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Soil compaction of forest plantations in interior British Columbia

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Abstract

Grazing cattle on forest plantations in the interior of British Columbia (B.C.) is a common practice, but its impact on soil compaction is not well documented. This study evaluated the effects of cattle grazing and forage seeding on soil compaction in lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) plantations near Kamloops, B.C. Grazing regimes consisted of ungrazed exclosures and pastures grazed to achieve 50% utilization of forage vegetation. Seeding treatments were 0 and 12 kg ha^{-1}. Soil bulk density and penetration resistance were determined in 1996 and 1997, before and after the one-month grazing period on study sites grazed since 1989. Water infiltration rates were measured in 1997 after the one-month cattle grazing period. Bulk density was 6% higher on grazed pastures compared to the exclosures. Pastures seeded to domestic forage species had significantly greater soil bulk density at the 0-7.5 cm depth than unseeded pastures. Soil penetration resistance was higher throughout most of the soil profile in the grazed treatments than in the ungrazed exclosures. On pastures without grazing, seeding of the domestic forage species resulted in lower soil penetration resistance relative to unseeded pastures. This was especially true at depths below 6 cm. The rate of water infiltration was not affected by long-term grazing and forage seeding. The bulk density and penetration resistance data indicate that plantation grazing at 50% forage utilization does not lead to root-limiting increases in soil compaction.

Key Words: forest grazing, cattle, bulk density, soil penetration resistance

Resumen

El apacentamiento de ganado en plantaciones forestales del interior de Columbia Británica (C.B.) es una práctica común, sin embargo, sus impactos en la compactación del suelo no han sido bien documentados. Este estudio evaluó los efectos del apacentamiento de ganado y la siembra de forraje en la compactación del suelo de plantaciones de "Lodgepole pine" (Pinus contorta Dougl. Ex Loud. Var. Latifolia Engelm) cercanas a Kamloops, C.B. Los tratamientos de apacentamiento fueron: áreas sin apacentamiento (excluidas) y áreas apacentadas hasta alcanzar un 50 % de utilización de las especies forrajeares. Los tratamientos de siembra fueron 0 y 12 kg ha^{-1}. En 1996 y 1997, se determinó la densidad aparente y la resistencia a la penetración del suelo antes y después de un período de apacentamiento de 1 mes, las mediciones se realizaron en los sitios de estudio apacentados desde 1989. Las tasas de infiltración de agua se midieron en 1997 después del período de apacentamiento de 1 mes. La densidad aparente fue 6% mayor en potreros apacentados que en los excluidos. En los porteros sembrados con especies forrajeras nativas la densidad aparente del estrato de 0-7.5 cm fue significativamente mayor que la de los potreros sin sembrar. La resistencia de penetración de la mayor parte del perfil de suelo fue mas alta en los tratamientos con apacentamiento que en las exclusiones. En potreros sin apacentamiento, la siembra de especies forrajeras nativas resultó en una menor resistencia de penetración del suelo en comparación con los potreros sin sembrar, esto fue especialmente cierto a profundidades mayores de 6 cm. La tasa de infiltración del agua no fue afectada por el apacentamiento a largo plazo ni por la siembra de forrajes. Los datos de densidad aparente y resistencia de penetración del suelo indican que el apacentamiento al 50% de utilización no limita el crecimiento de raíces por efecto de la compactación del suelo.

Forests in the interior of British Columbia (B.C.) provide over 8.3 million ha of summer and fall range for livestock and account for nearly 80% of the total area of Crown land grazed. The onset of clearcut logging in the early 1960's provided opportunities for grazing livestock and wildlife on areas that were not previously available. This also created conflicts between range use and silviculture on mid- and high-elevation forests. The conflicts were further exacerbated by a concern that the cattle grazing of forest plantations can lead to severe soil compaction.

Soil compaction is quantified by bulk density and/or penetration resistance. Critical values for these 2 parameters that are limiting for root growth are affected by complex interactions among soil strength, water and nutrient availability, and aeration (Greacen and Sands 1980). Hence, it is very difficult to establish critical values.

