Effect of Slash on Forwarder Soil Compaction

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ABSTRACT

A study of the effect of slash on forwarder soil compaction was carried out. The level of soil compaction at two soil moisture contents, three slash densities (0, 10, and 20 kg/m^2), and two levels of traffic (one and five passes) were measured. Results indicated that, on dry, loamy sand soils, the presence of slash did not decrease soil compaction after one forwarder pass, but did provide some protection from subsequent passes. The density of slash (over 10 kg/m^2) did not affect compaction. On the same soils in a wetter condition, however, slash density at 20 kg/m^2 was significantly less than on bare plots. At 10 kg/m^2, the increase in bulk density after five passes was smaller than on the bare plots, but not significantly so.

Keywords: *Soil compaction, forwarders, slash.*

INTRODUCTION

Cut-to-length (CTL) systems are increasingly perceived as filling an important niche in forest harvesting. Many reasons are cited for this, including improved work conditions, more efficient product recovery, and lowered environmental impacts [2, 5, 6]. There are specific situations where the CTL systems are cost competitive with tree-length harvesting. Many of these advantages, however, have not been sufficiently defined to the point that rational choices can be made concerning the appropriateness of a system for a specific task. This is especially true in the area of environmental impacts.

Harvesters spread limbs and tops in their path as they process stems. This ground cover is said to decrease soil compaction by providing a pressure absorbing layer, lowering the net ground pressure of passing equipment. The effects of skidding with a slash covering of 18 kg/m^2 has been reported [4]. Trails covered with slash showed lower decreases in air filled porosity, total porosity, and saturated hydraulic conductivity after three passes, but the effect was not present after seven. Rut depths and saturated hydraulic conductivities after 15 passes were nearly the same regardless of the presence of slash, and this was true at 0 to 5 cm and 5 to 10 cm depths. A slash layer provided significant reduction in rut formation and an increase in soil support capacity [12]. For each additional 10 kg/m^2 of residue over 10 kg/m^2, there was an apparent increase of 25% in soil strength. Based on previous work [13], one study [14] predicted an average decrease in effective machine ground pressure of 34 and 27% for slash amounts typical of first and second thinnings, respectively. The effect of a residue layer in reducing soil compaction was considered positive, although a statistically significant influence was not found [1, 8].

It is clear from the literature that there is some incremental benefit from covering extraction trails with slash, but by how much and under what conditions has not been clearly defined. This research was intended to investigate to what extent surface slash decreases soil compaction, and how this effect interacts with the number of machinery passes, soil moisture, and slash density.

OBJECTIVES

This study evaluated the protective influence of an organic matter layer in reducing soil compaction resulting from forwarder traffic. Specific objectives were:

a. to determine the effect of two slash densities left over trails;

b. to measure the degree of benefit after one and five forwarder passes; and

c. to evaluate the interaction with two soil moisture contents after five forwarder passes.

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EXPERIMENTAL METHODS

The tests were carried out at Auburn University's E.V. Smith Agricultural Research Center near Tallassee, AL. Fields at the Center have been used for several years in examining the effect of tillage practices on soil compaction. A field that had been used in 1994 in a test of grain sorghum yields with and without subsoiling was made available for the slash study. The tests were conducted in late winter, and the field had been disked the previous fall after harvest. Soils in the test areas were loamy sand, had no surface vegetative cover, and had very uniform physical properties.

Two linear test sections (167 x 4 m and 58 x 4 m) were installed. The longer of the two was used as a 'natural', or 'dry', moisture condition. It was divided into three 55 m blocks, and further divided into six plots within each block. Each plot measured 8 m long by 4 m wide, with 1 m between each and 2 m between blocks. The following six treatments (combination of slash density and number of passes) were assigned to one each of the plots within each block: a) bare soil, one and five passes, b) 10 kg/m^2 slash, one and five passes, and c) 20 kg/m^2 slash, one and five passes.

Slash densities were chosen to be compatible with those used by elsewhere [12]. The densities (10 and 20 kg/m^2) are reasonable for typical plantations of the southern United States. For a 20-year-old loblolly pine (*Pinus taeda*) plantation in the south, a reasonable estimate for weight of total biomass might be about 346 green t per ha (23 cm average dbh, 15.2 m average height, 2.4 x 3.7 m spacing [11]). Suppose 50% of the basal area were being removed in a thinning of this stand, and of the harvested biomass, 30% remained as residues [10]. Also assume that the thinning was a fifth row removal with selective cutting between removed rows. Then, for a cut-to-length harvesting system, residues would be concentrated in about 40% of the total area. Slash densities, for these conditions, would be about 13 kg/m^2, comparable to the values used in our tests. The choice of number of passes was made based on previous research that indicated most compaction occurs within the first few trips [7].

