Agroforestry Systems **21**: 1—10, 1993.

The effect of cattle foot traffic on soil compaction in a silvo-pastoral system

P. G. BEZKOROWAJNYJ, A. M. GORDON* and R. A. McBRIDE
*University of Guelph, Guelph, Ontario, Canada (*Address for correspondence: A. M. Gordon, Agroforestry, Dept of Environmental Biology, University of Guelph, Guelph, Ontario, N1G 2W1, Canada)*

Key words: silvo-pasture, compaction, cattle traffic, penetrometer, bulk density, nitrogen, seedlings

Abstract. This paper reports on the extent of soil compaction due to cattle traffic around hardwood and softwood tree seedlings established in existing pasture, and subject to cattle pressure. A higher soil penetrometer resistance in the grazed areas pointed to a significant change in soil structure (i.e. dry bulk density) as a result of cattle traffic in the area.

In a related experiment comparing the effect of three different levels of soil compaction on tree seedling growth and nitrogen cycling, it was found that water infiltration and nitrogen uptake were reduced in soils treated with a medium and high level of compactive effort. This resulted in a slower rate of growth of the tree seedlings. The addition of an additional nitrogen source improved seedling growth in both the medium and high density compactive treatments.

1. Introduction

Trees incorporated into pasture may increase land productivity by producing wood and other products in addition to providing forage for cattle [7]. However, the effect that cattle traffic has on soil properties such as bulk density may adversely affect tree growth with the net effect of reducing total system productivity.

The increase in soil bulk density resulting from trampling by cattle has been well documented [3, 8, 11, 12, 15]. Mature cattle can exert a static ground pressure of approximately 1.7 kg/cm^2 of hoof-bearing area; this is equivalent to that exerted by heavy-wheeled tractors [9], which may affect bulk density to a depth of as much as one metre [13].

The effects of increased soil compaction from cattle traffic will cause a decrease in porosity as larger pores are compressed resulting in lowered soil water infiltration rates [10], impeded plant root system growth, increased activity of soil denitrifiers [6] and reduced nitrogen uptake [16]. Subsequently, all these factors contribute to the adverse effect on tree growth [4] which can be detrimental to establishing silvo-pastoral systems.

The objective of this study was to examine the extent of soil compaction due to cattle traffic around both hardwood and softwood tree seedlings established in existing pasture, and subject to cattle pressure. In a separate but related study, the effects of different levels of soil compaction on tree seedling growth were also examined.

2. Materials and methods

Red oak (*Quercus rubra* L.), hybrid poplar (*Populus spp.*), Norway spruce (*Picea abies* (L.) Karst.), and white pine (*Pinus strobus* L.) seedlings were planted on a 1 ha area of marginal (soil: sandy loam) pasture consisting of a grass legume mix on a farm near Grand Valley, Ontario. The experimental design consisted of 6 replications of a split-plot design with grazing (cow) and no-grazing (no-cow) as main treatments. Twelve trees were planted at 3 m spacings per experimental plot with 4 plots per block; 576 trees were planted in total in twelve, 15 × 21 m block areas.

Dry dairy cattle were pastured in the treatment plots in the latter part of the growing season at a density of 2 head in July for 7 days, 5 head in August for 3 days, and 2 head in September for 7 days. Fresh water from a water tank located between replication plots 3 and 4 in the middle of the experimental area was readily accessible by cattle during grazing periods.

Soil penetrometer resistance was measured with a Rimik Recording Cone Penetrometer System. Resistance was measured to a depth of 30 cm at 1.5 cm increments for each main treatment each month for 5 months during the growing season. The average reading of 3 replicate probe events within a 1 meter radius of the seedling (i.e. a soil pedon) within a treatment was automatically calculated by the Rimik penetrometer, and the average of 4 readings were recorded per treatment per replication for a total of 24 average penetrometer resistance profiles per main treatment per month. Measurements were taken within the same pedon at the beginning of each month.

Gravimetric soil moisture contents were determined from 4 soil samples taken from the Apk horizon (0—19.5 cm) per replication within 1 m of where penetrometer resistance readings were taken. A total of 24 samples were taken per main treatment per month.

