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Assessment of Crawler Tractor Effects on Soil Surface Properties

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ABSTRACT
Skidding operations can cause considerable and wide spread soil disturbance. The objective of this study was to evaluate the effects of ground skidding operations on soil compaction, moisture content, and total porosity at different levels of slope and traffic frequency. Four levels of traffic intensity (3, 8, 13, and >13 passes of a Crawler Tractor Onezhets – 110) and three levels of slope (<10%, 10%-20% and > 20%) were applied to assess soil disturbance. The soil samples from the depth interval 0-10 cm were collected with a soil hammer and rings. Results showed that dry bulk density, moisture content and total porosity were affected considerably by slope and traffic frequency of skid trails. Bulk density was drawing near to the critical value after 8 passes in the trail with the slope >20%; when the number of machine passes increased from 8 to 13 passes, the additional bulk density increment was negligible. Irrespective of traffic frequency, dry bulk density increased significantly in the slope >10% compared to the slope <10%; however there was no significant difference between slopes 10-20% and >20% . Minimum moisture content was measured as 27% on the skid trail versus 47% in the undisturbed area. A negative correlation was found between moisture content and dry bulk density. Total porosity was measured as a maximum 58% to a minimum 44% on the skid trail treatments, and 65% in the undisturbed area. Soil disturbance was extended dramatically on the treatments with slopes >20%, so dry bulk density on the treatments with 8 passes and slopes >20% (1.38 g cm-3) was significantly higher than on the treatment with 13 passes and slopes <10% (1.32 gcm-3). Results showed that slope >10% increased soil disturbance quite dramatically.

Keywords: *Bulk density, Moisture content, Skidding, Soil disturbance, Skid trail slope, Total porosity*

INTRODUCTION
With increasing mechanization of forest harvesting operations, the impacts on soil have increased quite dramatically (Greacen and Sands 1980). Undisturbed forest soils have high macroporosity and low soil bulk density and are easily compacted by logging machinery (Botta *et al.*, 2006). Bulk density, soil moisture content, and porosity are three principal factors directly affected by forest management practices which could change long-term soil productivity (Powers *et al.*, 1997). Machines induce soil compaction owing to the exerted normal pressure, vibrations and shear stress (Kozlowski 1999). Reductions in tree height, diameter and volume growth are often observed where soils have been compacted by skidding activity (Gomez *et al.*, 2002, Pennington et al., 2004, Murphy *et al.*, 2004, Tan *et al.*, 2005). Negative correlation between bulk density and soil moisture content suggested a potential decrease in soil moisture at higher bulk densities, presumably due to compaction (Carter and Shaw 2002). Soil compaction and forest floor removal reduced the water content of mineral soil after forest floor removal, probably as a consequence of reduced water infiltration rate and greater runoff of water (Greacen and Sands 1980).

The negative impacts of wheeled tracks in forest soils upon soil aeration that control the respiration processes of microorganisms is documented by Schäffer et al. (2001). When air-filled porosity falls below 10% of the total soil volume, microbial activity and plant growth can be severely limited in most soils (Brady and Weil 2002). Compaction mainly reduces soil macropores, therefore affecting gas exchange rates between the soil and atmosphere (Shestak and Busses 2005).

Soil properties, the magnitude and nature of compressive forces, skid trail conditions, forest stand characteristics, harvesting system, and training, experience and expertise of equipment operators are among the most important factors influencing the extent and severity of soil compaction (Demir *et al.,* 2007). Traffic intensity (number of passes) plays an important role in soil compaction because deformations can increase with the number of passes and may lead to excessive soil disturbance (Mosaddeghi et al., 2000). Soil bulk densities are differently related to traffic intensities (McNabb et al., 1997). Most of the surface compaction occurred during the first few passes, although density continued to increase in amount and depth with the number of passes (Ampoorter et al., 2007, Brais 2001).

Krag et al. (1986) showed that during timber harvesting, slope steepness had a strong effect on soil disturbance. Their data suggested that disturbance increased in both extent and depth with increasing slope.

