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Soil Compaction from Off-Road Transportation Machine on Tropical Hill Forest Land

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ABSTRAK

Ketumpatan pukal 15 cm tanah atas di bawah tek trektor lipan meningkat dengan purata sebanyak 54.0% kepada 1.52 g/cm³, kenaikan sebanyak 37.0% untuk tanah di antara trek yang dimampatkan oleh penarikan balak dan 24.0% untuk busut dibandingkan dengan tanah yang bersebelahan yang tidak terganggu selama dua tahun selepas pembalakan. Ruang rongga makro menurun sebanyak 21.2% untuk tanah trek; 14.0% untuk terganggu-balak dan 9.0% untuk busut. Ruang rongga mikro tanah trek, terganggu-balak dan busut masing-masing menaik sebanyak 80.0%, 60.0% dan 20.0%. Ketara sekali mampatan merendahkan jumlah ruang rongga tanah trek, tanah terganggu-balak dan busut, masing-masing dengan 20.4%, 13.4% dan 8.8% berbanding dengan tanah tidak terganggu. Ketahanan penyusupan tanah trek bagi kedalaman 15 cm tanah atas menaik 10 kali ganda ke atas tanah tidak terganggu. Keterangan ini dapat menolong keputusan terhadap pengangkutan tanpa-jalan, tatarajah trek-mesin atau tayar dan program pengurusan musim trafik untuk mengurangkan kemungkinan mampatan.

ABSTRACT

Bulk densities of the upper 15 cm of soil under a crawler tractor track increased by an average of 54.0% to 1.52 g/cm³; the increase was 37.0% and 24.0% for the soil between the tracks compacted by the skidding of logs and berm, respectively compared to those of adjacent undisturbed soils two years after logging. Macroporosity was reduced 21.2% for the soil in the track; 14.0% for log-disturbed and 9.0% for the berm. Micropore spaces of soils in the track, log-disturbed and berm increased by 80.0, 60.0 and 20.0%, respectively. Compaction significantly reduced the total porosity of track soil, log-disturbed soil and berm by 20.4%, 13.4% and 8.8%, respectively compared to that of undisturbed soil. Resistance to penetration of soils in the track for the upper 15 cm soil depth increased 10 fold over that of the undisturbed soil. This information should facilitate decisions concerning off-road transportation, machine-track or tire configuration and seasonal traffic programme management, to reduce the chances of compaction.

INTRODUCTION

The energy required to compact soil may arise from rainfall, growth of tree roots, foot traffic from both man and animals and from the weight of vegetation and the soil itself. However, the main forces causing compaction of forest soils come from machinery used to manage and harvest the crop. Mechanization of some forest operations has greatly intensified over the last decade, particularly in plantations, and forest managers are currently expressing concern about the compaction of forest soil and its consequences.

The problems associated with soil compaction produced by logging machines on forest land are well documented by Dryness (1965), Foil and Rawlston (1967), Moehring and Rawls (1970), Hatchell *et al.* (1970), Dickerson (1976), Miles (1978), Hillel (1980), Sidle and Drlica (1981), and Gent and Morris (1986).

Compaction occurs through a process of densification in which the soil aggregates are shifted relative to one another, crushed, or deformed by the vertical pressure and vibratory force exerted by off-road transportation machines, resulting in a change of volume for a given mass of soil.

The effects of soil compaction are readily measured as an increase in bulk density, decrease in infiltration capacity, decrease in gaseous exchange, and an increase in resistance to penetration (Vomocil and Flocker, 1961, Froehlich, 1979; and Kamaruzaman Jusoff and Nik Muhamad Majid, 1986a). These physical changes can inhibit root elongation, impede soil drainage and slow the exchange of nutrients needed for plant growth (Steinbrenner, 1955, Youngberg, 1959; Hassan, 1978; Wert and Thomas, 1981, and Mitchell *et. al.*, 1982). Further deterioration in site productivity may occur from surface soil displacement during logging and accelerated surface erosion because of increased overland flow on skid trails (Free *et al.*, 1947; Frederikson, 1970; Megahan *et al.*, 1972).