The shorter (58 m) test section was used for the experiments in which the moisture content of the soil was manipulated. Three plots were established in each of two blocks. Because the sampling process was lengthy and drying rates were high, it was likely that the test plots would dry significantly between tests of one and five passes. Therefore, number of passes was not evaluated in the test and all plots received five forwarder passes only. The same three slash density treatments (0, 10, and 20 kg/m^2) were randomly assigned one each to plots within the two blocks. The test section was irrigated (travelling gun) overnight prior to the tests. The amount applied was dictated by the rate of application of the irrigation system, plus the fact that it was run overnight, and totaled about 25 mm water.

Logging slash was trucked to the site, sorted to eliminate hardwood components, then spread in a random fashion at the required density over the plots. The slash was collected from a *Pinus taeda* and *P. palustris* mixed stand that was being clear-cut. Trees were delimbed using a gate. There was a large variation in limb size, probably greater than would be expected in a thinning using CTL equipment. There were some large (10–15 cm diameter) limbs mixed in. These would have been about equivalent to tops remaining after processing, but their relative frequency may not have been the same.

Soil compaction was analyzed using changes in bulk density and soil strength following traffic. The soil samples for bulk density were collected with a soil hammer with 5 cm diameter and 5 cm length rings. Oven-dry weight (72 hours at 105°C) was used to express bulk density as weight/unit volume (Mg/m^3) and moisture content. A recording soil penetrometer (Findlay, Irvine Ltd.; available in the US from Ben Meadows) was used to measure soil strength. Measurements were taken to a depth of 52.5 cm in 3.5 cm increments. This particular model of penetrometer did not provide feedback on insertion speed, but from using other machines that do, a reasonable estimate would be in the range of 5 to 10 m/min. There was no organic matter layer on the soil surface to interfere with penetrometer measurements.

Sampling patterns varied with test section. For the dry, or natural, test condition, ten samples were taken for bulk density at each of three depths in the soil profile (0–5, 7.5–12.5 and 15–20 cm), for a total of 30 from each plot. This sampling regime was applied both pre- and post-treatment (total of 60 samples per plot). Ten cone penetrometer readings were taken pre- and post-treatment. Pre-treatment samples (bulk density and soil strength) were taken along the center line of the plot, and post-treatment from the rut centers (five in each rut). In addition to changes in soil physical properties, soil disturbance was quantified using measures of rut depth and total cross-sectional area at the midpoint of each plot, using the methodology [7].

A modified sampling scheme was used on the 'wet' test section to get a more accurate estimate of moisture conditions at the time of treatment. All samples were collected after traffic, with undisturbed samples collected from the plot center line, and disturbed samples from one rut center. Although some disturbance from traffic was possible at the plot center line, it felt that it would be small relative to the amount caused within the tire rut itself [9]. Six samples at each of three depths were collected for both undisturbed and disturbed conditions, for a total of 36. Depths were the same as in the dry tests. A similar scheme was used for soil strength, with six measurements at each of the plot and rut center lines. Rut depth and cross-sectional area were not measured.

The forwarder used in the study was a Franklin 170 with a total loaded weight of 17 t (6 f, 11 r). The forwarder was equipped with 23.1 x 26 LS2 tires inflated to 210 kPa, and passed over the plots in one direction at about 3.6 km/h. One pass was defined as one trip of the loaded tractor.

The study was a randomized complete block design with two (wet) or three (dry) replicates. Treatment effects were evaluated using analysis of variance with number of passes and slash density as main effects.

RESULTS AND DISCUSSION

Bulk Density

The average soil water contents at the time of the study were 10.8% for the wet plots and 8.1% for the dry plots. Pre- and post-treatment bulk density means are shown in Table 1. The initial soil bulk density values were high, all 1.80 or higher for depths greater than 7.5 cm. This was despite disking the prior fall. Bulk density in the 15 to 20 cm depth range averaged 1.95 Mg/m^3. The increase in bulk density with depth indicated the presence of a hard pan.

Pre-treatment bulk density means in Table 1 marked with an asterisk (*) showed a statistically significant change following traffic (α = 0.05). A significant increase in bulk density was found in all treatments at the soil surface (0 to 5 cm depth). No increases were found at 15 to 20 cm depth. The magnitude of the increase was a function of the number of passes and the slash density. Comparisons between the non-zero increases in bulk density are shown in Table 2. All comparisons shown are for means within the same moisture level. Results showed that, in the dry soil, the magnitude of the increase in bulk density was the same for all treatments after one pass. Bulk density continued to increase after five passes for the bare soil, but did not subsequently change for either slash treatment. The bulk density increase for the bare plots was nearly twice that of the covered plots after five passes. This result indicated, for the dry conditions, that a layer of slash did not mitigate the effect of a single forwarder pass but did limit the effect of subsequent passes up to five. Also, the density of the slash made no apparent difference within the bounds of the experimental design.

Results were different on the wet plots. The increases in bulk density observed after five passes were roughly equal to that on the dry plots. There were differences, however, in the magnitude of the increases between slash densities. The 10 kg/m^2 treatment had greater compaction than the 20 kg/m^2 treatment, though it not significantly higher. The 20 kg treatment was significantly lower than the bare plot treatment. This result indicated an interaction of the effect of slash with moisture content. Unlike the dry conditions, a greater amount of slash appeared beneficial on the wetter soil.