Effective management of machine mobility, the control of site disturbance and moderation of potential soil damage due to wood harvesting and extraction machinery traffic requires characterization of the effects of soil–machine interaction. The interaction should take into account the influence of machine variables on a range of forest terrain that may be encountered. This study hypothesized that traffic frequency and skid trail slope affect dry bulk density, moisture content, and total porosity. The objectives of this study were to characterize the impacts of ground skidding on soil disturbance at different levels of trail slope and traffic intensity, and to establish threshold levels for machine traffic and skid trail slope.

MATERIALS AND METHODS

Study Site

The study area - Tarbiat Modares University Forestry Experiment Station, located in a temperate forest in North of Iran, between 36º 31' 56" N and 36º 32' 11" N latitudes and 51º 47' 49" E and 51º 47' 56" E longitudes, is dominantly covered by *Fagus orientalis* and *Carpinus betulus* stands. Canopy cover was estimated as 0.75, with an average diameter 35 cm, average height 22 m, maximum haul distance 400 m and stand density 185 trees/ha. Records showed 1500 m3 timbers were skidded in May, 2007 and immediately thereafter the current study was conducted. Elevation was approximately 600 m above sea level with a north aspect. At the time of skidding, weather conditions were wet with the average soil moisture content of 32%. Soil texture was analyzed using the Bouyoucos hydrometer method and was determined to be clay loam along the trail. The machine used was a crawler tractor "Onezhets 110" (Table 1).

Treatments

A skid trail 4 m wide and 400 m in length, which ran parallel to the slope, was selected for the experiments. The skid trail passed through the stand in an east-west direction and had been used recently.

In this study, the impacts of skidding on the skid trail in the surface soil layer (0-10 cm in depth) were examined using dry bulk density, soil moisture, macroporosity and total porosity, in comparison to the undisturbed area at different levels of slope and skidding traffic. There were twelve combinations of slope classes (<10%, 10%-20% and >20%) and traffic intensities (3, 8, 13 and >13), and three replicates were used for each treatment resulting in a total of 36 plots. The plots, 10 m in length and 4 m in width, were delineated randomly prior to skidding.

There was at least a 5 m buffer zone between plots to avoid interactions. Samples were taken along four randomized lines across the wheel track perpendicular to the direction of travel with 2 m buffer zones between lines to avoid interactions. The soil samples from the depth interval 0-10 cm were collected with a soil hammer and rings (diameter 6 cm, length 10 cm), put in polyethylene bags, and labeled immediately. Samples brought to the laboratory from the research area were promptly weighed. Soil samples were dried in an oven under 105˚ C for 24 h. The moisture content in the soil samples

Table 1. Timber industry crawler tractor Onezhets110 technical description

Overall dimensions, mm	
Length	6200
Width	2680
Road clearance, mm	3000
Track, mm	1850
Tractor mass maintenance, kg	12500
Loader device	
Winch drum storage (length), m	40
Maximum tactile force of winch, kn	105
Maximum capacity of bundle skidded, m3:	
with the butts	8
with the tops	10
Engine	
Operating power, kWt (h.p.)	88,2 (120)
Fuel tank capacity, l	140
Transmission	
Speeds, km/h	3,04-11,10
Steering mechanism	Two multidisk dry friction clutches, spring-loaded
Number of teeth	15
Circular pitch, mm	160
Width of caterpillar, mm	640
Ground unit pressure, MPa	0.03

was measured gravimetrically after drying in the oven. Total soil porosity was calculated as AP = (1 - Db/2.65) / VC where AP is apparent total porosity, Db the soil bulk density, 2.65 is the assumed particle density, and VC is the volume of the soil cores (502.4 cm^3) (Fernández et al., 2002).

Analysis of variance (ANOVA) was carried out to compare the effects of slope and traffic on soil properties and means were analyzed by Duncan's multiple range test.

RESULTS

Bulk Density Average soil bulk density was measured as a minimum of 1.09 g cm-3 to a maximum of 1.46 g cm-3 on the skid trail and 0.93 g cm-3 in the undisturbed area. The results showed that the dry bulk density was affected by skid trail slope.