Though forest managers are aware that soil compaction is occurring as a result of mechanized logging operations, the degree and extent of such compaction has not been well evaluated and documented for tropical forest soils. The objective of this study was to determine the typical degree of soil compaction produced by an off-road transportation machine (a D8 Caterpillar crawler tractor) on hill forest soils in Central Pahang, Malaysia.

MATERIALS AND METHODS

Site Description

The study was conducted in compartment 24 of Sungai Tekam Forest Reserve, located in Jengka of Central Pahang, Malaysia *(Fig. 1)*.

The study area 722 ha, lies roughly between longitudes 102° and 103° East and latitudes 4° and 5° North and has a rolling terrain with steep hills. It consists mainly of mixed hill dipterocarp

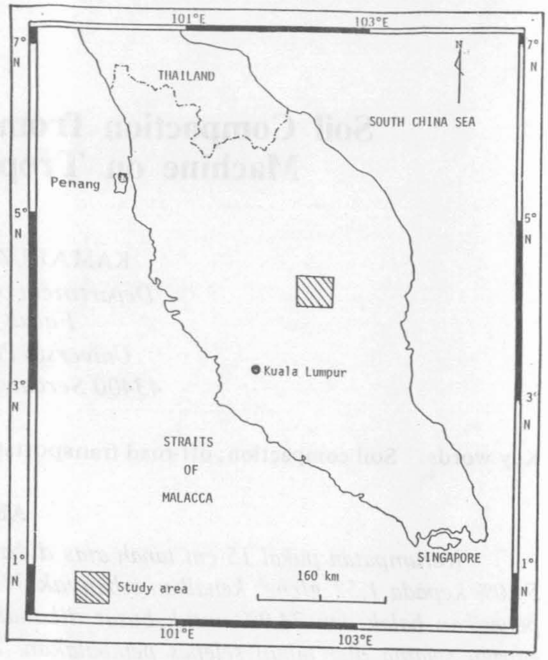

Fig. 1: A map of Peninsular Malaysia showing the study site.

species. The average elevation is 345 m above sea level. The slope gradient ranges from 20 to 45°. Annual precipitation is approximately 205 cm, occurring mainly between April to May and October to December. The mean annual temperature ranges from 21 to 32 °C.

The principal soil occurring on this study site belongs to Durian Series (order Ultisols). The texture of the topsoil is sandy loam.

Data Collection

A D8 Caterpillar crawler tractor (14,640 kg weight, 2.40 m^2 ground contact area) was the off-road transportation machine examined in this study. In 1984, several skid trails of varying lengths were created by skidding straight up slopes at a speed of 7.0 km/h. One tree-length (TL) hardwood log averaging 10 m long, 36 cm at breast height (dbh) and 1,000 kg mass was skidded 35 times over each trail.

Measurements were made two years after skidding. Soil cores, 7.6 cm in diameter and 4.0 cm high were taken from the upper 15 cm of the surface of each trail by driving metal core rings into the ground and removing the samples intact.

A total of 10 samples were taken from a control site and from each of three skid trail disturbance classes adopted from the Canada Soil Survey Committee 1978 (Smith and Wass, 1985) as follows:

a. the soil compacted by the crawler track (track soil)
b. the soil between the tracks compacted by the tree-length log (log-disturbed soil)
c. the disturbed soil down to the buried original surface (berm), and
d. the upper undisturbed area adjacent to the trail (undisturbed soil as a control).

Volumetric water content of the surface soil during the study was 0.25 m^3/m^3.

Laboratory and Field Analysis

Several direct measures of soil compaction were carried out by monitoring the dry density, total porosity, and resistance to penetration of the soil. Bulk density was determined by drying the soil samples to a constant weight at 105 °C in an oven. The total porosity, which is similar to bulk density as a measure of compaction (Lenhard, 1986) was computed from the bulk density.

Macroporosity or the non-capillary pore space is an indicator of a soil's ability to conduct, store and make required amounts of water and oxygen available to tree roots. Also referred to as aeration porosity, which is the air-filled pore space (since these macropores normally drain under gravity and are filled with air at field capacity) was calculated from the following relationship (Mbagwu *et al.*, 1983):

$$S_a = S_t - \theta_v (0.1)$$

where,

S_a = aeration porosity

S_t = total porosity

$\theta_v(0.1)$ = percentage volume of water held at 0.1 bar suction taken as field capacity.

