller amounts of organic matter in heavy treatments would also make the soil more susceptible to compaction (Naeth et al. 1990).

The compacting effect of heavy intensity treatments was evidenced by higher surface bulk density in heavy June versus light June treatments at Kinsella and in heavy and very heavy treatments compared to light, moderate, and control treatments at Stavely. Penetration resistances at the soil surface were lowest in light June and control treatments and at 2.5 cm in the control at Kinsella. However, higher penetration resistances at the surface, 5, and 10 cm under light autumn grazing at Kinsella did not support the compacting effect of heavy grazing. Since the light June treatment had been grazed the month before measurements were made, wetting-drying cycles and plant growth would have had

Table 5. Penetration resistance (kPa) with depth at Kinsella and Stavely

	Treatment	Location depth (cm)					
		Surface	2.5	5	10	15	30
Kinsella							
Light June	Path	414a	1020a	952a	924a	945a	1407a
	Grazed	365a	910b	827b	745ab	1041a	1510a
	Exclosure	207b	537c	563c	683b	772b	910b
Heavy June	Path	862a	1020a	986a	965a	1041a	1717a
	Grazed	821a	917a	931a	889a	786b	1648b
	Exclosure	372b	496b	648b	717b	752b	1207c
Light autumn	Path	1083a	1193a	1076a	1034a	1083a	1310ab
	Grazed	814b	924b	986a	1069a	1076a	1600a
	Exclosure	407c	621c	676b	855b	917a	1055b
Heavy autumn	Path	896a	1193a	1158a	1234a	958a	1648a
	Grazed	696b	1014b	1117a	1207a	1138a	1813a
	Exclosure	393c	600c	662b	855b	945a	1234b
Stavely							
Light	Path	1296a	1607a	1779a	1689a	1503a	1572a
	Grazed	986b	1234b	1248b	1282b	1220a	1724a
	Exclosure	483c	710c	889c	1214b	1393a	1662a
Moderate	Path	1076a	1620a	1689a	1655a	1565a	2006a
	Grazed	924a	1214b	1207b	1345b	1524a	1827a
	Exclosure	607b	703c	669c	814c	1041b	1738a
Heavy	Path	1427a	1751a	1855a	1972a	1882a	1979a
	Grazed	917b	1393b	1393b	1482b	1620ab	1862a
	Exclosure	427c	703c	883c	972c	1165b	1393b
Very heavy	Path	834a	2069a				
	Grazed	765a	1772b	1848a	1917a	2069a	2069a
	Exclosure	579b	662c	731b	958b	1255b	1744b

a-c At a given site, treatment, and depth, location means with the same letters are not significantly different ($P < 0.05$).

ameliorating effects on grazing impacts. Autumn treatments had not been grazed for approximately nine months prior to measurements but were affected by the same cycles. Soil textural differences in this treatment did not account for the discrepancy. However, soil water was lower under light autumn grazing which could affect penetration resistance (Naeth 1988).

It was expected that heavy intensity grazing at Brooks would cause compaction compared to the control. The lack of differences was likely due to the naturally high bulk densities of the Solonetzic soils. However, these differences were evident from penetration resistance data to 2.5 cm. Voorhees et al. (1978) found bulk density increased 20% or less due to wheel traffic on a silty clay loam, but penetration resistance increased by as much as 400% indicating it is a more sensitive parameter. Results reported here are not supported by those of other studies in Canadian mixed prairie (Lodge 1954; Smoliak et al. 1972; Martens 1979). The heavy continuous grazing regime and higher clay content of the Solonetzic soils in this study would account for these differences.

Early season grazing resulted in more compaction than did late season grazing. Higher organic matter in the heavy autumn treatment compared to the heavy June treatment at Kinsella and in the late season grazed treatment