Dry bulk density on the treatment with 8 passages and slope >20% (1.38 g cm-3) was significantly higher than those of 13 passes and slope <10% (1.32 g cm-3). Within all traffic, dry bulk density increased considerably with an increase in slope from <10% to 10-20%; however, from that slope class interval onwards, bulk density remained constant with slope (Table 2). Dry bulk density increased significantly ($p<0.01$) with skidding cycles from 0 to 8 passes. When the number of machine passes increased from 8 to >13, the additional bulk density increment was negligible (Fig.1). Number of skidder passes ($p<0.01$) and slope ($p<0.01$) significantly influenced dry bulk density, but the interaction between number of skidder passes and slope was not significant (data not shown).

Table 2. Effect of skid trail slope on dry bulk density (g cm-3).

Slope (%) \ Passage	3	8	13	>13
(0-10)	1.09 b	1.26 b	1.32 b	1.34 b
(10-20)	1.25 a	1.36 a	1.37 a	1.37 a
(>20)	1.29 a	1.38 a	1.39 a	1.46 a

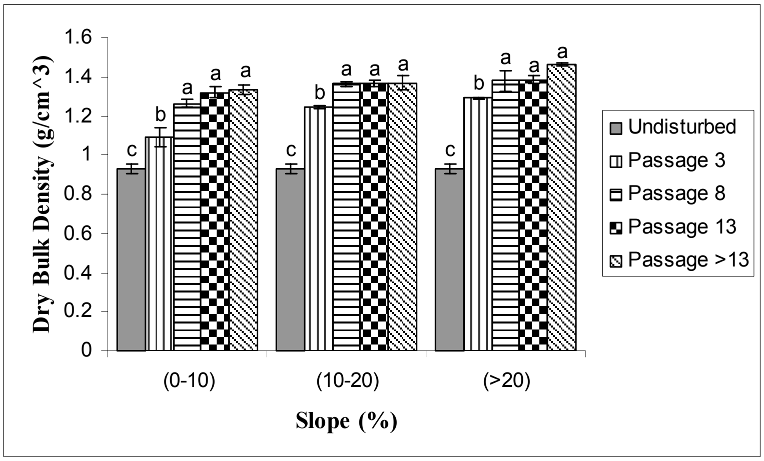

Fig. 1. Effect of traffic intensity on dry bulk density (g/cm-3)

Moisture Content

In the mineral soil, the effect of soil compaction on soil moisture content was significant ($p<0.01$). The results showed that soil water content decreased 20% after skidding (number of passes: >13, skid trail slope: >20%, Table 3).

Average moisture content was measured as 35% on the skid trail treatments compared to 47% in the undisturbed area. Moisture content decreased significantly after 8 passes. When skidder passes increased from 8 to >13 , the effect of traffic on soil moisture was not considerable. There was a negative correlation between dry bulk density and soil moisture content (Fig. 2).

Table 3. Effect of traffic frequency on moisture (%).

Passage \ Slope (%)	(0-10)	(10-20)	(>20)
undisturbed	47.15 a	47.15 a	47.15 a
3	46.67 a	40.92 a	43.38 a
8	37.20 b	32.51b	33.98b
13	36.60 b	34.18 b	32.10 b
>13	34.62 b	31.88 b	27.14 b

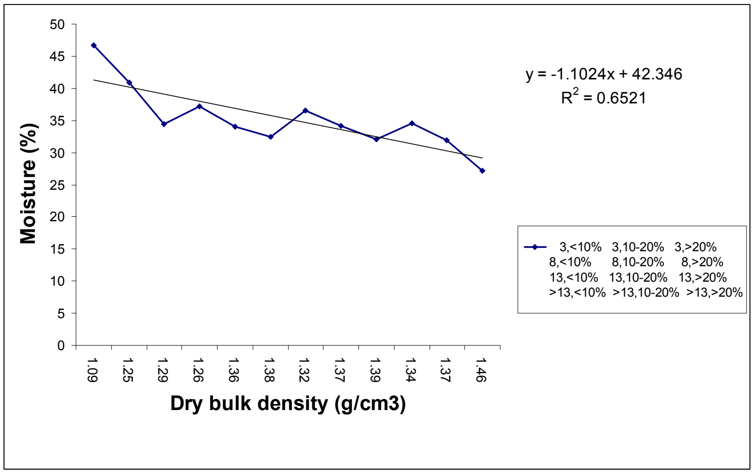

Fig. 2. Correlation between dry bulk density as independent variable and moisture as a function variable