Soil Strength

Figures 1 and 2 show the pre- and post-treatment penetrometer readings for one and five passes on the dry, bare-soil plots. Pre-treatment soil strength showed a hard pan layer at about 21 cm depth. One pass of the forwarder tended to disrupt this hard pan. Although the bulk density results showed an increase in the 0 to 5 cm depth range, this was not detected in the penetrometer measurements.

For five passes, penetrometer readings showed a statistically significant increase in soil strength between 3.5 and 14 cm depth. The additional passes also nearly replaced the hard pan layer broken up after one pass.

Table 1. A summary of pre- and post-traffic soil bulk densities (Mg/m^3).

Depth	1 Pass (dry)			5 Passes (dry)			5 Passes (wet)		
(cm)	0 kg/m²	10 kg/m²	20 kg/m²	0 kg/m²	10 kg/m²	20 kg/m²	0 kg/m²	10 kg/m²	20 kg/m²
0–5									
Pre	1.70*	1.71*	1.73*	1.70*	1.72*	1.73*	1.67*	1.73*	1.76*
Post	1.82	1.84	1.81	1.91	1.86	1.85	1.90	1.89	1.86
7.5–12.5									
Pre	1.80*	1.85	1.85*	1.88	1.88	1.88	1.86	1.87	1.86
Post	1.86	1.89	1.90	1.91	1.91	1.92	1.88	1.93	1.90

* – indicates that the pre- and post-treatment difference in mean bulk density is significant ($\alpha = 0.05$).

Table 2. Summary and comparison of non-zero differences in pre- and post-traffic bulk density. Statistical comparisons were not made across soil moisture conditions.

Depth	1 Pass (dry)			5 Passes (dry)			5 Passes (wet)		
(cm)	0 kg/m²	10 kg/m²	20 kg/m²	0 kg/m²	10 kg/m²	20 kg/m²	0 kg/m²	10 kg/m²	20 kg/m²
0–5	0.12[b]	0.13[b]	0.08[bc]	0.21[a]	0.14[b]	0.12[b]	0.23[a]	0.16[ab]	0.10[b]
7.5–12.5	0.06[c]		0.05[c]						

[a] – Values with the same letter are statistically the same ($\alpha = 0.05$).

Figures 3 and 4 show the corresponding soil strength measures for the dry plots, 20 kg/m² treatment after one and five passes, respectively. There was no statistical difference in response between the slash treatments, and the 20 kg treatment is shown as representative of both. Results for one pass appeared similar to that for the bare soil. In fact, there were no significant post-traffic differences in soil strength between any of the treatments at nearly all depths after one pass. The soil strength results for one pass, therefore, showed the same trends as the bulk density results, i.e., there were no differences after one pass as a result of slash density in the range of 0 to 20 kg/m².

For five passes, the soil strength magnitudes were significantly lower ($\alpha = 0.05$) for the two slash treatments than the bare plots at depths ranging from 7 to 10.5 cm, but were not different from the bare plots at any other depth. This result tended to confirm that, at least near the surface, the presence of slash did tend to mitigate compaction for multiple passes up to five in dry soil, but that there was no benefit from slash above 10 kg/m².

Figures 5 and 6 show penetrometer readings as a function of depth for the bare soil and 20 kg/m² plots on the 'wet' test section. Again, the 20 kg treatment was chosen as representative of both slash densities – there were no significant differences detected between the two levels. Both graphs show a definite increase in soil strength near the surface, but the increase for the bare plots was significantly higher ($\alpha = 0.05$). Again, the difference in soil strength between bare and slash-treated plots was significant to a depth of 14 cm.

Rut Measures

Measurements of rut cross-sectional area and depth, defined as the largest average difference across the width of one tire, were highly variable. There were no differences detected between any of the treatments, probably because the ruts even for the bare plots were very small (averaging less than 4 cm in depth). This level of disturbance was also present in the slash-treated plots because of the tendency of the weight of the forwarder to bury some of the slash, causing shallow displacement of soil when it was removed for measurement. The ruts tended to be more coherent in the bare plots, but not any larger in terms of the volume of soil displaced.