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Several studies have shown that increased soil bulk density can have a negative impact on growth of young tree seedlings (Heilman 1981) and productivity of older plantations (Minore 1986, Froehlich et al. 1986, Bosworth and Studer 1990). Minore et al. (1969) assessed the effects of soil compaction on root growth in pots of seven coniferous species in sandy loam soils of the Pacific Northwest. Roots of lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latipedia* Engelm.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) were more resistant to increases of soil compaction than roots of Sitka spruce (*Picea sitchensis* [Bong.] Carr.), western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), and western red cedar (*Thuja plicata* Donn. ex D. Don). Reduced root growth was observed in the latter 3 species at soil bulk densities greater than 1.45 Mg m^{-3}, while no species could penetrate a soil with bulk density greater than 1.59 Mg m^{-3}. In a study by Heilman (1981), root growth of Douglas-fir seedlings declined linearly with an increase in bulk density of a loam soil from 1.37 to 1.75 Mg m^{-3} and root growth was prevented above 1.75 Mg m^{-3}.

Relatively few studies have used penetration resistance to describe soil compaction and its effects on root growth, especially for tree species. Greacen et al. (1969) reported that critical values for penetration resistance ranged from 800 to 5,000 kPa (mean 2,500 kPa) depending on species, soil type, and type of penetrometer used. It has been commonly cited that root growth is restricted beyond 2,000 kPa, as measured by a flat-tipped penetrometer (Gerard et al. 1982, Busscher and Sojka 1987), which corresponds to about 2500 kPa for the 13-mm cone tip (30°) penetrometer (Busscher et al. 1986).

The objectives of this study were to evaluate the effects of cattle grazing on lodgepole pine plantations on soil compaction and to determine if forage seeding ameliorated soil compaction. This study tested the hypotheses that (i) long-term cattle grazing results in greater bulk density and penetration resistance and lower water infiltration rates relative to an ungrazed control, (ii) bulk density and penetration resistance are lower before than after 1-month of cattle grazing, and (iii) forage seeding reduces bulk density and penetration resistance and increases water infiltration rates.

Study Site and Methods

Site Description

The study was replicated at 3 sites, which had been established for a large scale forest grazing study (Wikeem et al. 1991), in the Very Dry Cool Montane Spruce biogeoclimatic subzone (Lloyd et al. 1990). Two sites were located near Tunkwa Lake (50 km SW of Kamloops, 50° 33' N, 120° 56' W) and one near Helmer Lake (30 km NE of Merritt, 50° 21' N, 120° 37' W). Elevations and slopes of the 3 sites are similar averaging 1400 m and 10-15%, respectively. Aspects at Tunkwa Lake are NW and at Helmer Lake the aspect is mostly west. The climate is cool, continental, with cold winters and moderately short, warm summers. Mean annual precipitation is 355 mm. The soils are generally Melanic Brunisols (Eutrochrept Inceptisol) with Luvisols (Boralf) occurring in mesic areas. Parent material is predominantly glacial till. Surface soil texture (0–7.5 cm) is sandy loam for the Tunkwa Lake Site 1 and loam for Tunkwa Lake Site 2 and Helmer Lake. Average contents of coarse fragments (diameter >2 mm) were 14, 20, and 22% (volume) on Tunkwa Lake Site 1, Tunkwa Lake Site 2, and Helmer Lake Site, respectively. Average organic matter contents at the 0-7.5 cm depth of the mineral soil were 19.1 metric-ton ha^{-1} for the Tunkwa Lake Site 1, 21.5 metric-ton ha^{-1} for the Tunkwa Lake Site 2, and 21.3 metric-ton ha^{-1} for the Helmer Lake Site.

The trees on the Tunkwa Lake sites were harvested and windrowed in fall 1986, burned, and then drag-scarified in fall 1987. The majority of the Helmer Lake site was harvested in 1985 with an additional 10 ha harvested in fall 1987, when the whole site was rough-piled, track-and-blade-scarified, and burned. Forage seeding occurred in the spring of 1988. The forage seeding mix included 35% orchardgrass (*Dactylis glomerata* L.), 5% timothy (*Phleum pratense* L.), 40% alsike clover (*Trifolium hybridum* L.), and 20% white clover (*Trifolium repens* L.) by weight. Seeding treat-