Resistance to penetration in each of the disturbance classes was measured by a self-recording penetrometer (made in the Netherlands) equipped with a 1 cm^2 base surface cone to measure soil strength. Ten replicates of each probe at a 15 cm depth were made in each of the disturbance classes.

The amount or degree of compaction was expressed by three indexes, namely the actual numerial change in bulk density, total porosity and soil strength from the value of these properties for the undisturbed site.

Statistical Analysis

The data was subjected to a one-way analysis of variance (ANOVA). Duncan's New Multiple Range Test was conducted to separate significant differences in moisture, macroporosity and soil strength between treatments (disturbance classes).

RESULTS AND DISCUSSION

Soil compaction from the off-road crawler tractor measured two years after the harvesting operation, showed that the track caused the greatest change compared to the other two disturbance classes. The track increased the average bulk density of soils in the track to 1.52 g/cm^3, 54.0% greater than adjacent undisturbed soils (Table 1). Bulk densities from log-disturbed areas and berms averaged 1.35 and 1.22 g/cm^3. respectively; 37.0 and 24.0% more than the average for undisturbed soils (Table I).

The crawler tractor reduced the average macropore space of soil under the track to 39.7%, a loss of about one-third of the macroporosity of undisturbed soil. Macropore spaces of log-disturbed soil and berm averaged 46.9% and 51.9%,' respectively, 14.0 and 9.0 percentage points below that of undisturbed soil. Micropore space of track and log-disturbed soils were 2.9% and 2.7%, respectively, about 38.0% and 33.0% greater than that of undisturbed soil (Table I).

An increase in bulk density and loss of macropore space reduces the percolation rate of compacted soils (Steinbrenner and Gessel, 1955; Raghavan *et al.*, 1976, Sands *et al.*, 1979; and Burger *et al.*, 1984). A reduced percolation rate causes a substantially lower infiltration rate and larger amounts of surface run-off (Dyrness, 1965; Dickerson, 1976; and Kamaruzaman Jusoff *et al.*, 1986). In addition, most compacted soil in crawler tractor logged areas occurs in bare track ruts which serve to channel run-off water (Dyrness, 1965).

A loss in macropores generally leads to a re-

TABLE 1.
Main effects of off-road transportation machine on some selected soil physical properties

Disturbance class	Bulk density (g/cm)^3	Macropores (%)	Micropores (%)	Total porosity	Resistance to penetration (N/cm^2)
Track soil	1.52 ± 0.07[b]	39.7 ± 2.36[c]	2.9 ± 0.33[c]	42.6 ± 2.70[c]	323.9 ± 151.86[c]
Log-disturbed soil	1.35 ± 0.02	46.9 ± 0.40	2.7 ± 0.28	49.6 ± 0.58	243.5 ± 108.23
Berm	1.22 ± 0.04	51.9 ± 1.83	2.3 ± 0.37	54.2 ± 1.52	86.7 ± 50.55
Undisturbed soil	0.98 ± 0.05	60.9 ± 2.76	2.1 ± 0.32	63.0 ± 2.45	20.3 ± 14.33

[a]Data are mean of 10 replications ± standard deviation of the mean.

[b]All means in column are not significantly different at the 0.05 level as determined by Duncan's New Multiple Range Test.

[c]All means in column are significantly different at the 0.05 level as determined by Duncan's New Multiple Range Test.

duction in saturated hydraulic conductivity (Freitag, 1971, Greaçen and Sands, 1980; Gent *et al.*, 1983 and Fritton *et al.*, 1986). These changes in saturated hydraulic conductivity may affect plant growth because this factor determines the rate at which excessive moisture can leave the soil system and how rapidly water, required for plant growth, can move through the soil system. Much work has been done to determine levels of soil compaction that are critical to plant growth (Hatchell, 1970; Grable, 1971; Baver *et al.*, 1972; Mitchell *et al.*, 1982 and Jones, 1983). Some workers have noted a relationship between poor survival and growth of tree seedlings and soil compaction. Youngberg (1959), Froehlich (1979), and Mitchell *et al.* (1982) found a highly significant decrease in the growth of planted Douglas fir seedlings on compacted tractor roads and soils as compared with seedlings from undisturbed soils.