Soil penetrometer resistance measurements and soil moisture readings were taken each month with the exception of the month of August when recording equipment was inoperable.

This field experiment was part of a larger study to test the aversion behaviour exhibited by cattle to manure slurry and the effect it may have on reducing browsing damage if applied to tree seedlings in a silvo-pasture system [1].

In the associated controlled greenhouse experiment, 30 poplar cuttings (clone: DN 177) at 15 cm lengths in 30 cm diameter pots were planted in a 2 × 3 factorial, completely randomized, block design with 5 replications. The main factor treatments were 3 levels of soil compactive effort (low, medium and high), and 2 levels ('no slurry', 'slurry') of a nitrogen source from manure slurry application. The soil used was a sandy loam with high levels of free carbonates (HCl test) and a pH of 7.5.

All cuttings were planted such that the distal end of the cutting was flush with the surface of the soil in the pot. The soil was then compacted using a standard Proctor rammer (2.5 kg piston falling 30 cm) to the appropriate compaction levels: low density (Proctor rammer not used), medium density (100 falls of the Proctor rammer per pot), and high density (200 falls of the Proctor rammer per pot). Cuttings were pushed further into the soil with the Proctor rammer during the compaction event and the tops of all cuttings remained flush with the surface of the soil after compaction was completed. Subsequently, 2 litres of water were added to each pot; thereafter, 1 litre of water was added to each pot every 3 to 4 days. The time of sprout emergence was recorded and height growth increment measurements were taken 2 times per week for the duration of the experiment (115 days).

In order to simulate what might result from the application of manure slurry to trees in the field, manure slurry from dairy cattle was added to the soil in the appropriate pots (15 pots) at 102 days after planting. Tree height measurements were continued for the remainder of the trial period.

Intact soil core samples were taken from each treatment pot to calculate the saturated hydraulic conductivity (K_{sat}) and the soil dry bulk density. Cone penetrometer (Rimik recording cone penetrometer) readings were used to measure soil resistance to penetration with depth in the pots. At the end of the experimental period, all leaves from the poplar seedlings were harvested, dried at 40 °C, ground using a Wiley mill, and analyzed for total nitrogen using a 'Technicon 2' auto-analyzer. No leaf loss was experienced during the experimental period.

Regression analysis was used to determine differences in the rate of sapling growth, and ANOVA [14] was used to test treatment effects on the nitrogen content of the leaves.

3. Results and discussion

Soil penetrometer resistance is dependent upon the moisture content of the soil. The less moisture a given soil contains, the more resistance there is to penetration by a penetrometer probe or a plant root assuming all other physical soil properties (e.g. dry bulk density) are equal [4]. In order to determine that the differences in soil penetrometer resistance between the main treatments were not due to a change in soil moisture content, gravimetric soil moisture content was measured for the 'cow' and 'no-cow' treatment for each month. During the decrease in soil moisture content toward the middle of the season, and increase toward the end, moisture content was not significantly different between the two treatments in any of the months

Table 1. Average soil penetrometer readings and gravimetric soil moisture contents of pasture areas with and without cattle from May to October, 1989. (Apk horizon to 19.5 cm.)

Month	No cow		Cow	
	Penetrometer resistance (MPa)	Gravimetric soil moisture (% kg kg^{-1})	Penetrometer resistance (MPa)	Gravimetric soil moisture (% kg kg^{-1})
May	0.84[a]	38.1[1]	0.85[a]	36.5
June	1.65[a]	26.2	1.70[a]	26.0
July	2.04[a]	14.8	2.07[a]	14.2
Sept	1.48[a]	22.3	1.70[b]	23.8
Oct	1.22[a]	35.6	1.44[b]	36.1

[a,b] Means by row between treatments followed by different letters represent a significant difference at $p < 0.05$.
[1] There was no difference in soil moisture content across treatments for any month.

tested (Table 1). This would suggest that any change in soil penetrometer resistance in the 'cow' treatment is due to a change in soil structure resulting from cattle traffic in the pasture area.

