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DETERMINING THE EFFECT OF TRAMPLING ON SOILS IN HILLSLOPE-WOODLANDS

A. Ferrero[1], *J. Lipiec*[2]

[1]National Research Council, Institute for Agricultural Mechanization, Strada delle Cacce 73, 10135 Turin, Italy
[2]Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, P.O. Box 201, 20-290 Lublin, Poland

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A b s t r a c t. Soil compaction by animal trampling and by vehicular traffic influences many soil parameters. However, the knowledge on the suitability of particular parameters to estimate trampling effects on sloping soils is limited. This study was aimed to determine sensitivity of some strength, hydraulic, aeration and chemical properties of loamy soil in hillslope-woodland subjected to compaction. Three compactness levels were obtained with a pneumatic compactor. Water infiltration and penetration resistance measured in the field and pore size distribution and saturated hydraulic conductivity determined in the laboratory were most sensitive to compaction. Most compaction effects were limited to the surface and intermediate (down to 20 cm depth) soil layers. Repeated compaction adversely affected the growth of the two sodseeded grasses (*Lolium perenne and Phleum pratense*), but to different extents. The response was more sensitive within two months after sowing than during later growth.

K e y w o r d s: sloping woodland, soil trampling, compaction measurements, hydrological properties

INTRODUCTION

Decidous coppices occupy a large part of the agricultural land of the Italian hills, but since they are mainly located on plots difficult to mechanise, they tend to be abandoned.

Their use in a sylvopastoral system integrating pastures with adjacent woodlands has been proposed. This management involves repeated human and animal intervention, which may produce heavy impact on the local ecosystem [16]. Several studies to evaluate the effects of trampling have been performed by adopting artificial compaction simulating the hooves of cattle [1], which is spotwise in contrast to stripwise under a vehicle tyre [9].

The traffic of agricultural machinery on sloping land (over 10°), repeated on oblique stretches of land, has a more destructive effect on the soil structure than on flat land. The biggest effect of animal trampling on pasture is soil compaction: a cow imparts a dynamic pressure of 0.5-0.7 MPa [2]. This effect is largely influenced by soil water conditions [5, 6,10]. A ten-year experiment on the integrated utilisation of pasture and coppice plots by cattle, on the hilly areas of Piedmont (N.W. Italy), has indicated that the rotating animals grazing in woods do not seriously damage soil structure provided attention is paid to soil moisture content and its bearing capacity [4].

Measurement of the changes in the physical properties of the soil in time and space under rotational grazing is complex: it is difficult to describe the level of soil compaction using only one parameter, which would have to be sufficient to describe both soil conditions and the influence of compaction on the plant growth [12,14]. Numerous criteria have been used for quantifying soil reaction to trampling. Resistance to penetration has been found to be correlated positively to the increased animal trampling on pasture [8] and thereby trampling increased the resistance of root penetration [11].

Other researchers have reported that water infiltration is very sensitive to changes in the soil compaction, but difficult to measure; bulk density and total porosity have been found to have lower resolution capability than air permeability and cone penetrability [17].

On the sloping soils infiltration is of particular importance because it affects water intake and the amount of water lost by runoff. Pereira, quoted by Kayombo and Lal [7], found that slight rainfall infiltration into trampled soil resulted in 40% loss of rain water by runoff. However, the measurements of water infiltration on the sloping and trampled soil are more difficult and need to be adapted. The lack of suitable methods limits research aiming at quantifying soil compaction effects in the sloping woodlands [3].

In this context, a plot experiment has been conducted over four years to determine the critical level of soil compaction caused by animal trampling and vehicular traffic. Moreover, we aimed to determine more suitable methods and devices to measure the effects of trampling on the physical properties of soil and to define their resolution capabilities in sloping woodlands.