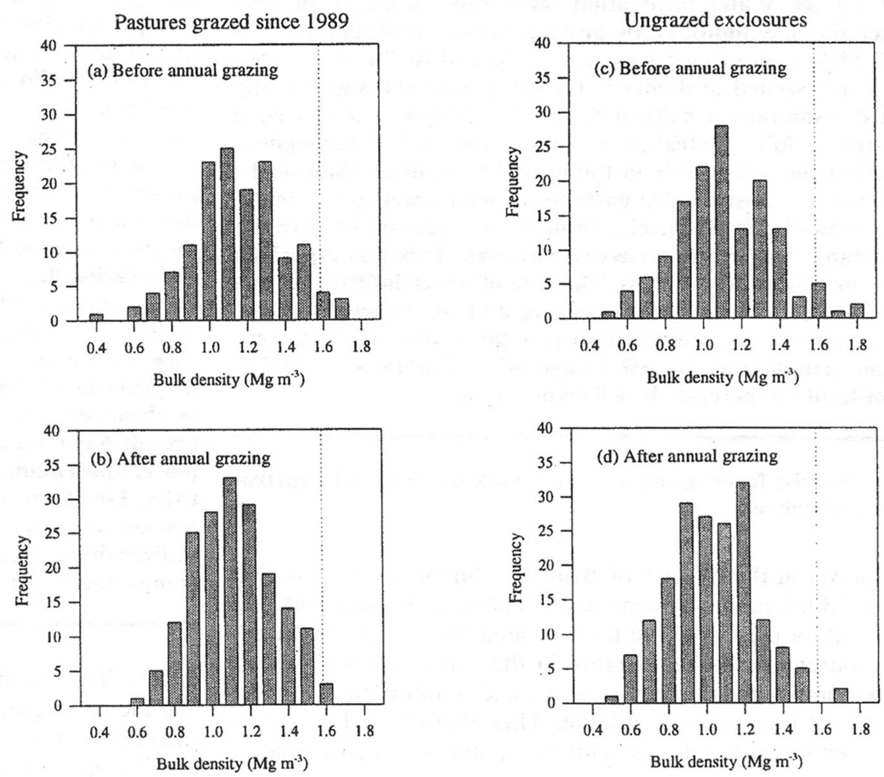

Fig. 1. Distribution of bulk density values (averaged over two years) on pastures grazed since 1989 taken before (a) and after annual grazing (b) and on ungrazed exclosures taken before (c) and after annual grazing (d). The dashed line indicates the critical value for root growth determined by a survey of literature.

ments were 0 and 12 kg ha^{-1}. Immediately after forage seeding, one-year old nursery grown lodgepole pine seedlings were planted on all three sites at a density of 1,400 stems ha^{-1} (2.7-m spacing). In each of the 2 forage seeding treatments exclosures (0.5 ha) were constructed as ungrazed controls, while the rest of the pastures were grazed to achieve 50% utilization of forage vegetation. Grazing started in 1989 using cow-calf pairs for one month per year. In 1996 grazing occurred between 16 July and 16 August, while in 1997 grazing occurred between 15 July and 15 August. At the time of sampling, the unseeded pastures were dominated by pinegrass (*Calamagrostis rubescens* Buckl.) (36%) and a mix of broadleaved native forbs (47%). The seeded pastures contained a similar component of broadleaved native forbs (57%) but much of the pinegrass was replaced by timothy, orchardgrass, and white clover. Alsike clover was no longer present at the time of sampling.

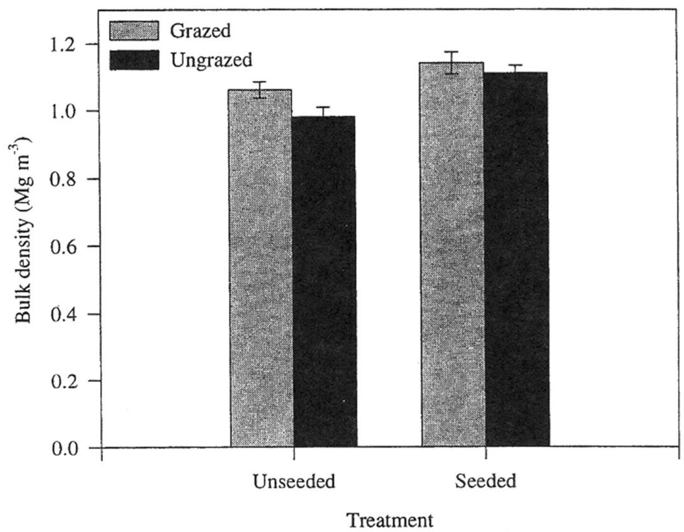

Fig. 2. Soil bulk density following long-term grazing and seeding to domestic forage species. Error bars represent standard error of the mean (n=12).