No significant difference was found between the 'cow' and 'no-cow' areas during the months of May, June and July before the cattle were allowed to graze in the appropriate areas (Fig. 1). In the month of September after cattle were allowed access to the 'cow' treatment areas, however, a significantly higher ($p < 0.05$) resistance to soil penetration at increments of 1.5 cm to a depth of 14.0 cm of the soil profile was found in the 'cow' treatment compared to that of the 'no-cow' treatment. Mean resistance for the total Apk horizon (0—19.5 cm) was found to be 1.70 MPa for the 'cow' treatment and 1.48 MPa for the 'no-cow' treatment. In the month of October, a significantly higher resistance was found to an even greater depth of 24.0 cm in the 'cow' treatment areas. Penetration resistance in the overall Apk horizon in October was also found to be significantly different with 1.44 MPa in the grazed areas (compared to only 1.22 MPa in the ungrazed areas).

In the greenhouse environment, compaction of the soil with the Proctor rammer resulted in an uneven distribution of soil penetration resistance in the soil profile as indicated by measurements taken with the Rimik cone penetrometer (Fig. 2). This is indicative of a field situation such as that found by Duvall and Linnartz [3] in which soil bulk density increased to a greater extent near the soil surface compared to the subsoil after an impact or static load was put onto the soil surface.

Compaction of the soil in the greenhouse experiment resulted in reduction of shoot growth rate. A significantly longer period of time was taken for sprouts to appear in the medium (19 days) and high (20.4 days) density soils, than in the low density soil (13.7 days). Regression analyses indicated signifi-