MATERIALS AND METHOD

The experiment was carried out on four plots of woodland soil, with uneven slope in the range 7 to 22° in a hill-side coppice with hardwood flora components that belong to the original *Quercus-Fagus* association, mixed with other broad-leaved trees in various ways. The topsoil was loamy, (some characteristics are given in table 1) overlying a gravel sandy clay loam bed. The plots were set up on cleared ground and left for one year exposed to weather conditions.

The year after, three plots were submitted to mechanical compaction by means of pneumatic compactor of 76 kg mass, delivering the energy of about 27 kJ/m^2. The control plot (C) was left undisturbed, the others were given one (C_1) two (C_2) and three (C_3) compaction treatments simulating cattle trampling. The treatment was repeated each year with the soil water content of approximately 15% by weight.

In the beginning and end of the experiment, samples were taken from the three depth-intervals for textural, chemical and density determinations: 0 to 100 mm, 101 to 200 mm, 201 to 300 mm. Some chemical properties: pH (H_2O), organic matter content (Walkely & Black), total carbonate, total nitrogen (Kjeldahl), available phosphorus (Olsen), were determined by the SISS (Italian Society of Soil Science) methods [15]. Dry bulk density was measured by the core method taking up samples with a 73 mm diameter standard probe.

Resistance to penetration was monitored over the whole growing season at different soil water contents using a recording penetrometer, with 30° cone, and crank advance [18]; concurrent with cone resistance measurements, soil samples were taken from up to 300 mm depth, for the purpose of calculating the regression line, for each depth interval and plot, between penetration force and soil moisture.

T a b l e 1. Basic physical and chemical properties at three depths in the woodland soil under experiment

Soil characteristics	Depth (mm)		
	0-100	101-200	201-300
Texture (%, w/w)			
Coarse sand (2000-200 μm)	8.4	7.3	6.3
Fine sand (200-50 μm)	33.9	34.4	36.7
Silt (50-2 μm)	37.6	36.1	33.2
Clay (<2 μm)	20.1	22.3	23.8
Particle density (g cm^{-3})	2.61	2.62	2.64
pH (H_2O)	6.7	6.9	6.8
Total carbonate (%, w/w)	2.1	2.6	3.1
Organic matter (%, w/w)	4.2	3.7	3.3

Further gravimetric controls of the moisture content, M (% w/w), were performed periodically after significant rainfall or wetting, and during the drying period under various weather conditions.

Undisturbed samples of 100 cm^3 from the all three depths were also taken, to determine water content (% v/v) at saturation point (SP) and at field water capacity (FWC), at matric potential -33 kPa, and total porosity with a method proposed by Luppi [13].

The second and third year of the trial, on bare soil, cumulative water infiltration and infiltration rate were measured in triplicate on each plot, by means of double cylinder infiltrometers, developed for the use on hill sites [3], with the inner-ring diameter of 250 mm, the outer one of 500 mm, and constant water head of 20 mm.

In the summer of the third year, eight undisturbed samples (100 cm^3 in volume) were taken from the upper two layers of each plot and the measurements of the water content at different matric potentials (pF), of saturated hydraulic conductivity (SHC), concurrent with the determinations of soil dry bulk density and pore-size distribution were performed. Moreover, air permeability at different pF values in the soil cores with various water content were measured. Air permeability measurements were taken in the 100 cm^3 core samples with an air-flow meter (Instrument Co., Wadowice, Poland).

At the end of the field tests, on one part of each plot, a growth test was carried out by sodseeding two forage crops, *Lolium perenne* and *Phleum pratense*, with different rates of establishment and different susceptibility to trampling and soil compaction. Growth parameters were determined by observing the number of emerged and live plants 10 days after seeding; after 30 and 60 days, on 24 plants of each species, randomly selected per plot, height, number of stems and leaves and leaf area were determined. After 80 days from sowing, 12 plants of each type from each of the four plots were sampled, with a core of 120 mm in diameter, to determine dry matter production of shoots, and roots per unit volume in the top 250 mm of the soil. The roots were separated from the soil by washing.

The data were examined by variance analysis and by comparing the means with Duncan's multiple-range test.