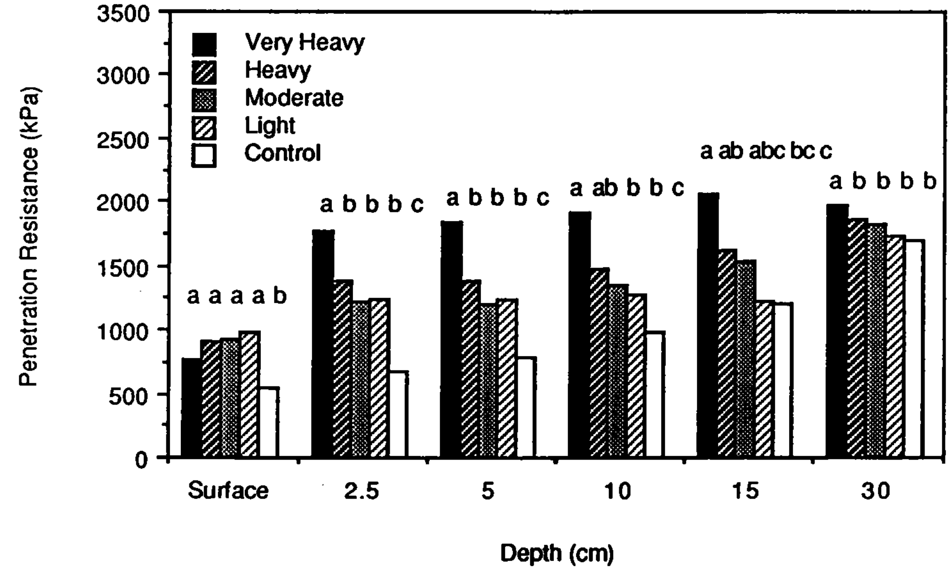

Fig. 2. Penetration resistance at Stavely. At a given depth, means with the same letters are not significantly different ($P < 0.05$).

compared to the early season grazed treatment at Brooks could lessen compaction (Naeth et al. 1990). More rainfall occurs in June than in autumn at all sites, leading to wetter soils that are more susceptible to compaction by grazing. At the time of measurements, the late season treatment had not been grazed for nine months, but the early season treatment was near the end of the grazing for that year. Overwinter decreases in bulk density due to freeze-thaw processes may have occurred in the late season grazed treatment, although this was not assessed in the present study.

Grazing can reduce root growth and activity, which in turn can have an effect on soil bulk density and penetration resistance. However, there was no evidence of this since bulk density under defoliated and non-defoliated areas at Kinsella and Stavely did not differ significantly.

The effects of compaction under heavy grazing intensities were relatively uniform on both cattle path and non-path areas. However, under light grazing, heavier use areas such as the cattle paths were more compacted than were other areas of the treatment. Selective grazing in these lighter grazed treatments led to some areas being utilized less extensively and thus treaded less frequently than others.

Depth Of Compaction

Direct effects of treading on soil compaction will be observed most often in the upper 30 cm of the soil profile where soil bulk density is generally lowest and pressure exerted by a moving animal would have the greatest impact. At Stavely, higher bulk densities in the very heavy treatment from the surface to a 15-cm depth were due to the direct impact of animal treading. However, at 55 and 65 cm, increases in bulk density in heavy and very heavy treatments are more likely an interaction of plant species changes due to grazing, reduced root activity, and treading. As grazing intensity increases, more shallow-rooted species replace deep rooted species such as rough fescue. Soil factors were not considered to be significant because soil texture at this depth did not differ among the treatments (Naeth 1988).

Differences in penetration resistance with depth between grazed and heavily trampled cattle paths were most affected by heavy intensity and/or early season grazing. Effects of grazing intensity were most evident at Stavely. At Kinsella, surface penetration resistance for trampled and grazed areas did not differ in June treatments but was different in autumn treatments indicating overwinter freeze-thaw amelioration is not occurring at this site. More compaction occurs on wetter soil during June grazing. Higher total organic matter in autumn treatments reduces the compacting effects of grazing. Under heavy June grazing, significant differences between penetration in cattle paths and the regular grazed areas were manifested to a greater depth than under light June grazing. However, nonsignificant differences between these areas under autumn grazing to 15 cm indicated grazing intensity had less impact if grazing did not occur during the early part of the growing season.

Effects of Compaction On Plant Growth

Soil bulk density and penetration resistance ranges considered detrimental to plant establishment, growth, and yield are reported in the literature, although these values are species specific. Russell and Goss (1974) documented that plant roots can exert pressures up to 1000 kPa and that 2000 kPa penetration resistances of soil can reduce root growth up to 50%. Hakansson et al. (1988) indicated limiting values of penetration resistance for most plant species lie between 2000 and 5000 kPa. Taylor et al. (1966) found no taproots penetrate where soil strength was greater than 2500 kPa, regardless of soil material. If these values are accepted as growth limiting, only in the early season treatment at Brooks and the heavy and very heavy treatments at Stavely were penetration resistance values near 2000 kPa, a threshold likely to affect plant growth negatively.