The results showed that within all traffic treatments soil moisture was affected by slope so that lowest soil moisture was observed on the highest slope (Table 3). Moisture content were influenced significantly by number of skidder passes ($p \leq 0.01$) and slope ($p \leq 0.01$), but the interaction between numbers of skidder passes and slope was not significant (data not shown).

Porosity

Macroporosity

Microporosity increased during skidding operation but remained unchanged in treatments of >13 passes (Fig. 4). Within all slope treatments, maximum changes in microporosity were recorded in the first 3 passes (Fig 4). Mean values of total porosity in the skid trail decreased with an increase in skid trail slope and traffic frequency compared to the undisturbed area (Fig. 5).

Total Porosity

The effect of skid trail slope and traffic on macroporosity was significant at the 5% level in comparison to that in the undisturbed area (Table 4). Within all traffic treatments, macroporosity in the slope >20% was significantly lower than in <20% , but differences between treatments with the slope <10% and 10-20% were not significant (Table 4).

The macroporosity in 13 passes was not significantly different from that of >13 passes ($p \leq 0.05$). All slope macroporosities in the 8 passes was significantly lower than that of the 3 passes (Fig. 3).

Table 4. Effect of skid trail slope on macroporosity and total porosity.

Macroporosity					
Passage		3	8	13	>13
Skid trail slope	(0-10)	39.92a	26.14a	18.27a	10.93a
	(10-20)	39.02a	25.20a	14.38a	11.92a
	(>20)	25.25b	18.10b	6.65b	9.60b
Total Porosity					
Passage		3	8	13	>13
Skid trail slope	(0-10)	64.85a	58.81a	54.28a	51.48a
	(10-20)	64.06a	58.97a	52.84a	51.94a
	(>20)	58.62b	54.63b	49.35b	51.27b