Sampling Methods

Soil sampling locations were systematically established along 4 transects within each of the exclosures and grazed pastures. Soil samples for bulk density and water content determination, as well as measurements of soil penetration resistance were obtained before annual cattle grazing (24–28 June 1996 and 7–9 July 1997) and again after cattle left the sites (16-20 September 1996 and 15-17 September 1997). Measurements of the rate of water infiltration were performed only after cattle grazing on 15–17 September 1997.

Soil bulk density was determined by the core method (Blake and Hartge 1986). Surface forest floor/slash material was removed and intact soil cores (7.5 x 7.5 cm) were collected from the 0-7.5 cm depth of mineral soil (3 cores per transect). Core samples were dried at 105°C for 48 hours in a forced-air oven. Coarse fragments (diameter >2 mm) and other large organic debris within the mineral sample were separated and weighed. Volume of mineral coarse fragments was determined from dry mass with an assumed mineral particle density of 2.65 Mg m^{-3}, while volume of organic debris was determined from dry mass and assumed particle density of 1.3 Mg m^{-3}. Soil bulk density was calculated as the mass of dry, coarse fragment-free mineral soil per volume of field-moist mineral soil, where volume is also calculated on a coarse fragment-free basis.

Table 1. Analysis of variance (mean squares-MS and significance probability associated with the F ratio) for treatment effects on soil bulk density (2-year average).

Source of variation	df	MS	Pr>F
Site	2	0.0074	0.2214
Time of sampling (T)	1	0.0102	0.2214
Error a	2	0.0033	
Seeding (S)	1	0.1240	0.0249
T X S	1	0.0096	0.3848
Error b	4	0.0101	
Grazing (G)	1	0.0374	0.0246
T X G	1	0.0014	0.6065
S X G	1	0.0096	0.1985
T X S X G	1	0.0033	0.4335
Error c	8	0.0392	0.8704

Soil penetration resistance (Bradford 1986) was measured to the 20 cm depth (forest floor/slash material included), at intervals of 1.5 cm, using a hand-pushed 13-mm diameter cone (30°) penetrometer with data logger (Agridry Rimik PTY Ltd., Toowoomba, QLD, Australia). Eight profiles were recorded per transect, 3 of which were located where the bulk density samples were taken.

Since penetration resistance is strongly affected by the soil water content at the time of measurement, the penetration resistance was corrected to a single soil water content using the method proposed by Busscher and Sojka (1987). This correction allows comparisons of absolute penetration resistance, which are independent of the original soil water content. Corrections were adjusted to a reference water content of 0.29 kg kg^{-1}, which was an average value for the 3 sites at the time of penetration resistance measurements. Average soil water contents were 0.35 kg kg^{-1} before and 0.25 kg kg^{-1} after grazing.

The rate of water infiltration in the field was determined using a double-ring infiltrometer (Bouwer 1986). Three sets of an outer (56 cm diameter by 30 cm height) and inner (30 cm diameter by 30 cm height) cylinders were used per pasture. These were nested and pounded 5 cm into the ground forming a watertight seal. The change in water depth of the inner ring was measured over a period of 2 hours at the following

Table 2. Analysis of variance (mean squares-MS and significance probability associated with the F ratio) for treatment effects on soil penetration resistance (2-year average) at 3, 6, 9, 12, 15, and 18 cm depths.