Barley et al. (1970) found as normal point resistance increased above 1000 kPa, primary root elongation rates decreased. Since total root length/unit volume of soil may be one of the most important factors determining uptake of water and nutrients (Barley et al. 1970), penetration resistances above 1000 kPa affect plant growth and development. Thus the Brooks site was most affected, since ungrazed soil values are near 1500 kPa below 2.5 cm and increase to 2000 kPa under early season grazing. At Kinsella penetration resistance values greater than 1000 kPa only occurred below 30 cm. At Stavely, values in the control are greater than 1000 kPa at 15 cm, and in the grazed treatments are greater below 2.5 cm. The very heavy treatment poses the greatest problem, with penetration resistance as high as 1750 kPa at 2.5 cm.

Management Implications

Grazing managers can use select grazing regimes to maintain soil surface conditions that can withstand the compacting forces of grazing without changes in bulk density and penetration resistance that are detrimental to vegetation growth. These grazing regimes maintain high levels of soil organic matter, litter, and vegetative cover that provide a cushioning effect between the soil and the grazing animal and thereby minimize factors leading to compaction. These regimes optimize infiltration which in turn reduces ponded water and wet soil surface conditions which can increase compacting damage.

On Alberta rangelands, high density Solonetzic soils often found in mixed prairie are not as easily compacted as the Chernozemic soils in the fescue grasslands. Late season grazing at Brooks and light to moderate continuous grazing at Stavely may clearly be used as management models to reduce compacting impacts of grazing. Trends are not as clear at Kinsella, but the light and/or autumn grazing regimes appear to be the best management models. Compacting impacts of grazing will be reduced with lighter grazing intensities in any season.

With short duration grazing becoming an important management alternative in Alberta, it is important to consider the increasing compaction under wet and moist soil conditions. Under wet or very moist conditions such as springmelt, during intense or long duration rains, the duration of grazing will have to be reduced in order to minimize compaction.

CONCLUSIONS

Heavy intensity grazing had the greatest compacting effect, increasing bulk densities and penetration resistances. Early season grazing had greater compacting effects than late season grazing.

Grazing affected soil bulk density to depths of 7.5 cm in aspen parkland fescue grassland on Chernozemic soils at Kinsella and 65 cm at Stavely in foothills fescue grassland on Chernozemic soils, but did not affect soil bulk density in mixed prairie on Solonetzic soils at Brooks. Grazing treatment affected penetration resistance to 2.5 cm at Brooks, 15 cm at Kinsella, and 30 cm at Stavely. Compaction occurred at greater depths under heavy intensity grazing than under light intensity grazing.

Defoliation without trampling did not increase soil bulk density. Within a given treatment, heavier trampling on cattle paths compared to the regular grazing treatment caused greater changes in penetration resistance to 30 cm under heavy intensity and/or early season grazing at Kinsella and Stavely. Under light intensity and/or late season grazing, differences were not manifested below 10 cm.

ACKNOWLEDGMENTS

The financial support of NOVA Corporation of Alberta is gratefully acknowledged. K. Ostermann, V. Naeth, J. Scott, J. McGill, G. Hoppe, and D. White are thanked for their technical assistance. The Lethbridge Research Station of Agriculture Canada, the Eastern Irrigation District, and the Department of Plant Science, University of Alberta are acknowledged for the use of their long-term grazing treatments.

Bailey, A. W., Willoughby, M. G. and Irving, B. D. 1987. Effect of grazing on forage and beef production from rough fescue rangeland in central Alberta. Farming for the Future Final Report. Project No. 84-0335. 41 pp.

Barley, K. P., Farrell, D. A. and Graecen, E. L. 1970. The configuration of the root system in relation to nutrient uptake. Adv. Agron. **22**: 159–201.

Coupland, R. T. 1961. A reconsideration of grassland classification in the Northern Great Plains of North America. J. Ecol. **49**: 136–167.

Gifford, G. F., Faust, R. H. and Coltharp, G. B. 1977. Measuring soil compaction on rangeland. J. Range Manage. **30**: 459–460.