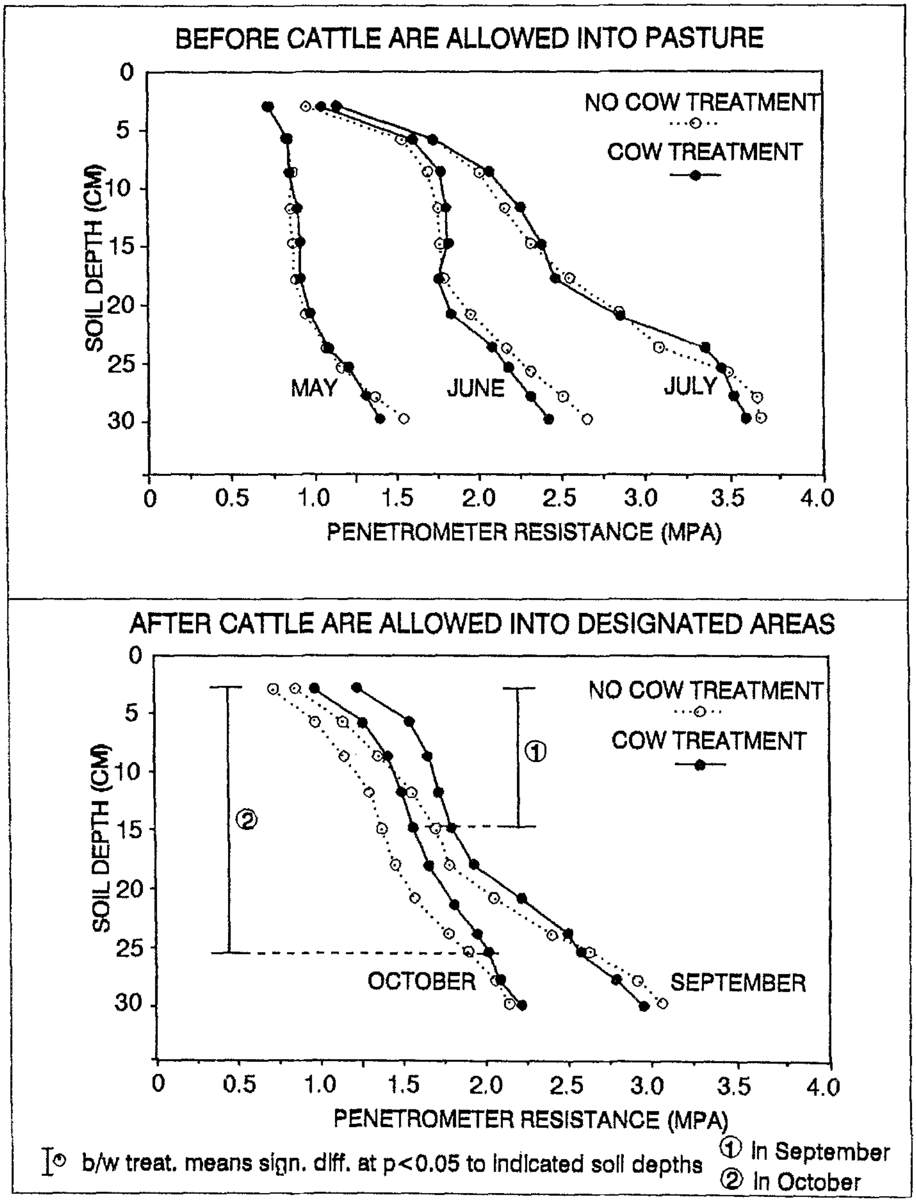

Fig. 1. Soil penetrometer resistance to 30 cm depth in cow/no-cow treatments during the growing season.

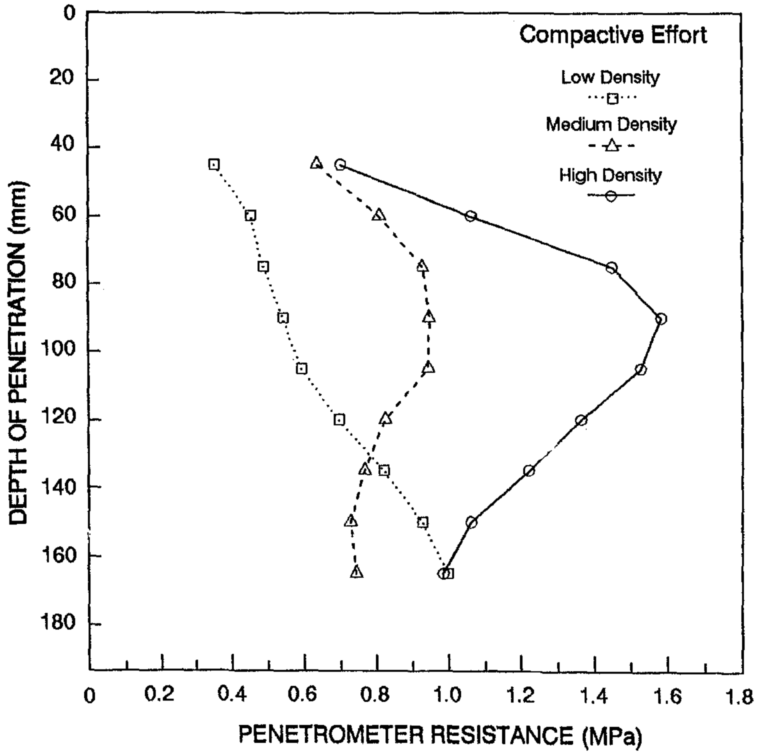

Fig. 2. Mean penetration resistance profiles of potted soil with poplar cuttings after three levels of soil compactive effort applied with a Proctor rammer.

cant differences in seedling growth reflecting higher growth rates in the low density soil treatment compared to those of the medium and high density treatments (Table 2).

When manure slurry was applied on the soil surface of the appropriate treatment pots on day 102, height growth rate of saplings in the slurry treat-

Table 2. Mean rate of height growth of poplar seedlings under three compaction levels after manure slurry had been applied as a treatment.

Compactive effort treatment	Mean rate of height growth (cm wk^{-1})	
	No slurry	Slurry
Low	8.8[a]	8.8[a]
Medium	6.4[b]	9.5[a]
High	6.6[b]	9.5[a]

[a,b] Within row or column values followed by the same letter are not significantly different at $p < 0.05$.

ments increased significantly (compared to the slower growing saplings without the slurry treatment) in the medium and high density soils. However, no difference in the rate of growth was found between the 'slurry' and 'no slurry' treatments in the low density soil (Table 2). Following application of manure slurry, the growth rate of treated seedlings in the medium and high density soils increased sharply to a rate equivalent to that of the faster growing seedlings (both with and without slurry application) in the low density soil.