RESULTS AND DISCUSSION

Soil properties

The organic matter content was notably lower in the top 100 mm of soil of plot C_3 compared to the control plot (Table 2). The organic carbon-total nitrogen ratio (C/N) showed a tendency to increase with increased intensity of compaction.

Dry bulk densities, reported as mean values of three determinations repeated at different times with soil water contents ranging from 27 to 29% w/w, were significantly higher in the more compacted plots (C_2,C_3) and in the top two layers (0-200 mm). Bulk density was also higher in the top two layers of plot (C_1) than in the control, though the difference was less marked.

The free moisture content (% v/v) at saturation point (SP), was very much reduced in the upper layers of plots C_2 and C_3; less pronounced differences were found in the deeper soil, and between the control plot and plot C_1.

The water content at field water capacity (FWC), did not differ, significantly though it tended to decrease with the increase of compactive trampling.

These results were partially confirmed by the soil water retention curves (pF), showing the relations between matric potential and soil moisture content (%,v/v) (Fig. 1). There was a marked reduction of water content at saturation in the more heavily trampled soils (C_2, C_3), indicating a severe reduction of total pore space. The differences were greatest at pressure heads close to zero, while the moisture content at pressure head -10 kPa (close to FWC) did not differ markedly between treatments and depths.

As can be seen from the water retention curve (Fig. 1), porosity for pores of equivalent diameter greater than 30 μm, (at pressure head

Table 2. Effects of three compaction treatments[1] on some chemical and hydrological[2] characteristics at three depths in the woodland soil under experiment

Plot	Depth (mm)	Organic matter (%,w/w)	C/N	Bulk density (g cm^{-3})	SP (%,v/v)	FWC (%, v/v)	K (mm d^{-1})
C	0-100	4.5^{a}	10.28	1.21^{c}	50.8^{a}	39.2^{a}	50.2^{a}
	101-200	3.8	10.23	1.26^{e}	49.3	38.8	33.1^{d}
	201-300	3.6	10.12	1.32	47.1	38.3	--
C_1	0-100	4.7^{a}	10.71	1.34^{b}	48.3^{ab}	38.4^{a}	28.4^{b}
	101-200	3.6	11.32	1.38^{d}	48.1	38.2	12.1^{e}
	201-300	3.3	10.30	1.36	46.9	38.0	--
C_2	0-100	4.2^{ab}	10.12	1.44^{a}	44.9^{b}	37.8^{ab}	5.9^{c}
	101-200	3.6	9.88	1.40^{d}	44.7	37.9	2.9^{f}
	201-300	3.4	10.51	1.37	45.3	38.1	--
C_3	0-100	3.9^{b}	10.38	1.46^{a}	43.6^{c}	37.3^{b}	3.6^{c}
	101-200	3.5	9.76	1.41^{d}	43.9	37.1	1.8^{f}
	201-300	3.2	10.52	1.39	44.8	37.8	--

[1]Control - C, compaction treatments performed once - C_1, twice - C_2, three times - C_3; [2]SP - saturation point, FWC - field water capacity, K- saturated hydraulic conductivity. [a, b] Means relating to the same depth, with different letter differ at the 0.05 level.

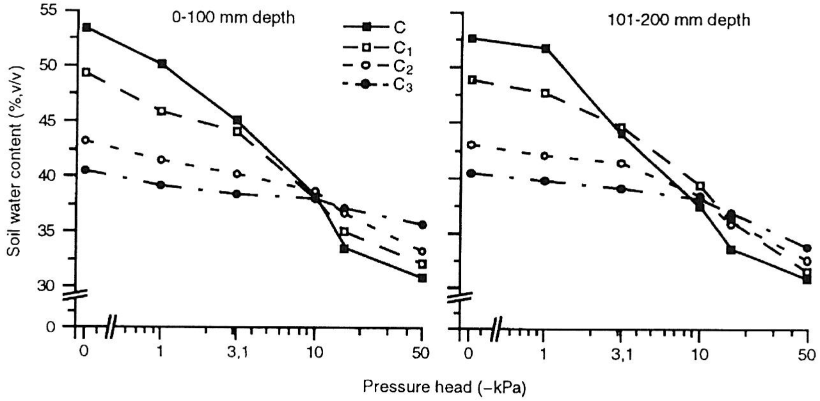

Fig. 1. Water retention curves of woodland soil under different compaction treatments: C - control, C_1 - compacted once, C_2 - twice, C_3 - three times.