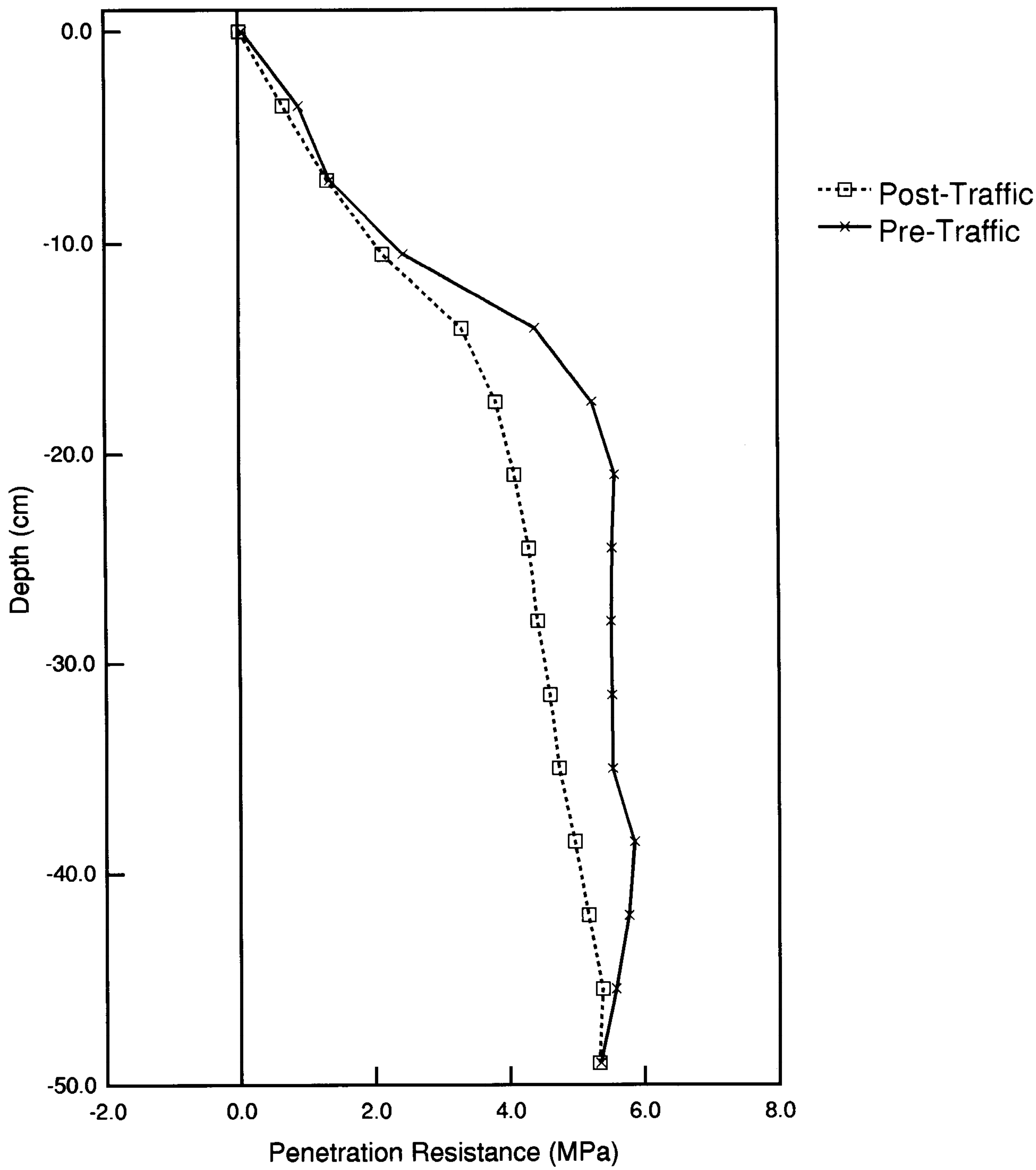

Figure 1. Soil strength, bare plots, dry condition, 1 pass.