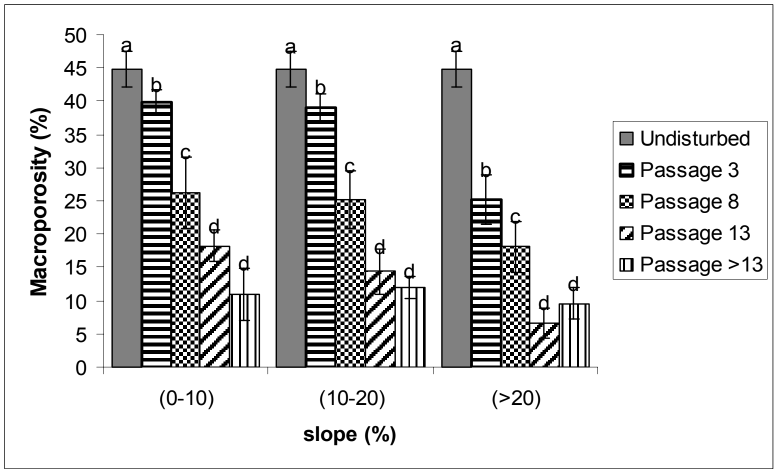

Fig. 3. Macroporosity changes on skid trail

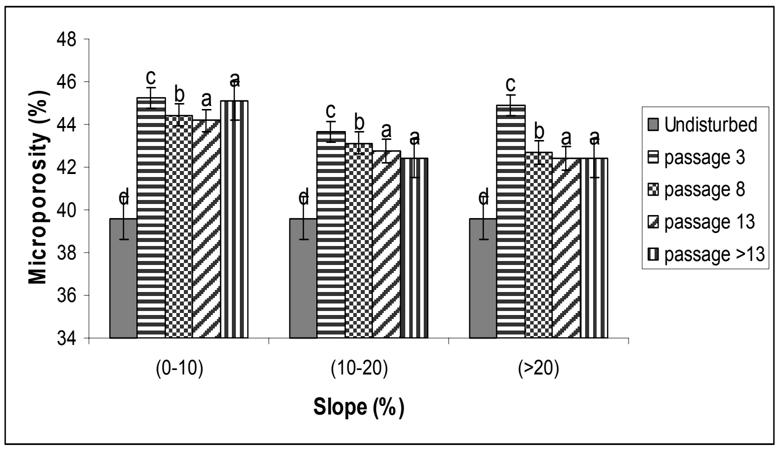

Fig. 4. Microporosity changes on skid trail

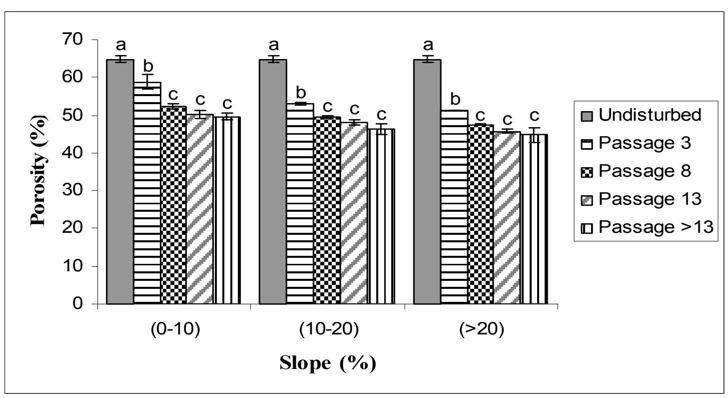

Fig. 5. Total porosity changes on skid trail

Total porosity in the surface soil layer was reduced up to 44% (number of passes: >13, skid trail slope: >20%) by soil compaction. The total porosity was significantly lower on the plots with slope >20% than those with <20% at all traffic treatments (Table 4). The total porosity in the 8 passes was significantly lower than 3 passes; however there were significant differences between 13 and >13 passes from a total porosity point of view at all slope treatments (Fig. 5). Changes in soil porosity were observed as negatively correlated with changes in traffic intensity at all slopes (Fig. 5); however increasing traffic intensity from 8 to >13 passes had no significant changes on total porosity.

Total porosity was influenced significantly by number of skidder passes ($p< 0.01$) and slope ($p<0.01$), but the interaction between numbers of skidder passes and slope was not significant (data not shown).

DISCUSSION

Bulk density

Soil compaction was affected by skidding intensity and trail slope. Average dry bulk density comes faster at higher slope levels. At lower slope levels, dry bulk density was drawing near the critical value after 8 passes, but at higher slope levels, dry bulk density was drawing near the critical value after just 3 passes. There was no significant difference between treatments with 3 passes and slope >20% and those with 8 passes and slope <10% in terms of bulk density . The increase of bulk density in the higher trail slope may be associated with the lower speed of skidders on slope steepness trail. When a skidder passes slower because of slope steepness, top soil vibrated more and consequently, got more compaction with the comparison to gentle slope trails. Furthermore, when logs were pulled on steep slope trails, usually the rear axle got more load and induced more pressure on soil compared to lower slope trails. Uneven load distribution caused slipping on the steep slope trail due to reduction of rear wheel radius. More pressure, slipping and lower speed dramatically increased soil disturbance on the steep slope trail. The studies of Raghaven et al. (1977) identified wheel slip on agricultural tractors as causing significant compaction, and wheel slip from forest vehicles should therefore contribute to compaction.

Most of the compaction, expressed as bulk density increase, thus takes place during the initial passes. As shown in Fig. 1, strong increases in bulk density (67.5%) for skid trails had already appeared after 3 passes of the skidder. Our results are in accordance with the results of Ampoorter et al. (2007) who found that bulk density increases more gradually with 50% of the total impact occurring after 3 passes. There are no significant differences between dry bulk density at 8, 13 and >13 passes. As shown in table 1, strong increases in bulk density for skid trails appeared after 8 passes of the skidder in the treatments. When the number of machine passes increases, the additional bulk density increment is negligible (Ampoorter et al., 2007). Bulk density between 1.40 and 1.55 g/cm3 is considered the critical level at which plant roots cannot penetrate soils with light and medium texture (Kozlowski 1999).