		Depth (cm)											
		3		6		9		12		15		18	
Source of variation	df	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F	MS	Pr>F
Site	2	11096		96320		233609		369938		609881		773728	
Time of sampling (T)	1	139321	0.2292	844291	0.0982	2572428	0.0486	3921633	0.0404	5401550	0.0269	5419008	0.0268
Error a	2	47584		96931		134766		168678		151316		151468	
Seeding (S)	1	26508	0.3417	16428	0.6858	2028	0.9173	7105	0.8647	374	0.9664	7	0.9943
Error b	4	22814		86711		165881		215391		185680		116504	
Grazing (G)	1	587419	0.0001	2581696	0.0001	283824	0.0001	2529090	0.0001	1842400	0.0001	1478412	0.0003
T X G	1	22707	0.0958	67500	0.0331	111940	0.0125	108110	0.0272	85177	0.1248	547	0.9099
S X G	1	26414	0.0762	67650	0.0330	86191	0.0227	91002	0.0384	177877	0.0383	216008	0.0487
T X S X G	1	6721	0.3345	39790	0.0839	25392	0.1652	28714	0.2020	29205	0.3448	35534	0.3737
Error c	8	6373		10217		10888		14861		28980		40041	

time intervals: 5, 10, 15, 20, 30, 40, 50, 60, 75, 90, 105, and 120 minutes. A head of 5–10 cm was maintained and readings were taken with a floating gauge. Conditions for the measurement of unsaturated hydraulic conductivity were assumed to occur after 20 minutes.

Statistical Analysis

Bulk density and soil penetration resistance data were analyzed as a split-split-plot, randomized, complete block design with 3 replications. The time of sampling (i.e., before and after annual grazing) was the main-plot treatment, the forage seeding rate was the subplot treatment, the grazing was the sub-sub-plot treatment, while the 3 sites represented replications. Soil penetration resistance data were analyzed separately for 6 selected depths (3, 6, 9, 12, 15, and 18 cm). Water infiltration data (unsaturated hydraulic conductivity) were analyzed as a split-plot, randomized, complete block design with three replications. The forage seeding rate was the main plot treatment, the grazing was the subplot treatment, and the 3 sites were considered as replicates. The general linear model procedure in the SAS package (SAS Institute 1990) was used.

Results and Discussion

Bulk Density

Due to the high variability of the bulk density data on the study sites (Fig. 1), data were pooled over 2 years and analyzed as average bulk density. There was no detectable change (P>0.05) in bulk density following 1 month of grazing use, i.e. before and after annual grazing (Table 1). One month of grazing per year at 50% forage utilization was not sufficient time to produce changes in soil bulk density during the 2 years of this study.

Pastures grazed since 1989 had higher soil bulk density (P<0.05) than ungrazed exclosures (Table 1). Eight years of cattle grazing has increased soil bulk densities by 6% relative to the ungrazed exclosures (Fig. 2). Similar increases in bulk density due to grazing were reported in studies on rangeland soils (Orr 1960, McCarty and Mazurak 1976, Chanasyk and Naeth 1995).

Pastures seeded to domestic forage species had significantly greater

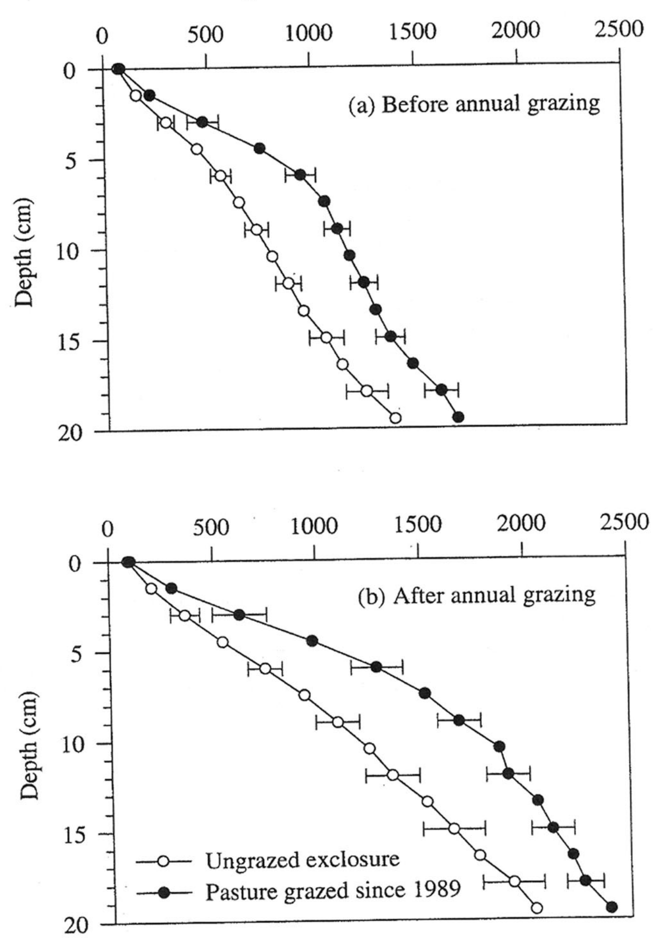

Fig. 3. Soil penetration resistance (2 year average) before (a) and after annual grazing (b). Error bars represent standard error of the mean (n=12).