The K_{sat} measurements on intact soil cores revealed that as soil dry bulk density increased, the saturated hydraulic conductivity in the soil decreased (Table 3). Since the hydraulic properties of the soil govern plant water uptake [5], the reduction in hydraulic conductivity may result in insufficient water availability at the root surface. In addition, as indicated by Wolkowski [16], lower levels of air-filled porosity for longer periods in higher density soils reduce the amount of oxygen available to the root system. In this study, in some of the medium and high density soils, water ponded on the soil surface for several hours after watering. Thus, restriction of oxygen availability to the roots may have provided a temporary anaerobic environment leading to the denitrification of nitrates in the soil.

Table 3. Saturated hydraulic conductivity and soil dry bulk density at three levels of soil compaction.

Compactive effort treatment	Saturated hydraulic conductivity ($cm\ sec^{-1}$)	Dry bulk density ($g\ cm^{-3}$)
Low	2.502×10^{-4} [a]	1.23[a]
Medium	1.507×10^{-4} [b]	1.48[b]
High	0.872×10^{-4} [b]	1.57[b]

[a,b] Within column values followed by the same letter are not significantly different at $p < 0.05$.

A probable reason for the marked increase in growth after the application of manure slurry in the medium and high density soils is that, with the addition of manure nitrogen, nitrates that may have been reduced to N_2O or N_2 through denitrification are replaced by available manure nitrates for root uptake. The results of the total Kjeldahl nitrogen analysis of the leaves supports this theory (Table 4). The leaves from the saplings in the low density soil contained similar concentrations of nitrogen in both the 'no slurry' and 'slurry' treatments (2.30 and 2.26% $kg\ kg^{-1}$, respectively). For this treatment, it is assumed that all soil nitrogen needed for plant growth was available to the saplings and that the addition of nitrates from the manure slurry produced a higher concentration than that needed by the plant. A marked increase in leaf nitrogen, however, was found in the 'slurry' treat-

Table 4. Total leaf nitrogen (% kg kg^{-1}) from poplar seedlings growing in soil at three levels of compaction with and without manure slurry.

Compactive effort treatment	Leaf total nitrogen (% kg kg^{-1})	
	No slurry	Slurry
Low	2.30^a	2.26^a
Medium	1.68^b	2.32^a
High	1.45^b	2.08^a

[a,b] Within row or column values followed by the same letter are not significantly different at $p < 0.05$.

ments compared to the 'no-slurry' treatments for the saplings of both the medium (2.32 and 1.68% kg kg^{-1}), and high density (2.08 and 1.45% kg kg^{-1}) soils.

Destructive examination of the rooting system revealed that average overall root length was significantly longer in the medium (130 cm) and high (130 cm) density soils than in the low density soils (81 cm). This is contrary to what might be expected in most soils: as dry bulk density increases, mechanical resistance to root growth increases and root length should decrease. However, Donald et al. [2] observed maize growing in soil of different aggregate sizes and found longer roots in soils of high resistance. As penetrometer resistance increased, the length of the main axes and primary laterals of the rooting system increased but the degree of branching in the root system decreased. Work conducted by Wolkowski [16] led to similar results. On closer examination of the rooting systems in both the medium and high density soils, however, it was observed that the majority of the root system mass formed at the interface of the soil and inner-pot surface. This may have represented the path of least resistance or an access point for oxygen for respiration (i.e., an artifact).

4. Conclusion

It was surprising to find a change in soil structural influences on penetrometer resistance in grazed areas, especially when considering the small number of animals that were grazed for only a short period of time. Since soil moisture levels for the Apk horizon were not significantly different at $p < 0.05$ between the treatments in any of the five months tested, we can assume that penetration resistance differences between the two treatments cannot be attributed to differences in soil moisture but to changes in soil structure (i.e. dry bulk density) caused by cattle trafficking in the plots.