greater than -100 hPa) decreased with increasing soil compaction. In C_3 compared to C treatment it was reduced by up to 80%. This implies greater probability of oxygen deficiency to occur in the compacted soil during wet growing seasons.

Measurement of the air permeability, as determined in the range of matric potential -1 to -50 kPa, confirmed these data: there was an evident reduction in the compacted plots (Fig. 2).

A further indicator of the changes in the soil structure between control and trampled plots are marked differences in saturated hydraulic conductivity (SHC) determined in the core

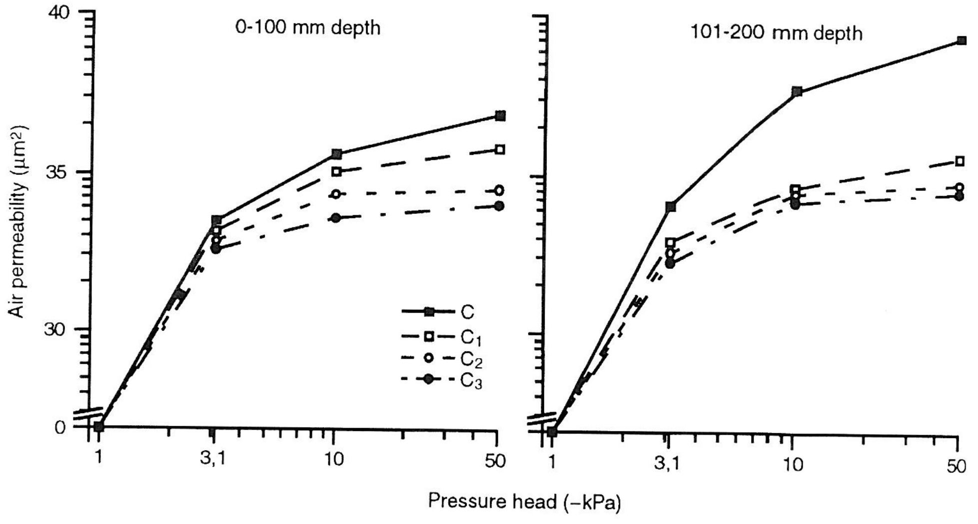

Fig. 2. Air permeability versus pressure head in core samples from woodland soil under different compaction treatments. Explanations as in Fig. 1.

samples (Table 2). It was significantly reduced in the upper two layers of plots C_2 and C_3; a 90% decrease was detected in C_3 compared with the topsoil of the control plot.

This difference was confirmed by the data relating to the cumulative water infiltration, measured *in situ* with a double ring infiltrometer (Fig. 3), in three replicates on each plot. The total amount of infiltrated water, after 4 h was markedly reduced, even by moderate trampling.

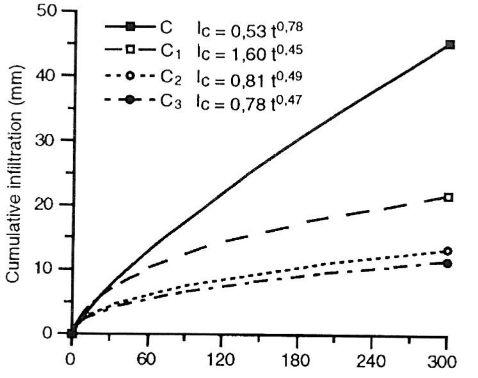

Fig. 3. Cumulative water infiltration in control (C), and in plots under different compaction treatments (C_1, C_2, C_3). Explanations as in Fig. 1.