Moisture Content

Moisture content was affected by skid trail slope and skidding intensity. Within all traffic intensities, soil water decreased with an increase in slope. Soil moisture was more responsive with slope in lower traffic intensities (Fig. 2); this shows that sufficient soil compaction had already occurred to induce a strong increase in compaction at higher traffic levels. There was considerable correlation ($R2= 0.65$) between soil moisture content as a function variable and dry bulk density. Similar to the results of dry bulk density, moisture content significantly decreased ($p<0.01$) with skidding cycles from 0 to 8 passes. When the number of machine passes increased from 8 to >13, the reduction of moisture content was negligible (Table 3). Negative correlation between bulk density and soil moisture content suggested a potential decrease in soil moisture at higher bulk densities, presumably due to compaction.

The effects of steep slope on soil moisture content could be interpreted similar to changes of dry bulk density on steep slope trails. Reduction of moisture with increase in slope is associated with more disturbances occurring in higher skid trail slope (Fig. 2). Skid trail soil moisture contents were low as a result of less pore space available for water infiltration and retention at elevated bulk density levels (Fig. 3, 5).

Soil moisture decreased by 20% due to ground skidding operations. This is similar to the result of Tan et al. (2005), who reported that soil compaction reduced water content by 11%. In the present study, significant negative correlations were found between bulk density and soil moisture content. This is in contrast to Carter and Shaw (2002) and Makineci et al. (2007).

MacroPorosity

A substantial change in pore volume was also related to compaction. The significant reduction of macroporosity in the slope >20% may be associated with the effect of slope on soil disturbance while in a given slope it was attributed to traffic intensity. Macropores decreased to 46% and 91% for the low (3 passage and slope <10%) and severe (13 passage and slope >20%) treatments, respectively. In contrast, the average microporosity in the skid trail was 14% higher than the undisturbed area. Reflected in this overall decline were large decreases in macroporosity, offset in part by increases in microporosity (Fig. 4). Moderate compaction was associated with changes in the volume of the larger micropores, while severe compaction was associated with changes in the volume of the smaller pores in comparison to the no compaction treatment (Fig. 4). Macroporosities below 10% are generally considered too restrictive for root proliferation (Koorevaar et al., 1983, Brady and Weil, 2002). Table 4 shows that in the present study, values of macroporosity at treatments with the slope >20% and traffic ≥13 were below the critical level (10%), therefore, root growth in this area may be affected.

Total Porosity

Total porosity on the skid trails is considerably lower than that in the undisturbed area. Total porosity decreased with slope and skidder traffic intensity. Negative correlation between total porosity and slope at all traffic intensities indicated that total porosity was affected by slope as well. Porosity is inversely related to bulk density, meaning that a decrease in mean porosity comes with an increase in mean bulk density at steep slope trails.

When soil is compacted, the total porosity is reduced at the expense of the macropores, i.e. pores that are drained of water at nominal field capacity. Such reduction in porosity has been demonstrated in forest soils following logging activities (Makineci et al., 2007). Ares et al. (2005) reported that total soil porosity decreased to 10 to 13% with compaction. Shestak and Busse (2005) reported that total porosity decreased to 26% in clay loam and to 20% in sandy loam with severe compaction. Motavalli et al. (2003) found that surface compaction significantly decreased total porosity in both the 0–10 and 10–20 cm depths. As compaction increased, the rates of total porosity decreased. Main effects of compaction were significant for changes in total porosity, macroporosity, microporosity and moisture.

CONCLUSION

This study was conducted with the overall objective of characterizing the effects of skid trail slope and skidder passage on bulk density, moisture content and total porosity. Compaction of soil with the impact of skidding caused decreases in macroporosity, total porosity and moisture equivalent rates on the skid road. As compaction increased, the rates of macroporosity, total porosity and moisture content decreased. When soil is compacted, total porosity is reduced at the expense of the large voids (Greacen and Sands 1980).

