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Bulldozer and Hydraulic Excavator Traffic Effect on Soil Bulk Density, Rolling Project and Tree Root Response

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Abstract

Measuring soil bulk density after road excavating by heavy equipments is a key element to determine rolling intensity and root response to compaction. In this study, soil bulk density in crawler bulldozer and hydraulic excavator construction area was measured at two depths (0-10 and 10-20 cm) of sandy clay soil. Results showed that the soil compaction caused by different number of bulldozer passes was more than the excavator. The mean of soil bulk density in bulldozer construction area was about 1.74 gr cm^{-3}. Thus, first pass of roller (5.5 tones) was sufficient to access the Aashto standard (1.75 gr cm^{-3}). In contrast, the mean of soil bulk density in hydraulic excavator construction area was about 1.62 gr cm^{-3} and 6 roller passes was need to access the standard bulk density. Also, according to USDA NRCS classification the bulldozer has restricted the root growth, whereas hydraulic excavator only may affect root growth. Rolling and leveling of the soil materials in bulldozer construction area should be done with the lightest rollers available and using the fewest passes possible.

Key words: Bulldozer, Hydraulic excavator, Bulk density, Rolling, Root responses.

INTRODUCTION

The total length of hyrcanian forest roads in Iran at the end of year 2000 was about 7000 km. Roads network planning and standard methods for their construction are performed according to principle of the bulletin No. 131 and 148, published by Plane and Budget Organization of Iran (PBOI) [7]. In recent years, excavator usage has become current in hyrcanian forests due to its environmental aspects. Furthermore, the crawler bulldozers are the other machines which use in earth working operation. Approximately 80% of forest roads are constructed by bulldozer (Figure 1). One major factor preventing the more usage of excavators is their low productivity [15].

Soil compaction from heavy equipment traffic is a common consequence of soil disturbance. Forest soils easily compact from the use of excavating machinery, such as bulldozer and hydraulic excavator machines [1 and 2]. The unprotected forest soil acts as a weak receptor against static and dynamic forces created by excavation machines especially on forest roads, skid trails and landings where high frequencies of machine movement exists [6, 8, 9 and 10]. After forest road excavation the rolling operation must be performed. A roller operates by traversing the road with a rotator cylinder for compacting and surfacing soil materials to provide a smooth surface [13]. As with other forms of road maintenance, grading and rolling has both economical and environmental benefits [3]. A well-graded road reduces haul costs by allowing vehicles to travel at design speeds, and reduces vehicle owner-ship and operating costs by reducing the amount of wear and tear incurred while traveling [4].

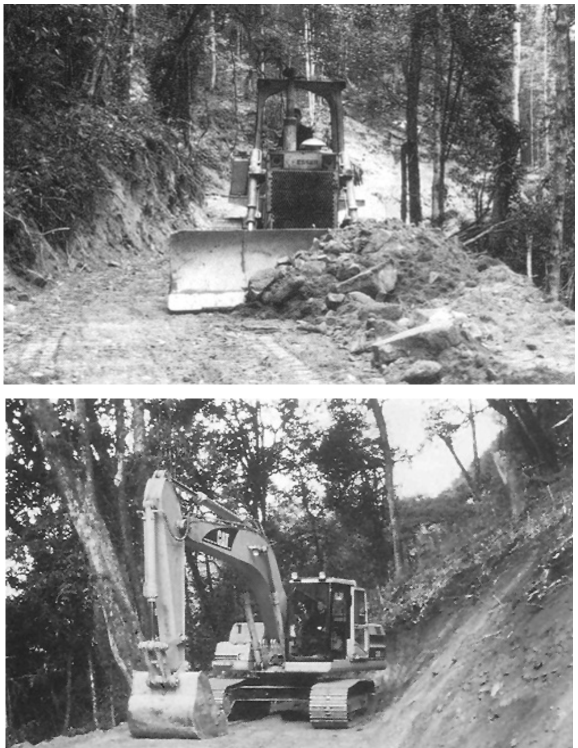

Figure 1. Road smoothening by means of the bulldozer's blade (Left) and excavator's bucket (Right).

