Soil compaction caused by 450C Timber Jack wheeled skidder (Shefarood forest, northern Iran)

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ABSTRACT: In forest harvesting operations usually after using skidding machinery (skidders), traces of soil damage in the form of soil compaction and wheel and logs ruts can be seen in the forest soil. Soil bulk density, which represents soil compaction, decreases soil porosity, infiltration rate and aeration and these in turn increase runoff and water erosion in the harvested area. On the other hand, a decrease in soil aeration prevents root growth and decreases the vegetative cover. In this study the changes in soil bulk density and relative soil compaction due to a different number of wheeled skidder passes from stump to landing for two soil types (clay soil with high and low liquid limits, CH, CL) are analyzed. The results showed that the effect of skidder traffic on an increase in soil bulk density at sample locations was significant ($\alpha = 0.05$). The range of soil bulk density increases in sample pits due to a different number of machinery passes was from 15.8% to 62.6% compared to the control area. The findings of this research showed that the interaction effect of skidder traffic and soil type on soil bulk density changes was not significant. Also the highest significant increase in soil bulk density occurred at the first 11 passes in skidding trails and from this number of passes onwards there was no significant difference in the soil bulk density increase in sample locations.

Keywords: soil compaction; forest soil; wheeled skidder; Iran

The northern forests of Iran with 1.9 million hectares are very important for their capability of producing timber and 1.3 mill ha of these forests are commercial. The forests border the southern coast of the Caspian Sea in a narrow strip which has special ecological and topographical conditions and also has exclusive plant species diversity.

In recent years the demand for wood has increased because of the population increase and diversity use of wood, and so it is necessary to harvest these forests in a methodical plan with the knowledge of different elements of harvesting, so that harvesting and efficiency are increased, but at the same time maintaining the natural balance of forest by not endangering the soil, plant and animal life.

On this basis, with the disappearance of traditional harvesting and the need for suitable forest mechanization systems, it is essential to transform the forest harvesting sector. One of these transformations is the use of suitable machinery with high efficiency.

The 450C Timber Jack skidder that has been imported from Canada in recent years is one of the machines used for a ground-based skidding system in order to extract logs from the stump area to roadside landing. The use of machinery in different environmental conditions (i.e. climate, topography and different type of soils) has diverse effects which can sometimes be destructive and cannot be compensated.

It is obvious that the skidder traffic and the extraction of wood cause soil compaction on the forest soil surface and because of this the soil water infiltration and aeration decrease and root growth will also be affected. Therefore the loading or in other words the traffic on soil must be specified, otherwise soil compaction will be destructive and will not be economically and technically compensable.

The amount of soil compaction is affected by the weight of machinery and load, number of machinery passes, resistance and hardness of the forest floor, soil structure, soil texture and soil moisture content (Adams, Froehlich 1981). The effect of machine traffic on soil will increase the soil wet bulk density and shear strength, decrease porosity and water and air infiltration (Davies et al. 1993).

In a study carried out by Jansson and Johansson (1998), the effect of wheeled and tracked machinery was studied on soil bulk density in silt loam soil in Sweden. The results showed that average bulk density increased 23% and 14% at 15 and 20 cm depth, respectively, after two passes of wheeled forwarder machinery (20 ton weight). The traffic of wheeled machinery at the first pass produces the highest compaction in soil and the following machinery passes have a lower effect, but overall soil compaction is produced which significantly affects the root growth (Hatchel et al. 1988). Studies by Burger et al. (1985) showed that the number of machinery passes significantly affects soil bulk density and the soil bulk density of top soil increases very rapidly in the first three passes and the following passes have a lower effect.

Skidding operations are the most common way of causing soil compaction (Senyk, Craigdallie 1997). The skidding machinery is designed and manufactured in a way so that it can transport heavy loads in off-road conditions. Hence a major part of soil degradation occurs on skid trails and landings due to skidding operations (Heninger et al. 2002). Froehlich and Mcnabb (1984) came to the conclusion that the initial few passes of skidder have the highest compaction effect on soil. In other words, the initial 5 passes exceptionally increase soil compaction whereas the following passes cause less soil compaction.