There is a positive relationship between soil compaction and skid trail slope which thereby supports the hypothesis that skid trail slope affects dry bulk density, moisture content, macroporsity and total porosity. The effect of slope on disturbance is in agreement with Krag et al. (1986) and Raghavan et al. (1977). The damage may be reduced by avoiding steep skid trails of >20% and controlling the number of machine passes.

REFERENCES

Ampoorter, E., Goris, R., Cornelis, W.M., Verheyen, K. (2007) Impact of mechanized logging on compaction status of sandy forest soils. *Forest Ecology and Management,* 241, 162-174.

Ares, A., Terry, T.A., Miller, R.E., Anderson, H.W., Flaming, B. L. (2005) Ground-based forest harvesting effects on soil physical properties and Douglas-Fir growth. *Soil Science Society of American Journal,* 69, 1822–1832.

Botta, G.F., Jorajuria, D., Rosatto, H., Ferrero, C. (2006) Light tractor traffic frequency on soil compaction in the Rolling Pampa region of Argentina. *Soil and Tillage Research*, 86, 9–14.

Brady, N.C., Weil, R.R. (2002) Elements of the nature and properties of soils. Upper Saddle River, New Jersey, pp. 202–212.

Brais, S. (2001) Persistence of soil compaction and effects on seedling growth in northwestern Quebec. *Soil*

Science Society of American Journal, 65, 1263–1271.

Demir, M., Makineci, E., Yilmaz, E. (2007) Investigation of timber harvesting impacts on herbaceous cover, forest floor and surface soil properties on skid road in an oak (Quercus petrea L.) stand. *Building and Environment*, 42, 1194-1199.

Fernández, R.A., Mac Donagh, P.M., Lupi, A.M., Rodolfo, M., Pablo, C. (2002) Relations between soil compaction and plantation growth of a 8 years-old Lobolly pine second rotation, in Misiones, Argentine. Written for presentation at the 2002 ASAE annual international meeting / CIGR XVth world congress sponsored by ASAE and CIGR Hyatt Regency Chicago Chicago, Illinois, USA. Paper Number: 025012.

Gomez, A., Powers, R.F., Singer, M.J., Horwath, W.R. (2002) Soil compaction effects on growth of young ponderosa pine following litter removal in California's Sierra Nevada. *Soil Science Society of America Journal,* 66, 1334–1343.

Greacen, E. L., Sands, R. (1980) Compaction of forest soils: a review. *Australian Journal of Soil Research,* 18, 163–189.

Kozlowski, T.T. (1999) Soil compaction and growth of woody plants. *Scandinavian Journal of Forest Research,* 14, 596–619.

Krag, R., Higgingbotham, K., Rothwell, R. (1986) Logging and soil disturbance in southeast British Columbia. *Canadian journal of Forest Research,* 16, 1345–1354.

Makineci, E., Demir, M., Yilmaz, E. (2007) Long-term harvesting effects on skid road in a fir (Abies bornmulleriana Mattf.) plantation forest. *Building and Environment,* 42, 1538-1543.

McNabb, K.L., Miller, M.S., Lockaby, B.G., Stokes, B.J., Clawson, R.G., Stanturf, J.A., Silva, J.N.M. (1997) Selection harvest in Amazonian rainforest: long-term impacts on soil properties. *Forest Ecology and Management,* 93, 153-160.

Mosaddeghi, M.R., Hajabbasi, M.A., Hemmat, A., Afyuni, M. (2000) Soil compactibility as affected by soil moisture content and farmyard manure in central Iran. *Soil and Tillage Research,* 55, 87-97.

Murphy, M., Firth, J.G., Skinner, M.F. (2004) Long-term impacts of forest harvesting related soil disturbance on log product yields and economic potential in a New Zealand forest. Silva Fennica, 38, 279-289.