The compaction of a soil is one of the important construction operations that influence the tree root growth [14]. Root responses to compaction may be complex, owing to the numerous ways in which compaction can modify the physical properties of soil [12]. There have been many attempts to find

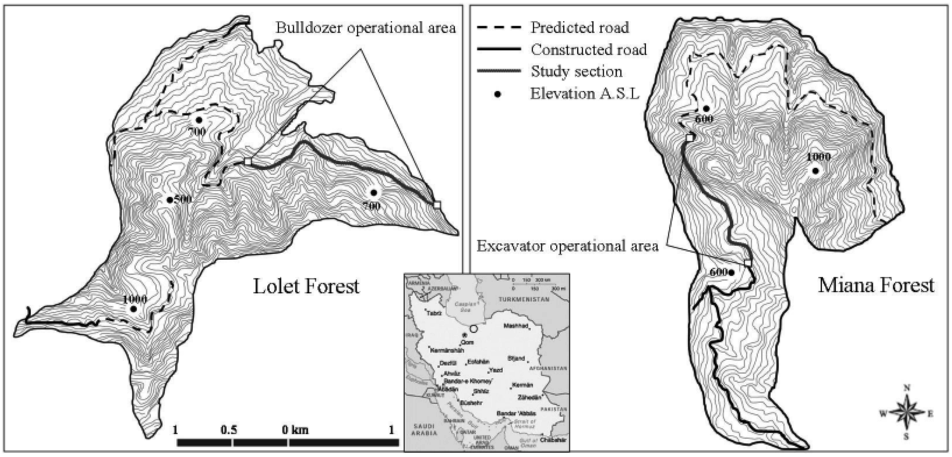

Figure 2. Location of study area on Lolet and Miana forest maps.

critical values of cone index, soil strength or permeability that are related to root growth limiting factors [5].

The objectives of this research were: (i) to quantify the effects of bulldozer and hydraulic excavator traffic on soil compaction, (ii) to determine the optimum number of roller passes in rolling project, (iii) to assess trees root response to soil compaction according to USDA NRCS standard table.

MATERIALS AND METHODES

Study Area

Two under construction road were selected in Miana (52° 56′ 30″ to 52° 59′ 25″ E and 36° 12′ 25″ to 36° 16′ 35″ N) and Lolet forest (53° 8′ 20″ to 53° 12′ 50″ E and 36° 13′ 40″ to 36° 17′ 45″ N), Hyrcanian forest, Mazandaran province, Iran. The locations of the road sections are given in Figure (2) and a summary of characteristics of study areas are presented in Table (1). These secondary forest roads were under construction by excavator and bulldozer in sandy clay loam soil (Table 2). The shrinkage limit (SL) was between 4 to 5.36% before commencing the excavation. The plastic limit (PL) changed in the profile from 36.21 to 46.50%; an increase is noted as depth increases. The liquid limit (LL) also exhibited changes in the profile; it varied between 41.67 and 69.37%. Before machinery traffic the average of soil bulk density in study area was about 1.44 gr cm^{-3}.

Soil Sampling

Ten test sites were randomly selected for each of excavator and bulldozer construction area. Core sampler (100 cm^3, metal cores) was used to evaluate roadbed bulk density at each site. Cores were taken at depths of 0-10 and 10-20 cm and then oven-dried at 105°C for at least 24 hours. Soil bulk density (*BD*) was calculated using Eq. (1).

$$BD = \frac{m_{soil}}{V_{cylinder}} \quad (1)$$

Where, M_{soil} and $V_{cylinder}$ are dry weight of soil (gr) and cylinder volume (cm^3) respectively. Significant difference among treatment averages for different parameters were tested at p<0.05 using least significant difference (LSD) test. SAS software was used for statistical analyses. Also, means and standards were compared using student's t-Test (equations 2).

Table 1. Main characteristics of the study area.

Site	Machine	Compartment	Elevation (m a.s.l)	Asp.	Soil (USCS)	Bed rock
Lolet	Bulldozer	2, 3, 4, 5	400 – 900	N	Sandy clay loam	Marl, Marl lime, Limestone
Miana	Excavator	4, 5, 6, 15, 16	450 – 950	E	Sandy clay loam	Limestone and conglomerate

Table 2. Technical data of the excavation equipments.