Gent et al. (1983) proved that in skidding operations using wheeled skidders, the severest compaction occurred at 10 cm depth of soil and the effect of compaction decreases with an increase in soil depth. In skidding trails that were used a lot, the soil compaction was reported at 30 cm depth. Butt (1998) showed that the increase in soil bulk density caused by wheeled skidders in harvesting sites compared to control sites was from 11% to 80% with average of 52% at 0–10 cm depth and 12% to 56% with average of 34% at 10–20 cm depth.

In this research the destructive effects of wheeled skidder in skidding trails on different soil types are studied. With respect to this, the amount of soil compaction from different machinery passes at sample locations is measured and when to use the machinery with respect to soil conditions.

MATERIALS AND METHODS

This research was carried out on parcel 925 and 926 of the ninth district of Shefarood forest in northern Iran, at the altitude ranging from 1,300 to 1,600 m above sea level and average annual precipitation of 1,100 mm. The forest was uneven-aged and its type was *Fagetum* (*Fagus orientalis* Lipsky) with the average growing stock 330 cubic meters per hectare. The slope of the parcel was 20 to 50% and the aspect of the slopes was northwest and west. The mineral soil was covered with an organic layer approximately 5 cm thick. The moisture content during the experiment was 29% at 15 cm depth. The parent material is calcareous and the type of soil is leached brown forest soil. The soil is clay and clay loam and deep, with moderate to good root penetration.

The total volume of production was 2,800 m^3 and the extraction of short and long logs from the stump area to roadside landing was done by a ground-based skidding system. The skidder type used in this study was 450C Timber Jack cable skidder, model 6BTA5.9 with 177 hp and 10,257 kg weight.

In order to study the soil compaction due to different machinery passes and therefore different volume of wood being extracted along skidding trails, the soil bulk density is determined by a field soil compaction test. Using this method the amount of soil compaction in skidding trails before any machinery passes and during skidding operations is measured. The soil samples were taken by an observation and field sieve analysis method along skidding trails where soil changes were expected in the form of texture and soil particles. Hence the number of samples in each skidding trail was different, in other words if the soil along the trail was similar from the aspect of soil texture and mechanical characteristics, the number of soil samples was lower and if it was dissimilar, the number of soil samples was higher.

In this study 10 locations along skidding trails were chosen for the analysis of bulk density changes due to different machinery passes and soil types. Sample pits were dug in these 10 locations and with the use of cylinder and standard sand, field soil compaction tests were carried out. Each pit was 10 cm in diameter and 15 cm in depth, the soil content of which was used for determining wet bulk density, percentage of moisture content and dry bulk density at different machinery passes (before any machinery passes in skidding trails, i.e. control pit, after the first pass, after 6^{th} pass, after 11^{th} pass, after 16^{th} pass, after 21^{st} pass and after the final pass).

The formulas below are used to determine the above parameters:

$$\text{wet bulk density} = \frac{\text{weight of soil removed from pit} \times \text{sand bulk density}}{\text{weight of sand poured in to the pit}}$$

$$\text{soil moisture content} = \frac{\text{weight of water}}{\text{weight of dry soil}} \times 100$$

$$\gamma_d = \frac{\gamma_w}{1 + w\%}$$

where: γ_d – dry bulk density (g/cm^3),
γ_w – wet bulk density (g/cm^3),
$w\%$ – moisture content percentage.

In this research a borehole was dug in each of the sample location along skidding trails. Therefore after transferring the soil to the laboratory, the mechanical properties of each location were determined. In the soil samples transferred to the laboratory the sieve analysis, Atterberg limit test and Proctor compaction test were carried out. By carrying out Proctor compaction test on the soil samples, the maximum bulk density ($\gamma_{d\,max}$) and optimum moisture content needed for $\gamma_{d\,max}$ are determined. These data are used to analyze bulk density changes due to different machinery passes at different moisture contents, and then they are compared with the optimum moisture content for soil compaction.

In this study in order to assess the effect of skidder traffic on soil bulk density changes (with the use of data collected from the results of field compaction test in sampling locations), the single factorial ANOVA was used. For assessing the interaction effect of two factors (skidder traffic and soil type), the two-way factorial ANOVA was used. Finally Newman-Keuls multiple range test was used to determine at what number of skidder passes the highest significant increase in soil bulk density occurred (Zarr 1974).

RESULTS AND DISCUSSION

With respect to the sieve analysis and Atterberg limit test of 10 soil samples from the studied area and on the basis of unified soil classification system (USCS), two types of soils with different mechanical characteristics were identified. Clay soil with high liquid limit (CH) and clay soil with low liquid limit (CL) (Table 1).