In the first 60 min, the control plot and C_1 behaved similarly, but later, the C plot gave greater continuity of infiltration.

Moreover, the less trampled plot, C_1, showed a slightly higher initial water intake that rapidly decreased. This behaviour can be explained by a lower content on the plot surface of organic debris more sticking to the soil particles, than on the control, and with the presence of few microcraks in the very superficial soil. After 300 min, the total cumulative infiltrated water was higher in the untrampled soil, by 18, 65 and 80% respectively, compared with plots C_1, C_2 and C_3.

The gravimetric water content, monitored by frequent sampling at intervals of between 3 to 5 days, after artificial wetting, were used to determine *in situ* water release trends from the soil in subplots of each type of treatment under study. The determinations lasted for a period of about 15 to 24 days according the different weather conditions.

After heavy wetting and resulting topsoil saturation, the highest soil water content was in the control plot, lower water content and smaller differences were recorded between the most trampled plots C_2 and C_3. At the depth below 100 mm the sensitivity to wetting was much lower than in the topsoil.

As shown in Fig. 4, the control plot gave evidence of greater numbers of macropores in the top 100 mm, since its drying to intermediate soil water content (32-30%, w/w) was faster than it was for the least compacted plot C_1. Light compaction appeared to have delayed drying in the upper 100 mm, confirming previous data from a trial of trampling of sandy -loam soil [3].

Differences and changes in resistance to penetration, with depth and treatment, were significant when measurement was done with the moisture content at FWC or slightly below (80%). The data revealed a much lower resistance to penetration in the control plot, over the full depth examined, while it was markedly higher in the more compacted plots (Fig. 5). All the trampling treatments produced similar results, characterised by a sharp increase in resistance at a depth of 40-50 mm for plot C_1, and at 70 mm in plots C_2 and C_3, then a modest drop at a depth of 140 mm and the tendency to increase below a depth of 250 mm, when the action of soil overburding prevails. This trend can be explained by the unequal moisture content along the profile and by the different relationship between the penetration resistance and soil water content in different plots.

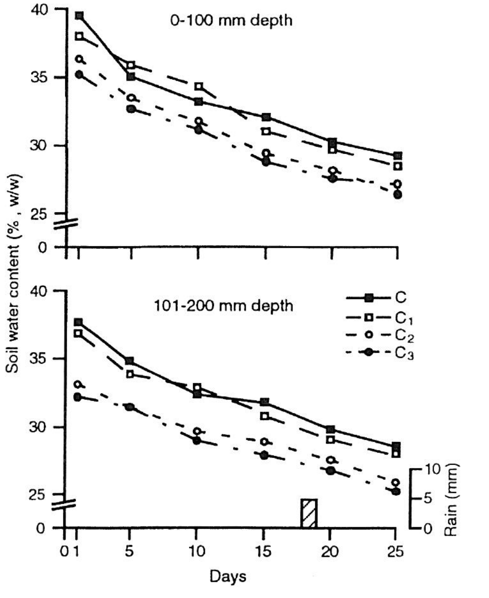

Fig. 4. Changes in water content with time and depth, on the four plots under different compaction treamtents. Explanations as in Fig. 1.

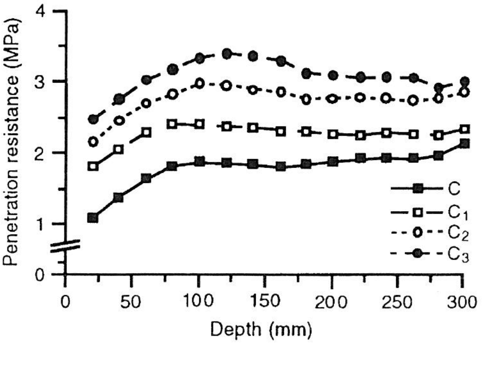

Fig. 5. Mean soil penetration resistance in control (C), and compacted plots (C_1, C_2, C_3), measured in the second year with moisture content near field capacity. Explanations as in Fig. 1.