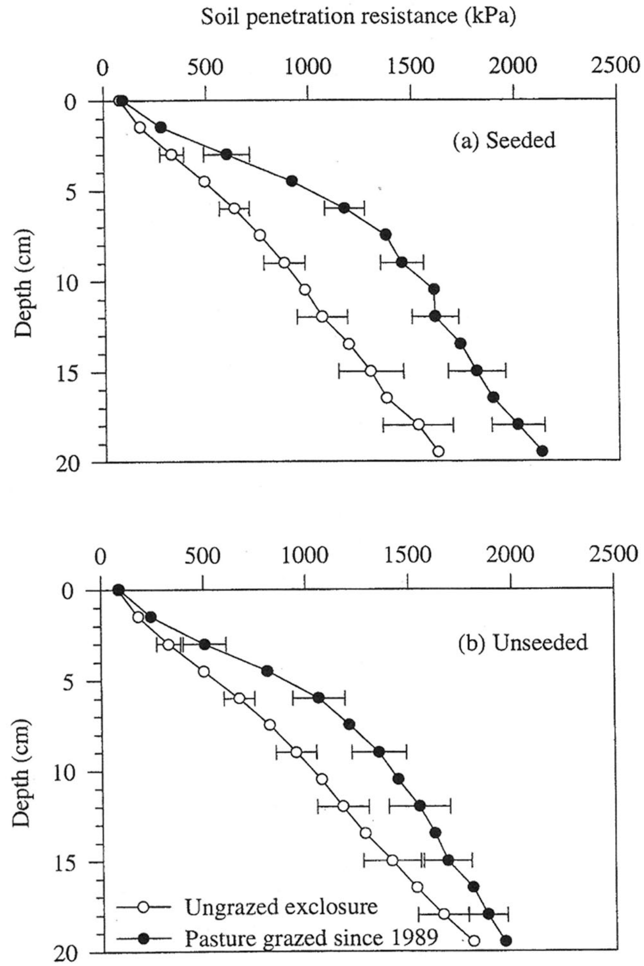

Fig. 4. Soil penetration resistance (2 year average) on seeded pasture (a) and unseeded pasture (b). Error bars represent standard error of the mean (n=12).

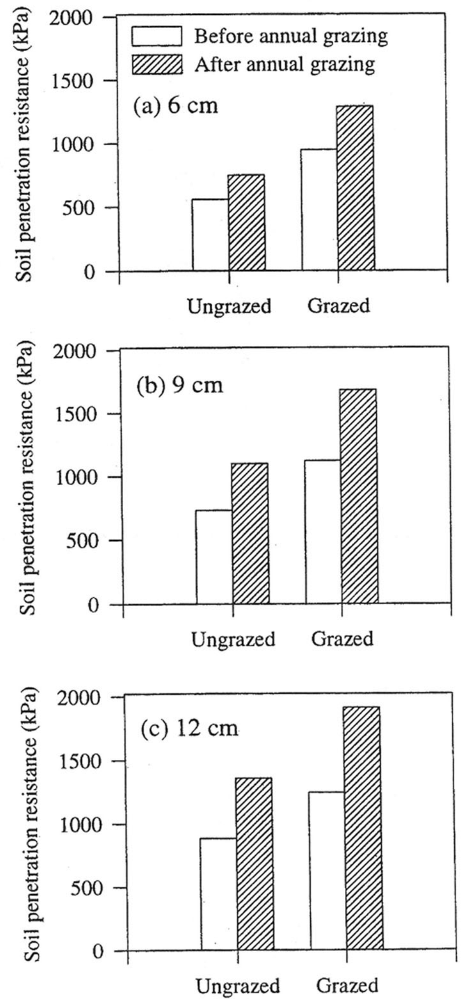

Fig. 5. Effect of time of sampling x grazing interaction on soil penetration resistance at 6, 9, and 12 cm depths.