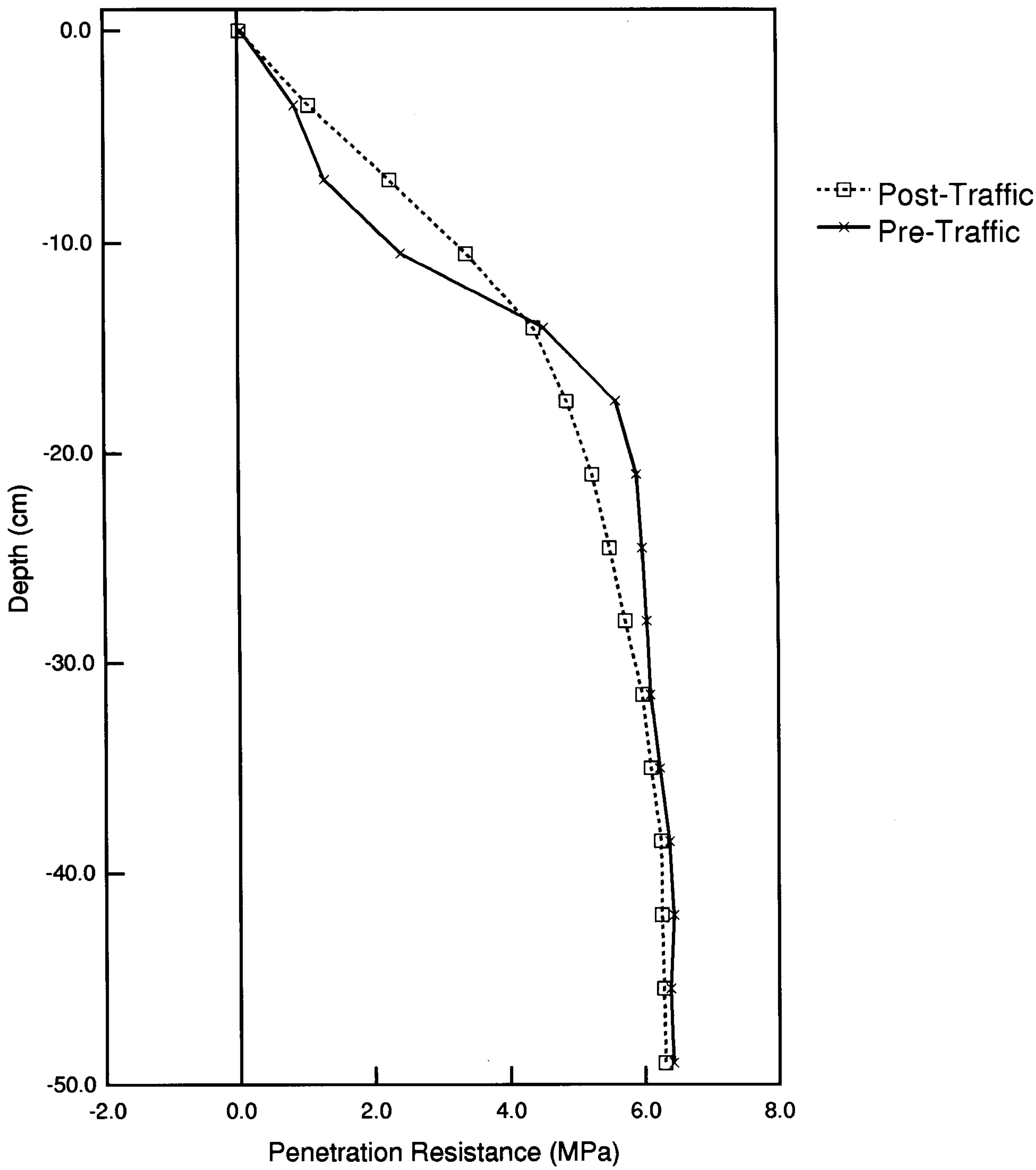

Figure 2. Soil strength, bare plots, dry condition, 5 passes.