Plant growth test

The trampling treatments had a significant effect on plant population and growth, but to different extents for the two grasses tested. For *Lolium perenne*, the emergence and number of living plants, determined respectively 10 and 40 days after sowing, were only reduced markedly, compared to the control, by the most compactive treatment (C_3) (Table 3). Shoot and root production per plant, and plant height, gave similar indications.

Trampling influenced *Phleum pratense*, the other grass tested, in a different way. Emergence and living plants were significantly lower in plots C_2 and C_3, than in plots C_1 and C. Root and shoot yields were similar in the control and in the less compacted soil, C_1.

Spatial distribution of roots was markedly affected by the repeated compaction; for both crops there was a marked concentration of roots in the top 50-70 mm.

The leaf area of the two grasses, measured at three harvest dates, was significantly smaller in the trampled plots than in the control plot. At the third harvest, the differences in the leaf area of *Lolium* from C and C_1 plots had narrowed noticeably, while the increase in the leaf area of the plants from C_3 plots continued to be much lower (Table 4).

Table 3. Main effects of compaction treatments[1] on growth of two forage plants, sod-seeded in experimental plots under different compactive regimes

Growth properties	*Lolium perenne* Control C	Compacted plots C_1	C_2	C_3	*Phleum pratense* Control C	Compacted plots C_1	C_2	C_3
Emergence (%)	96.8	94.3	93.2	91.5	92.8[a]	86.3[a]	82.1[b]	80.2[b]
DM yield per plant (mg)								
Roots	249[a]	230[a]	218[b]	201[b]	186[d]	191[d]	168[c]	151[c]
Shoots	1732[a]	1675[a]	1598[ab]	1371[b]	915[d]	878[d]	679[c]	581[c]
*Plant height (mm)	275[a]	268[a]	259[ab]	248[b]	298[d]	292[d]	276[c]	271[c]

[1]Compaction treatments performed once C_1, twice C_2, three times C_3, + 10 days from seeding, *50 days from seeding. [a,b]Means in the same row, relating to the same plant, with different letter differ at the 0.05 level.

Table 4. Main effects of compaction treatments[1] on growth of two forage plants, sod-seeded in experimental plots under different compactive regimes

Day from emergence	*Lolium perenne* Control C	Compacted plots C_1	C_2	C_3	*Phleum pratense* Control C	Compacted plots C_1	C_2	C_3
32 days	752[a]	614[b]	552[b]	494[c]	882[a]	753[ab]	709[b]	684[b]
46 days	1393[a]	1252[ab]	1106[b]	1018[c]	1283[a]	1131[ab]	994[b]	912[c]
60 days	1971[a]	1753[a]	1545[b]	1494[b]	1632[a]	1523[b]	1454[b]	1311[c]

*Mean of 20 replicates. [1]Compaction treatments performed once C_1, twice C_2, three times C_3. [a,b] Means in the same row, relating to the same plant, with different letter differ at the 0.05 level.

CONCLUSIONS

Field measurements of water infiltration and penetration resistance, and laboratory measurements of saturated hydraulic conductivity and air permeability were more useful in describing trampling effects in the hillslope woodlands than bulk density, water content at saturation point and at field water capacity. Reduction of the hydraulic properties in the most compacted soils was due to lower macroporosity.

The field measurements indicated that water infiltration and penetration resistance were most sensitive to soil compaction.

The four-year effect of soil trampling resulted in a considerable reduction of organic matter content. Grass growth parameters such as emergence and leaf area at early growth stages were most responsive to soil trampling. Growth tests, which resulted from trampling effects, were effective only with grass species sensitive to moderate compaction and within 60 days from sowing, after a longer period there would be the risk of changes in the soil conditions induced by external factors and by the plant themselves.

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