Type of equipment	Weight (Tone)	Bucket Volume (m^3)	Engine power (hp)
Bulldozer Komatsu D_{60}	17	5	220
Excavator Komatsu PC_{220}	24	1	180

$$t = \frac{\bar{x} - m}{S/\sqrt{n}} \quad (2)$$

Where $\bar{x}$ is mean of sampled soil bulk density. m is standard number. *S* is standard deviation of sampled cores and *n* is the number of sampled cores.

RESULTS and DISCUSSION

Machinery traffic effects on soil bulk density

Results of this study showed that the effect of bulldozer and excavator traffic on soil bulk density was significant (p<0.05). In general soil compaction caused by bulldozer passes was more than the excavator, because number of crawler bulldozer passes in construction area is generally more than excavator (Table 3). Adequate compaction cannot be achieved with hydraulic excavator and bulldozer alone. Excavators are a low-ground pressure machine and therefore are unsuitable for compaction process. Also, ground pressure of a 149 kW (200 hp), 23 tone bulldozer (Cat D_7, for example) is 0.7 bar (10.2 lb in^{-2}). By comparison, a loaded dump truck (3 axles, 10 m^3 box capacity) generates a ground pressure of 5 to 6 bar (72.5 to 87.1 lb in^{-2}) [5, 11 and 16].

Table 3. Comparison of soil bulk density values before and after of machinery traffic .

Treatment	parameter	bulk density (gr cm^{-3})	
		After traffic	Before traffic
Machine	Bulldozer	1.74^{a}	1.44^{b}
	Hydraulic excavator	1.62^{a}	1.43^{b}
Depth (cm)	0-10	1.67^{a}	1.42^{b}
	10-20	1.69^{a}	1.45^{b}

In a row, means with the different letters are significantly different at 5% level based on LSD test

Optimum number of roller passes in rolling project

Some compaction obtains during the leveling process as the bulldozer passes over the material. But controlled compaction with water and vibratory roller is necessary to achieve relative density of 95% [5]. Results in Table (4) showed that there wasn't significant difference between the soil bulk density in bulldozer construction area and Aashto standard, whereas this difference was significant for excavator at both depth of 0-10 and 10-20 cm ($p<0.05$). According to Aashto standard in sandy clay soils, tamping foot roller with a weight of 5.5 tones must be passed 13 times to access the density of 95% (1.75 gr cm^{-3}). Relationship between the soil properties and number of roller passes are illustrated in Figure (3) [13]. Mean of soil bulk density in bulldozer and excavator construction area was 1.74 and 1.62 gr cm^{-3}. Thus, first and 6 passes of roller was sufficient to access the standard density, respectively.

Compaction effect strongly depends on the weight of the rollers cylinder. The final compaction obtained after single pass using heavy cylinder (3000 N) was higher than the compaction obtained with repeated cycles using light cylinder (600 N) [10 and 12].

Table 4. Comparison of bulk densities in different machines construction area and Aashto standard.

Machine	Depth (cm)	Bulk density (gr cm^{-3})		T-value
		Sampled cores	Aashto standard	
Bulldozer	0-10	1.73 ± 0.030	1.75 (95%)	2.12^{ns}
	10-20	1.75 ± 0.029	1.75 (95%)	0.00^{ns}
Hydraulic excavator	0-10	1.60 ± 0.030	1.75 (95%)	15.70***
	10-20	1.63 ± 0.026	1.75 (95%)	14.45***

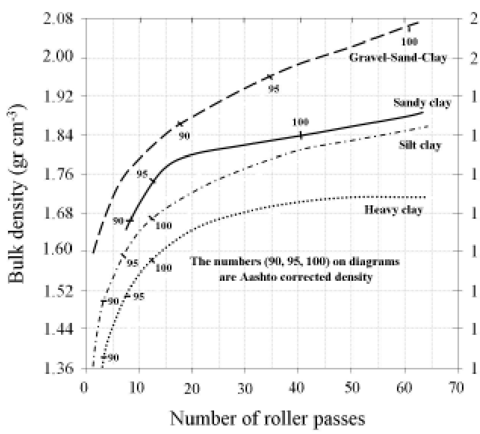

Figure 3. Relationships among soil texture, bulk density and optimum number of roller passes