(P<0.05) soil bulk density than unseeded pastures (Table 1). This resulted from the higher number of animals used to achieve 50% utilization of total forage on seeded than unseeded pastures. The hypothesized ameliorating effect of forage seeding on soil bulk density was negated by the higher cattle stocking rate required to achieve the same forage use.

The soil bulk densities obtained in the grazed pastures during this study were well below the root-limiting critical range reported by Minore et al. 1969, Heilman 1981, and Carr et al. 1991. The results indicate that long-term plantation grazing at 50% forage utilization will not lead to a significant reduction in root growth due to compaction.

Penetration Resistance

Eight years of grazing clearly increased (P<0.05) soil penetration resistance (Table 2) relative to the ungrazed exclosure throughout most of the soil profile (Fig. 3 and 4). The increase in soil penetration resistance resulting from the grazing treatment differed at the two sampling dates at 6, 9, and 12 cm depths (significant time of sampling x grazing interactions, Table 2, Fig. 5), however, soil penetration resistance was consistently lower in the ungrazed control.

The overall seeding treatment had no effect on soil penetration resistance at any depth (Table 2), but the seeding treatment affected the change in penetration resistance due to the grazing treatment (significant seeding x grazing interaction, Table 2, Fig. 6). Soil penetration resistance in ungrazed exclosures was lower in seeded than unseeded areas, while the trend was reversed in grazed pastures (Fig. 6). Since no grazing occurred in the exclosures, observed differences in soil penetration resistance were caused by forage seeding alone. On the other hand, in the pastures grazed since 1989 higher numbers of animals were used on seeded than unseeded treatments to achieve the same forage utilization. This resulted in higher trampling and consequently greater soil penetration resistance on grazed-seeded than on grazed-unseeded pastures.

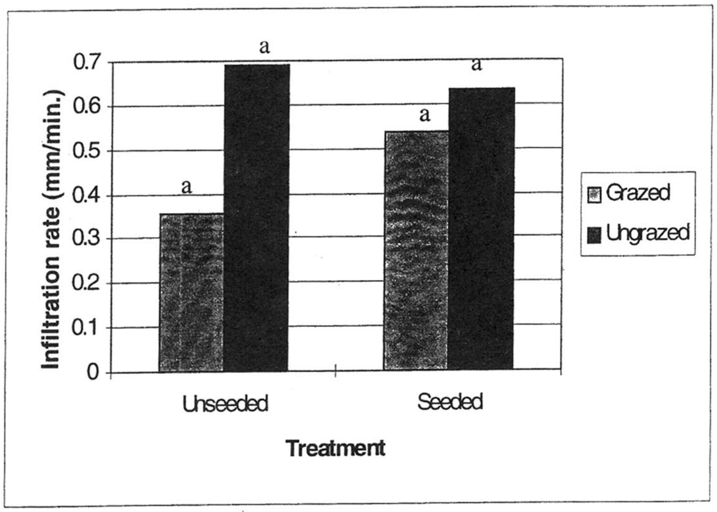

Fig. 7. Rate of water infiltration following long-term grazing and seeding to domestic forage species. Bars with the same letters indicate no significant difference (P>0.10).

Differences in soil penetration resistance between unseeded and seeded pastures without grazing increased with depth and become more apparent at depths below 6 cm (Fig. 6). This is a reflection of different rooting depths of pinegrass and domestic forage mix consisting of orchardgrass, timothy, and white clover. Generally, roots of pinegrass are distributed at a shallower depth than roots of seeded forage species (Spedding and Diekmahns 1972). Therefore, greater root biomass at depths below 6 cm on seeded ungrazed pastures could have resulted in lower soil penetration resistance than on unseeded pastures without grazing.

Soil penetration resistance above 2,500 kPa, when measured by the cone tip penetrometer, (Greacen et al. 1969, Busscher et al. 1986) has been reported as threshold of root-restricting conditions. It should be noted, however, that this threshold was not specifically developed for lodgepole pine, and that the penetration resistance threshold will vary depending on the soil water content at the time of penetration resistance measurement. With this understanding and using the 2,500 kPa as a threshold value, our data indicate that root growth was not restricted at any depth on the grazed pastures. Lodgepole pine trees grew equally well (P<0.05) on both grazed and ungrazed pastures in this experiment (unpublished data) indicating that the cattle grazing was not limiting root growth.