Table 1. Summary of the soil mechanical test of 10 soil samples from sample locations in skidding trails

Location	Liquid limit	Plastic limit	Plastic indices	Soil type
1	49	11	38	CH
2	38	20	18	CL
3	41	20	21	CL
4	52	11	41	CH
5	37	17	20	CL
6	40	21	19	CL
7	52	12	40	CH
8	53	12	41	CH
9	44	18	26	CL
10	51	11	40	CH

The data obtained from sample pits showed that the bulk density increase in comparison with control pit at the first machinery pass is on average 18.2% (Table 2). Measuring the bulk density after the 21st pass in the above sampling locations showed that the bulk density increase in comparison with control sample location was on average 58.5%. With regard to the data from Proctor compaction test of soil samples obtained from boreholes in sampling locations, the analyses of changes in optimum moisture content and maximum bulk density were carried out in soil samples from different soil types (Table 3).

The analysis of soil bulk density from sample locations, with the use of single factorial ANOVA, showed that the effect of skidder traffic on an increase in soil bulk density was significant ($\alpha = 0.05$) (Table 4). In general ground skidding operations caused a significant increase in soil bulk density in all skidding trails in the studied area.

The analysis of soil bulk density, with the use of two-way factorial ANOVA, showed that the effect of skidder traffic on soil compaction (with regard

Table 2. Results of the field soil compaction test at different pits from sample locations in skidding trails

Number of machinery passes	Average measurements		
	γ_d (g/cm^3)	MC (%)	$\Delta\gamma_d$ (%)
Control pit	0.99	28.5	–
First machinery pass	1.18	27.6	18.2
6th machinery pass	1.32	28.1	33.6
11th machinery pass	1.47	27.9	47.7
16th machinery pass	1.57	27.1	57.5
21st machinery pass	1.58	29.5	58.5
Final machinery pass	1.59	30.2	59.6

γ_d – average bulk density, MC – average moisture content, $\Delta\gamma_d$ – average bulk density increase compared to control

Table 3. The results of the compaction test of soil samples from a laboratory

Soil sample	Soil type	Maximum bulk density (g/cm^3)	Optimum moisture content (%)
1	CH	1.65	23.9
2	CL	1.71	20.8
3	CL	1.65	24.7
4	CH	1.62	22.3
5	CL	1.63	19.8
6	CL	1.59	24.2
7	CH	1.69	23.1
8	CH	1.63	20.2
9	CL	1.59	23.4
10	CH	1.71	22.8

to soil type) was not significant. In fact the interaction effects between the amount of compaction due to skidder traffic and soil type were not significant (Table 5). The comparison of mean soil bulk density of the final pass with other passes (Newman-Keuls test) also showed that there was a significant difference up to 11 passes. Furthermore, there was no significant difference between the final pass and the 16th and 21st pass (Table 6).

In this research soil bulk density due to traffic increased significantly and it was so because there was a decrease in the volume of soil pores. Similar results were reported by other researchers (Burger et al. 1985; Davies et al. 1993; Froehlich, Mcnabb 1984; Hatchell et al. 1988).

The results of this research and other researches (Burger et al. 1985; Butt 1998; Froehlich, Mcnabb 1984) showed that the highest bulk density increase (soil compaction) occurred at initial passes and with the increase in traffic the soil bulk density increase was not significant. This study showed that the increase in soil bulk density in skidding trails compared to the control at different machinery passes and at 15 cm depth is in the range of 15.8% to 62.6%. Adams and Froehlich (1981) in their research showed that these values with the use of skidding machinery were in the range of 15% to 60% and that soil moisture was an effective factor of changing this range of limits.