Table 5. General relationship of soil bulk density to root growth based on soil texture

Soil Texture	Ideal bulk density (gr cm^{-3})	Bulk densities that may affect root growth (gr cm^{-3})	Bulk densities that restrict root growth (gr cm^{-3})
Sands, loamy sands	< 1.60	1.69	>1.80
Sandy loams, loams	< 1.40	1.63	>1.80
Sandy clay loams	< 1.40	1.60	>1.75
Loams, clay loams	< 1.40	1.60	>1.75
Silts, silt loams	< 1.30	1.60	>1.75
Silt loams, silty clay loams	< 1.10	1.55	>1.65
Sandy clays, silty clays, clay loams (35-45% clay)	< 1.10	1.49	>1.58
Clays (>45% clay)	< 1.10	1.39	>1.47

Tree root response to soil compaction

A common response of the root system to increasing bulk density is to decrease its length, concentrating roots in the top layer and decreasing rooting depth [17]. The USDA NRCS Soil Quality Institute has developed Table (5) that shows a relationship between soil bulk density and root growth [14]. This relationship reveals that both the bulk densities that restrict root growth for sandy soils and those observed at sandy sites with very low permeability rates are greater than 1.8 gr cm^{-3}.

Results of this study also showed that the bulldozer and excavator had influenced the root growth. As bulldozer restricted the root growth, because soil bulk density in it's construction area was in restrictive range of root growth (1.75 gr cm^{-3}), whereas there was significant difference between the soil bulk density in excavator construction area and restrictive range of root growth. Thus, hydraulic excavator only may affect root growth (Figure 4).

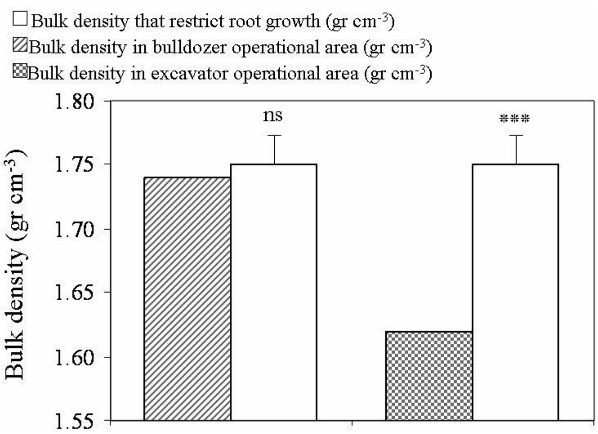

Figure 4. Comparing the bulk density in construction area and restrictive range of root growth.

CONCLUSIONS

With reference to the aim of this research, it must be stated that soil bulk density due to crawler bulldozer and hydraulic excavator traffic increased significantly and that the greatest soil compaction occurred in bulldozer construction area. The amount of soil compaction is affected by the weight of machinery, number of machinery passes, resistance and hardness of the forest floor and soil texture. Also, degree of compaction in bulldozer construction area was near to Aashto standard density. Thus, rolling and leveling of the soil materials in bulldozer construction area should be done with the lightest rollers and graders available and using the fewest passes possible. This ability of bulldozer can be useful for reducing the rolling cost and the time of forest road construction project.

The effect of soil compaction on root growth largely depends on the type of excavation machinery used and soil wetness during machine use. In this research bulldozer has restricted the root growth, whereas hydraulic excavator only may affect root growth. Tree roots may be directly damaged by bulldozer's blade and excavator's bucket that create wounds where insects and diseases can enter trees.

Roads must be constructed during the time of year when the best results can be achieved with the least damage to the roots. Excavation and creation of the road bench creates large expanses of bare soil and should be performed only during dry spring, summer or early fall conditions. Soils require an optimum moisture content to achieve the proper compaction. On the other hand, fine textured soils that are overly dry or very wet often cannot be compacted enough to produce the soil strength needed to support loaded trucks or to remain stable on steep slopes. If the soils are too wet, they should be allowed to dry, and if they are too dry, they should be watered to achieve adequate compaction.

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