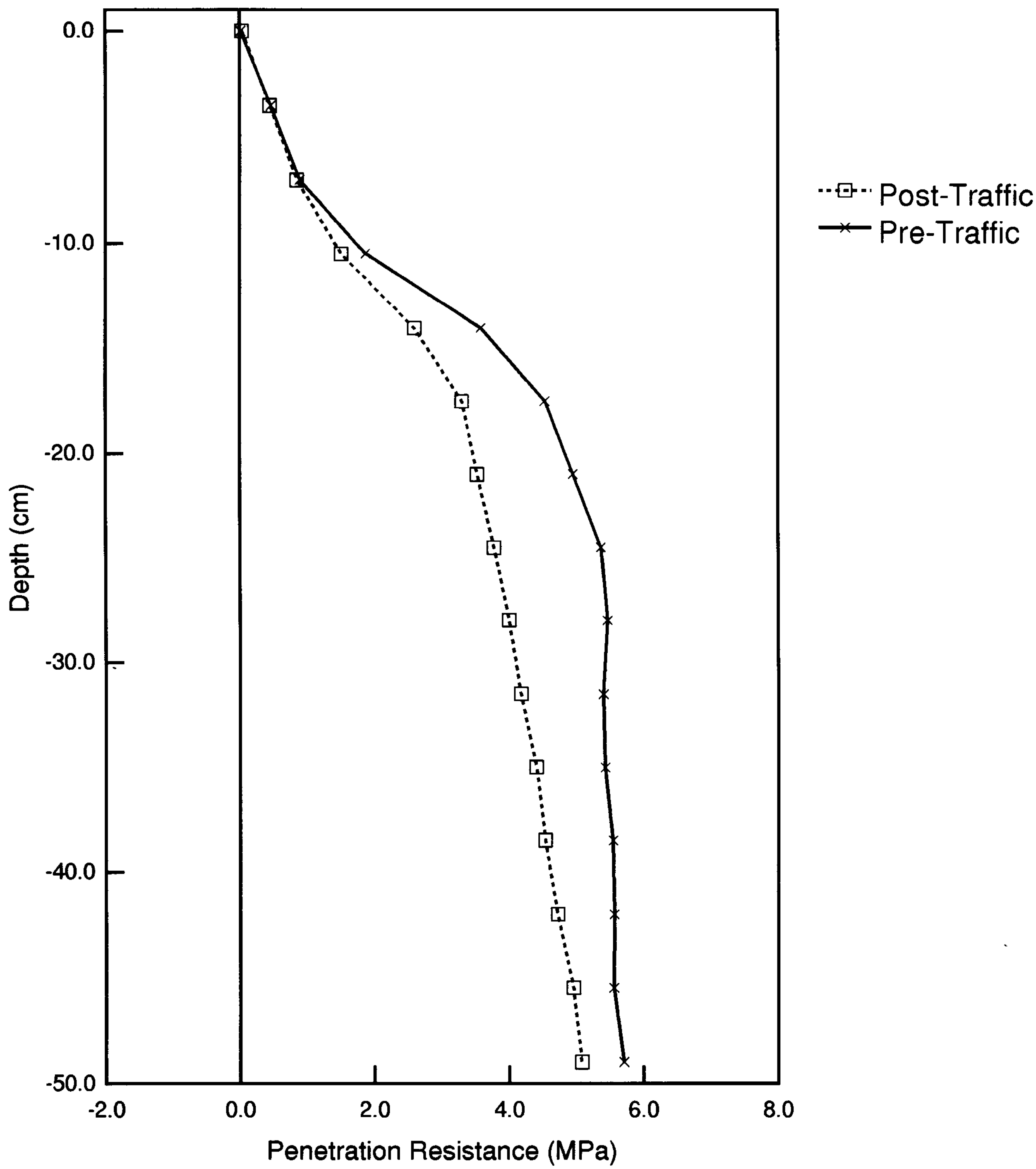

Figure 3. Soil impedance, 20 kg/m^2, dry condition, 1 pass.

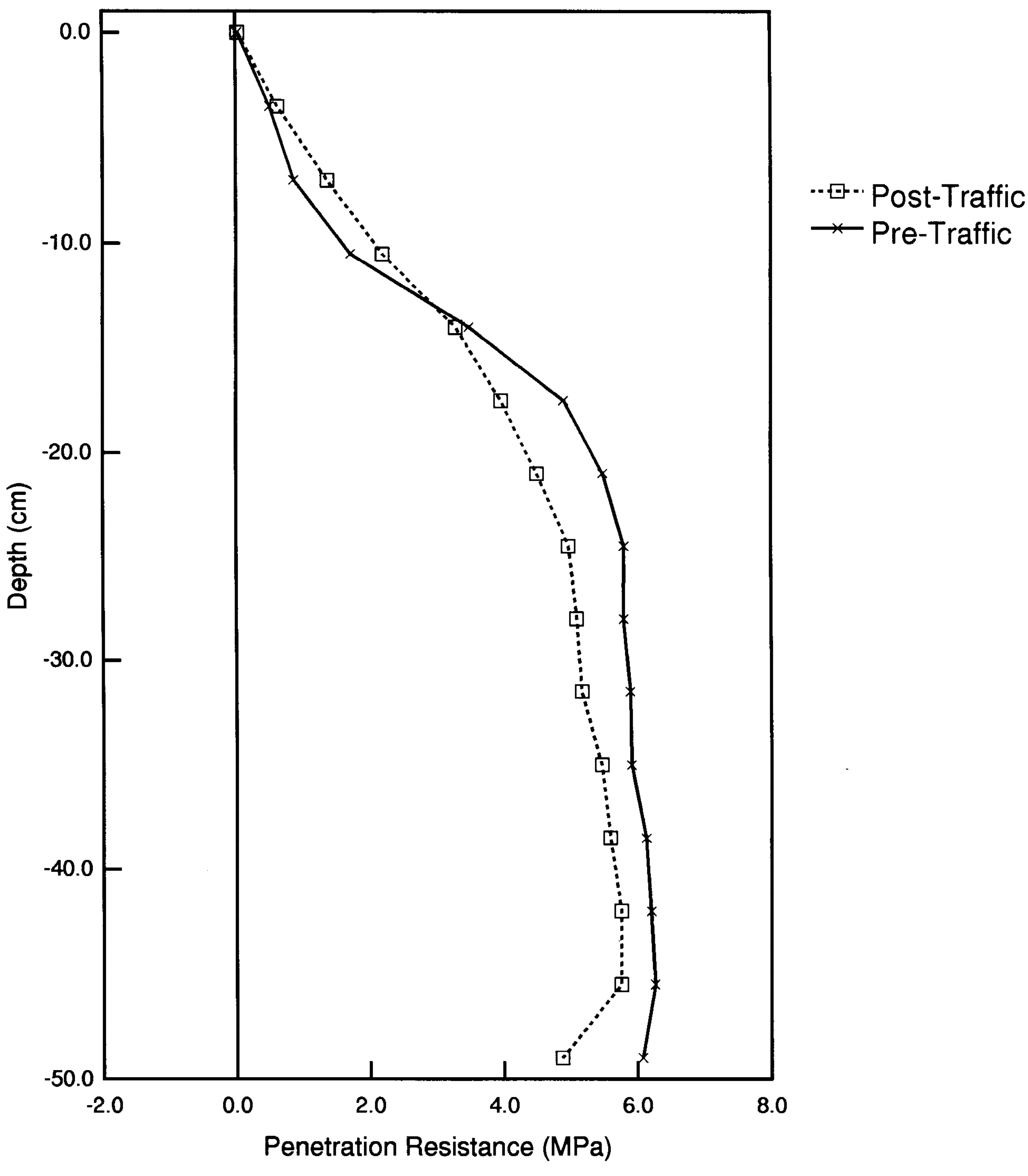

Figure 4. Soil impedance, 20 kg/m², dry condition, 5 passes.