Pennington, P.I., Laffan, M., Lewis, R., Churchill, K. (2004) Impact of major snig tracks on the productivity of wet Eucalyptus obliqua forest in Tasmania measured 17–23 years after harvesting. Australian. *Forestry Journal*, 67, 17-24.

Powers, R.E., Alban, D.H.M., Miller, R.E., Tiarks, A.E., Wells, C.G., Avers, P.E., Raghavan, G.S.V., McKyes, E., Beaulieu, B. (1977) Prediction of clay soil compaction. *Journal of Terramechanics*, 14, 1-8.

Schäffer, J., Hartmann, R., Wilpert, K.V. (2001) Effects of timber harvesting with tracked harvesters on physical soil properties In: J. Johansson, Editors, Proceedings from the third (final) meeting of a Concerted Action: Excavators and backhoe loaders as base machines in forest operations Pisa, Italy, in: SLU, Uppsala (2001), pp. 119–124 (Research Note No. 11).

Shestak, C.J., Busse, M.D. (2005) Compaction alters physical but not biological indices of soil health. *Soil Science Society of American Journal,* 69, 236–246.

Tan, X., Scott, X.C., Kabzems, R. (2005) Effects of soil compaction and forest floor removal on soil microbial properties and N transformations in a boreal forest long-term soil productivity study. *Forest Ecology and Management*, 217, 158–170.

ارزیابی اثرات تراکتور چرخ زنجیری بر خواص فیزیکی خاک

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چکیده

عملیات چوبکشی می‌تواند سبب تخریب جدی خاک شود. هدف ما از این تحقیق ارزیابی اثرات چوبکشی زمینی بر کوبیدگی، ظرفیت رطوبتی، و حفرات خاک در سطوح مختلفی از شدت ترافیک و شیب طولی مسیر چوبکشی بود. چهار سطح از شدت ترافیک (3، 8، 13 و >13 تردد توسط تراکتور چرخ زنجیری زتور) و سه سطح از شیب طولی مسیر چوبکشی (0-10٪ ، 20-10٪ و >20٪) به منظور ارزیابی تخریب خاک در نظر گرفته شد. نمونه‌های خاک با استفاده از سیلندر و از عمق 0-10 سانتی متری جمع آوری شد. نتایج نشان داد که وزن مخصوص ظاهری خشک، ظرفیت رطوبتی و مجموع حفرات خاک به طور قابل ملاحظه‌ای تحت تاثیر شدت ترافیک و شیب طولی مسیر است. وزن مخصوص ظاهری در مسیرهایی با شیب بالای 20٪ بعد از 8 تردد به حد بحرانی خود می‌رسد. وقتی تعداد تردد از 8 به 13 تردد افزایش می‌یابد مقدار افزایش وزن مخصوص قابل توجه نیست. صرف نظر از شدت ترافیک، وزن مخصوص ظاهری در شیبهای بالای 10٪ در مقایسه با شیب زیر 10٪ افزایش معنی داری می‌یابد، هرچند که اختلاف معنی داری بین تیمارهایی با شیب 20-10٪ و شیب >20٪ وجود ندارد. حداقل ظرفیت رطوبتی اندازه گیری شده در مسیر چوبکشی 27٪ بود در حالیکه میزان آن در مناطق شاهد 47٪ بود. یک همبستگی منفی بین ظرفیت رطوبتی و وزن خصوص ظاهری خشک تعیین شد. حداکثر مجموع تخلخل در مسیر چوبکشی 58٪ و حداقل میزان آن 44٪ و در مناطق شاهد 65٪ اندازه گیری شد. تخریب خاک در تیمارهای با شیب بالای 20٪ به طور چشمگیری وسعت بیشتری می‌یابد، به طوریکه وزن مخصوص در تردد 8 و شیب بالای 20٪ (1.38 گرم بر سانتی متر مکعب) به طور معنی داری بیشتر از مقدار آن در تردد 13 و شیب زیر 10٪ (1.32 گرم بر سانتی متر مکعب) است. نتایج نشان داد که شیبهای بیشتر از 10٪ تخریب خاک را به طور چشمگیری افزایش می‌دهند.

*مولف مسئول