The comparison of bulk density increase with the control after the first machinery pass in sampling locations confirmed that in locations where the moisture content (natural m.c.) of pit was near to optimum m.c., the percentage of bulk density increase was higher. Aust et al. (1998) in their research

Table 4. Single factorial ANOVA

Source of variation	*df*	*F*	*P*-value	Critical *F*-value
Groups	6	987.47	$P < 0.01$	2.25
Error	63			
Total	69			

Table 5. Two-way factorial ANOVA

Source of variation	*df*	*F*	*P*-value	Critical *F*-value
Soil types	1	1.784	0.19	4.0
Skidder passes	6	984.28	$P < 0.01$	2.26
Soil types × skidder passes interaction	6	0.83	0.55	2.26
Error	56			
Total	69			

Table 6. Newman-Keuls multiple range test

Comparison of average γ_d	Difference	SE	*q*	*p*	*q* distribution		Conclusion
B vs. A	X^b–X^a						
Final MP* vs. control pit	0.59	0.007	80.86	7	4.31	is rejected Ho:	μ7 ≠ μ1
Final MP vs.1st MP	0.41	0.007	56.22	6	4.16	is rejected Ho:	μ7 ≠ μ2
Final MP vs. 6th MP	0.27	0.007	36.21	5	3.98	is rejected Ho:	μ7 ≠ μ3
Final MP vs. 11th MP	0.13	0.007	17.70	4	3.74	is rejected Ho:	μ7 ≠ μ4
Final MP vs. 16th MP	0.02	0.007	2.59	3	3.40	not rejected Ho:	μ7 = μ5
Final MP vs. 21st MP	0.007	0.007	0.95	2			

*MP – machinery pass

showed that the optimum m.c. was an effective factor of an increase in the compaction in skidding trails.

CONCLUSIONS

With reference to the aim of this research, it must be stated that soil bulk density due to traffic increased significantly and that the greatest soil compaction occurred at the initial passes.

The effect of skidder traffic on soil compaction (in relation to soil type) was not significant.

Considering the permissible number of machinery passes and average amount of logs being carried at each pass, the carrying potential of each skidding trail can be estimated. Hence the amount of logs that can be carried along a skidding trail can be chosen so that machinery passes do not exceed the number of permissible machinery passes and consequently will not cause the soil destruction.

Therefore in the time of planning the machinery use (when to use machinery), it is important to stop skidding operations on days when the soil moisture content is close to the optimum m.c. In the studied area the optimum m.c. usually occurred a few days after rainfall and in these conditions machinery traffic (passes) can increase the soil compaction in skidding trails significantly. Thus the skidding operation after the skidding trails having been completely dried up can significantly decrease the extent of destructive effect.

These conditions (m.c. lower than optimum m.c.) occur very rarely in the northern forests of Iran and with regard to the climate of the area, the soil natural m.c. is at optimum and higher and the results of this study verify that. Therefore we cannot wait for days when m.c. is lower than optimum because in practice m.c. is at optimum and higher.

Hence skidding operations can be carried out at m.c. higher than optimum m.c. (a few days after rainfall) provided that the m.c. of skidding trails is not saturated, otherwise the soil will be damaged.

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Zhutňování půdy kolovým traktorem 450C Timberjack v lesích severního Íránu

ABSTRAKT: Po těžebních a dopravních operacích může – při nasazení soustřeďovací mechanizace (traktorů) – být obvykle vidět poškození lesní půdy formou zhutnění a vyjetých kolejí. Objemová hmotnost půdy, která je prezentována půdním zhutněním, nižší pórovitostí půdy, rychlostí infiltrace a aerací, postupně zvyšuje tendenci růstu odtoku a vodní eroze na těžebních plochách. Snižování provzdušňování půdy omezuje růst kořenů a zmenšuje plochu vegetačního krytu. Studie změn objemové hmotnosti půdy a změn relativního zhutnění půdy je analyzována kvůli rozdílnému počtu přejezdů kolového traktoru od pařezu na odvozní místo přes dva půdní typy (jílovitá půda s vysokým a nízkým obsahem vody, CH, CL). Výsledek ukazuje, že vliv traktoru na růst objemové hmotnosti půdy u vzorků byl statisticky významný (α = 0,05). Objemová hmotnost půdy roste ve vzorcích (při srovnání s kontrolní plochou) v rozdílných hodnotách od 15,8 % do 62,6 % kvůli rozdílnému počtu přejezdů stroje. Výsledky výzkumu ukazují, že vliv traktoru k půdním typům nebyl statisticky významný s ohledem na změnu objemové hmotnosti půdy. Nejvýznamnější nárůst objemové hmotnosti půdy nastal v prvních 11 průjezdech po přibližovací lince. Z dalších průjezdů nebyl růst rozdílu objemové hmotnosti půdy významný.

Klíčová slova: zhutnění půdy; lesní půda; kolový traktor; Írán

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