Hakansson, I., Voorhees, W. B., and Riley, H. 1988. Vehicle and wheel factors influencing soil compaction and crop response in different traffic regimes. Soil Tillage Res. **11**: 239–282.

Howitt, R. W. 1988. Soil survey of the county of Beaver. Alberta Soil Survey Report No. 47. Alberta Research Council Open File Report No 1987-4.

Johnston, A., Dormaar, J. F. and Smoliak, S. 1971. Long-term grazing effects on fescue grassland. J. Range Manage. **24**: 185–188.

Kjearsgaard, A. A., Peters, T. W. and Pettapiece, W. W. 1982. Soil Survey of the County of Newell No. 4, Alberta. Alberta Institute of Pedology Report S-82-41. 197 pp.

Lodge, R. W. 1954. Effects of grazing on the soils and forage of mixed prairie in southwestern Saskatchewan. J. Range Manage. **7**: 166–170.

Looman, J. 1969. The fescue grasslands of western Canada. Vegetatio Acta Geobotanica **19**: 127–145.

Martens, H. E. 1979. Content and distribution of organic matter in natural and managed ecosystems in the mixed prairie grassland region in Saskatchewan. M.Sc. Thesis. Dep. Plant Ecology, University of Saskatchewan. Saskatoon, Sask. 135 pp.

Moss, E. H. 1983. Flora of Alberta. 2nd ed. Revised by J. G. Packard. University of Toronto Press. Toronto., Ont. 687 pp.

Naeth, M. A. 1988. The impact of grazing on litter and hydrology in mixed prairie and fescue grassland ecosystems of Alberta. Ph.D. dissertation. Dep. Plant Science, University of Alberta, Edmonton, Alta. 173 pp.

Naeth, M. A., Bailey, A. W., Pluth, D. J., Chanasyk, D. S. and Hardin, R. T. 1990. The impact of grazing regime on litter and soil organic matter in mixed prairie and fescue grassland ecosystems of Alberta. J. Range Manage (in press).

Orr, H. K. 1960. Soil porosity and bulk density on grazed and protected Kentucky Bluegrass range in the Black Hills. J. Range Manage. **13**: 180–186.

Pavlick, L. E. and Looman, J. 1984. Taxonomy and nomenclature of rough fescues, *Festuca altaica, Festuca campestris* (*F. scabrella* var. *major*), and *Festuca hallii*, in Canada and the adjacent part of the United States. Can. J. Bot. **62**: 1739–1749.

Reed, M. J. and Peterson, R. A. 1961. Vegetation, soil, and cattle responses to grazing on Northern Great Plains range. USDA For. Serv. Tech. Bull. No. 1252. 79 pp.

Russell, R. S. and Goss, M. J. 1974. Physical aspects of soil fertility — the response of roots to mechanical impedance. Neth. J. Agric. Sci. **22**: 305–318.

Shapiro, S. S. and Wilk, M. B. 1965. An analysis of variance test for normality (complete samples). Biometrika **52**: 591–611.

Smoliak, S., Dormaar, J. F., and Johnston, A. 1972. Long-term grazing effects on *Stipa-Bouteloua* prairie soils. J. Range Manage. **25**: 246–250.

Steel, R. G. D. and Torrie, J. H. 1980. Principles and procedures of statistics: a biometrical approach. 2nd ed. McGraw-Hill, New York, N.Y. 633 pp.

Taylor, H. M., Roberson, G. M. and Parker, J. J. 1966. Soil strength-root penetration relations for medium- to coarse-textured soil materials. Soil Sci. **102**: 18–22.

Van Haveren, B. P. 1983. Soil bulk density as influenced by grazing intensity and soil type on a shortgrass prairie site. J. Range Manage. **36**: 586–588.

Voorhees, W. B., Senst, C. G. and Nelson, W. W. 1978. Compaction and soil structure modification by wheel traffic in the northern corn belt. Soil Sci. Soc. Am. J. **42**: 344–349.

Wheeler, G. W. 1976. Some grassland and shrubland communities in the parklands of central Alberta. M.Sc. Thesis. Dep. Plant Science. University of Alberta. Edmonton, Alta. 95 pp.

Wood, M. K. and Blackburn, W. H. 1984. Vegetation and soil responses to cattle grazing systems in the Texas Rolling Plains. J. Range Manage. **37**: 303-308.