The increase in bulk density could decrease the rate of water infiltration through the soil profile resulting in temporary anaerobiosis and subsequent denitrification of available soil nitrates. This would limit the amount of nitrogen available to roots resulting in a reduction in tree growth.

From the greenhouse experiment, the significant differences in total nitrogen concentration of the leaves in the 'no slurry' and 'slurry' treatments at the three compaction levels correspond very closely to the differences found in sapling height growth. The seedlings in the higher density soils grew at a slower rate and contained a lower concentration of leaf nitrogen than the seedlings in the low density soil. With the application of manure slurry as a deterrent to browsing cattle, the addition of nitrates from the manure could compensate for denitrified soil nitrates, and maintain an adequate concentration of nitrates at the root surface resulting in growth similar to tree growth in non-compacted soils.

The effect of cattle traffic on soil structure has been shown to warrant consideration when studying silvo-pastoral systems. The decrease in seedling growth rate will result in a suboptimal production of the system as a whole and reduce total potential productivity. Future research into silvo-pastoral systems should include the effects of soil compaction from cattle traffic.

References

1. Bezkorowajnyj PG (1990) Testing manure slurry as a cattle repellent in agro-silvo-pastoral system. MSc Thesis, 110 pp
2. Donald RG, Kay BD and Miller MH (1987) The effects of soil aggregate size on early shoot and root growth of maize. Plant and Soil 103: 251—259
3. Duvall VL and Linnartz NE (1967) Influences of grazing and fire on vegetation and soil of longleaf pine-bluestem range. J Range Manage 20(4): 241—247
4. Ferrero AF (1991) Effect of compaction simulating cattle trampling on soil physical characteristics in woodland. Soil and Tillage Research 19: 319—329
5. Gardner WR (1964) Relation of root distribution to water uptake and availability. Agron J 56: 41—45
6. German JC and Jacques D (1990) Denitrifying activity measurements by soil core method: Effects of depth and characterization of N_2O/N_2 ratio in different soils. Mitteilungen der Deutchen Bodenkundlichen Gesellschaft. Proceedings, International Workshop on Denitrification. Soil, Rhizoshere and Aquifer, Giessen, FRG, March 17—19, 1989
7. Lewis CE, Burton GW, Manson WG and McCormick WC (1983) Integration of pines, pasture, and cattle in south Georgia. Agroforestry Systems 1(4): 277—298
8. Linnartz NE, Hse CY and Duvall VL (1966) Grazing impairs physical properties of a forest soil in central Louisiana. J For 64: 239—243
9. Lull HW (1959) Soil compaction on forest and range lands. US Dep Agr Misc Publ 768, as cited by Raymond DR and SE Westfall. In: Non-grazing and Gophers Lower Bulk Density and Acidity in Annual-Plant Soil. USDA Forest Service Research Note PSW-254, 33 pp
10. Myhr K, Haland A and Nesheim L (1990) The effects of wet composted and untreated cattle slurry, and of soil compaction, on water infiltration rates in cultivated soils. Norsk Landbruksforsking 4(3): 161—172

11. Ratliff DR and Westfall SE (1971) Non-grazing and gophers lower bulk density and acidity in annual-plant soil. Pacific Southwest Forest and Range Exp Sta Research Note PSW-254
12. Read RA (1957) Effect of livestock concentration on surface-soil porosity within shelterbelts. J For 55: 529—530
13. Rhoades ED, Locke LF, Taylor HM and McIlvain EH (1964) Water intake on sandy range as affected by 20 years of differential cattle stocking rates. Jour Range Mgt 17: 185—190
14. SAS (1987) SAS/Stats Guide. SAS Institute Inc Cary, North Carolina, USA, 1028 pp
15. Suman RF and Halls LK (1955) Burning and grazing affect physical properties of coastal plain forest soils. Research Notes, Southeastern Forest Exp Sta, Asheville, North Carolina. January
16. Wolkowski RP (1990) Relationship between wheel-traffic-induced soil compaction, nutrient availability, and crop growth: a review. Journal of Production Agriculture 3(4): 460—469