The effects of 8 years of cattle grazing on lodgepole pine performance are difficult to infer using only soil penetration resistance data, due to the lack of applicable information on the relationship of lodgepole pine root growth to penetration resistance, and because soil water content will alter the threshold value. A full interpretation of the soil penetration resistance data requires the development of lodgepole pine root growth/ penetration resistance relationships over a range of soil water contents.

Water Infiltration

The rate of water infiltration was not affected (P>0.10) by long-term grazing or forage seeding rate (Fig. 7). The high variability of water infiltration measurements on the study sites resulted in low power to detect treatment differences.

Conclusions

Cattle grazing for 8 years has increased soil bulk density by 6% relative to the ungrazed exclosures. Similarly, penetration resistance throughout the entire soil profile was

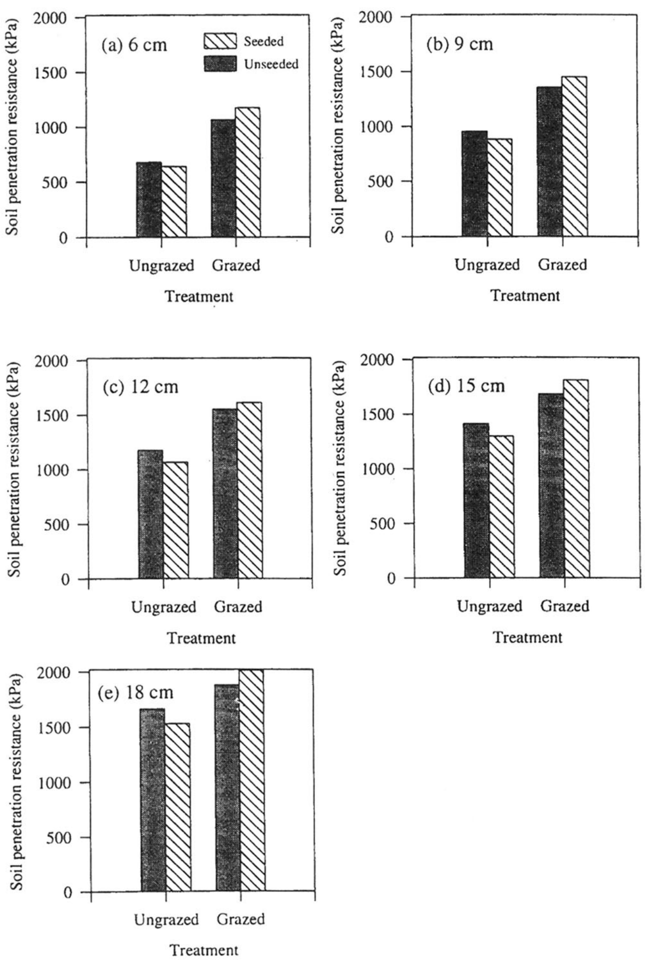

Fig. 6. Effect of seeding rate x grazing interaction on soil penetration resistance at 6, 9, 12, 15, and 18 cm depths.

higher on pastures grazed since 1989 than on ungrazed exclosures. This effect was consistent both before and after annual grazing.

Pastures seeded to domestic forage species had greater soil bulk density in the top 7.5 cm than unseeded pastures. This was related to the higher number of animals needed to achieve 50% forage utilization on seeded pastures. Greater soil penetration resistance was observed on ungrazed, unseeded pastures, dominated by pinegrass, than on pastures seeded with the domestic forage mix, while the reverse trend occurred on grazed treatments. Soil penetration resistance measurements in the ungrazed exclosures confirmed that forage seeding on replanted cutblocks can have an ameliorating effect on soil compaction.

Soil bulk density and penetration resistance data were well below the critical ranges considered to be limiting to root growth. It is unlikely that long-term cattle grazing at 50% forage use will lead to root-limiting increases in soil compaction on these forest plantations. Nevertheless, 8 years of cattle grazing increased both indicators of soil compaction relative to the ungrazed control. Therefore, caution should be exercised when more intense forage utilization is practiced.

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