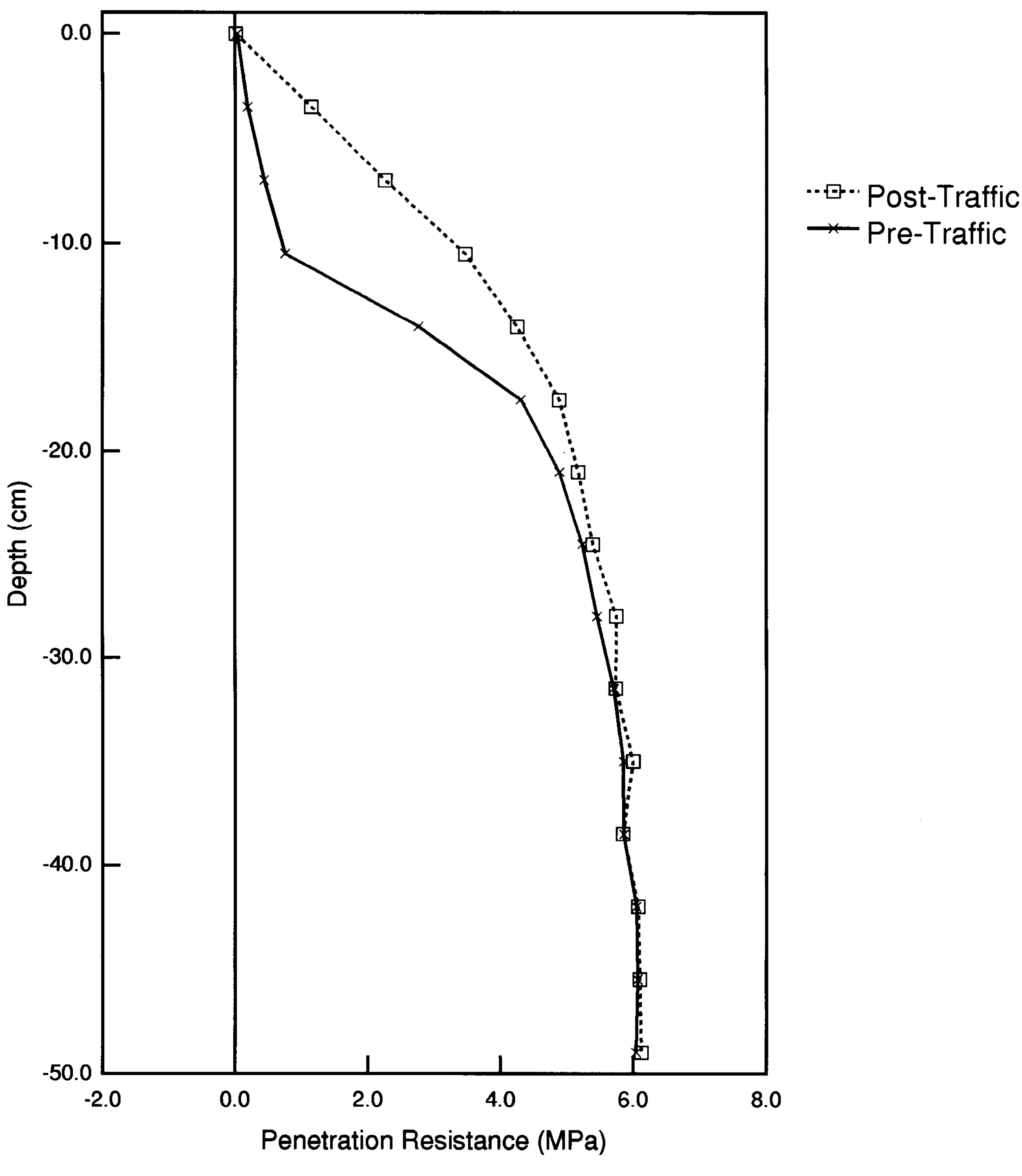

Figure 5. Soil impedance, bare plots, wet condition, 5 passes.

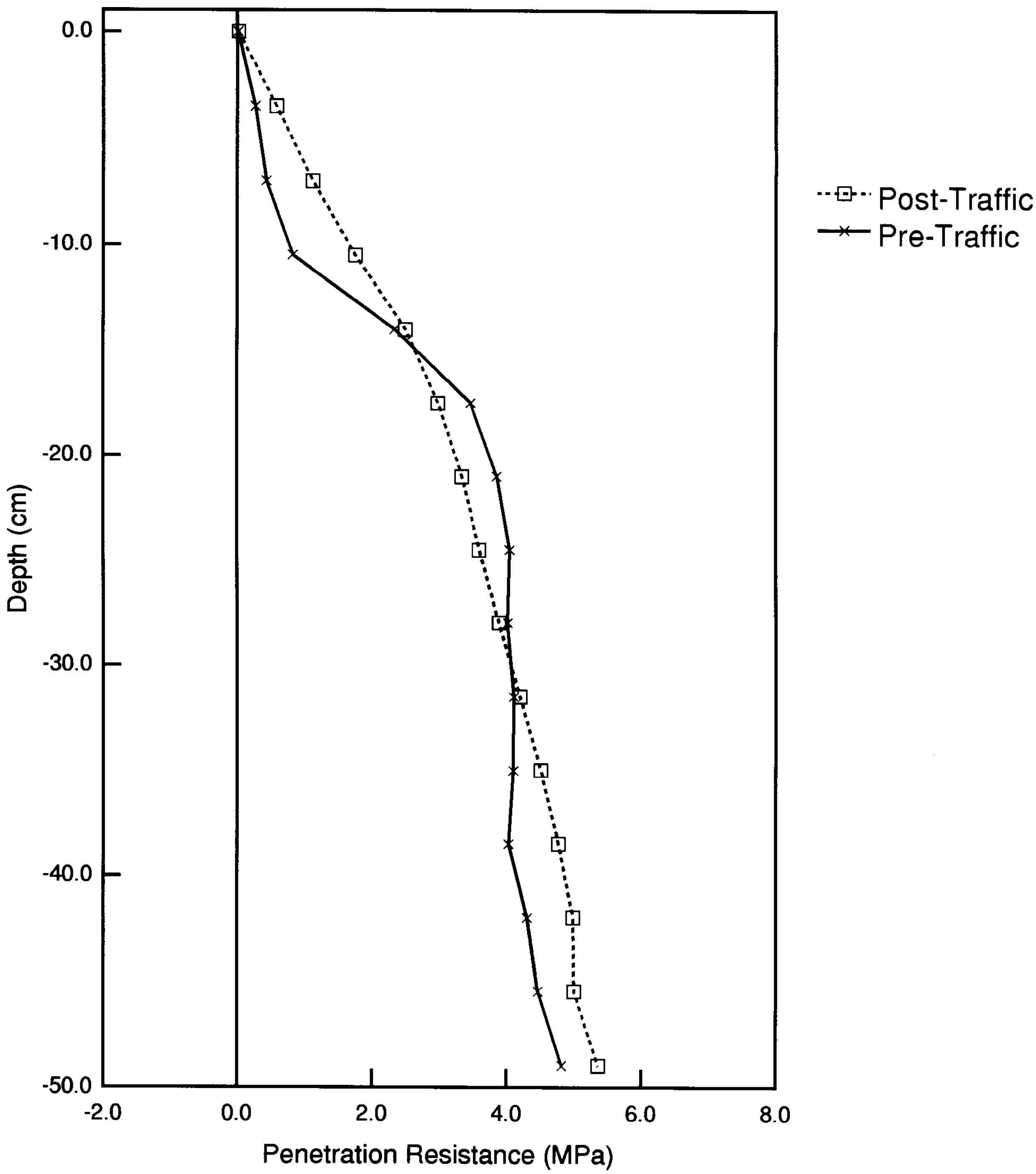

Figure 6. Soil impedance, 20 kg/m^2, wet condition, 5 passes.

SUMMARY AND CONCLUSIONS

Compared to bare soil slash coverings for the dry, sandy soils tested, at densities of 10 and 20 kg/m^2 did not decrease the level of compaction observed after a single forwarder pass. This result is exactly opposite that observed in other studies [e.g., 4, 8, 9], where the benefits of slash were generally seen in the first few passes of the equipment, after which the ability of the slash to absorb the weight of the machine seemed to decrease. We may explain the difference in the following way. In order to ensure an observable change in bulk density as a result of the treatments, the tests were made in a very controlled situation with fairly loosely packed soils (despite the high bulk density) and uniform conditions. Because the soils were loose, there was little difference observed between slash and no slash after the first pass – nothing short of a bridge could have prevented the soil from consolidating in that condition. As the soil became remolded, however, it returned to a state more like a natural forested condition, and there was a benefit observed from having slash in place. On subsequent passes, compaction on bare soils continued to increase, but stayed the same on plots having either density of slash covering present. Total compaction of slash-covered plots after five passes was about half that observed on bare plots. Increases in compaction were almost exclusively near the soil surface, above 7.5 cm in depth.

Moisture content affected the observed benefit of using slash to decrease compaction. With 25 mm of simulated rainfall, final bulk density after five forwarder passes was similar to that on the dry plots. Bare plots sustained about twice as high an increase as those covered with slash. Compaction was significantly higher (about 60%, or 0.06 Mg/m^3) for plots treated with 10 versus 20 kg/m^2 slash. Slash had a more significant effect on soils with lower bearing capacity [3], and the moisture content effect tended to confirm this. The soils were of generally high bearing capacity, and in a dry condition the presence of slash had some effect, but density of slash did not. With the increase in moisture content, and the consequent reduction in bearing capacity, the overall increase in bulk density for bare plots did not change. The amount of slash present, however, did affect the increase in bulk density observed after five passes.

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