When soil is compacted, it is clearly evident from Table 1 that the total porosity is reduced at the expense of the large voids or macropores. Hence, the proportion of the micropores was increased because micropores were relatively less affected by compaction. This has been demonstrated by Van Der Weert (1974) and Dickerson (1976) in forest soils following compaction after logging activities.

The mean penetrograph recordings shown in *Fig. 2* demonstrate the apparent degree of soil compaction caused by an off-road transportation machine. Resistance to penetration was significantly higher on the track than in the undisturbed soil. In addition, the berm showed higher resistance to penetration than the undisturbed soil. Of the skid trail components, the track was the least penetrable, the log-disturbed soil of intermediate penetrability and the berm most penetrable. The average penetration resistance of the first 15 cm layer for track pressure and undisturbed soil, respectively, were approximately 3.0 and 0.2 MPa, respectively (Table 1). This implies

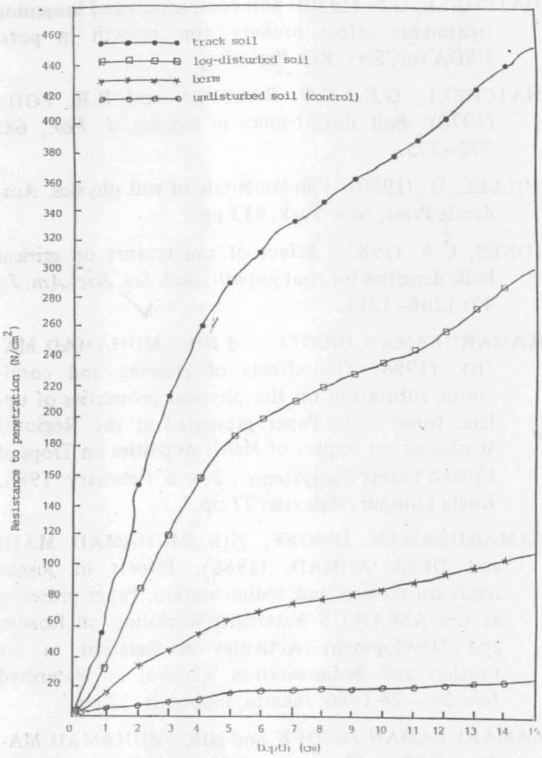

Fig. 2: Valuation of penetrometer resistance with depth as affected by off-road transportation machine for four different disturbance classes.

that the degree of compaction as measured by penetration resistance under the machine track was 15 times higher than in the undisturbed soil.

The degree of compaction in terms of change in bulk density and total porosity is shown in Table II.

Compaction in soil under the track of an off-road transportation machine was significantly higher (0.54 g/cm^3) compared to the log-disturbed soil (0.37 g/cm^3) and berm (0.24 g/cm^3).

Compaction in the log-distrubed area was generally quite different from that in the track. Here, it was caused by the skidded logs and surface soil removal occurred instead of complete compaction. The compaction areas were relatively shallow troughs of surface soil, at least partially covered by scattered litter, slash and bark peeled off during skidding. In addition, the contact stress between the log and the soil was minimised by the large area of contact between the soil and the log during skidding.

CONCLUSION

It appears that major compaction from off-road transportation machines, especially the crawler tractor, is limited to the track. Those areas of the forest which have been subjected to tree-length skidding and its scouring action, which forms the soft berms, are compacted to a much smaller degree.

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TABLE 2

Degree of soil compaction from off-road transportation machine (D8 Caterpillar crawler tractor) for the upper 15 cm soil depth, as expressed by difference from control

	Soil Compaction		
Disturbance class	Change in density (g/cm)^3	Change in porosity %	Change in penetration (MPa)
Track soil	0.54	20.4	3.0
Log-disturbed soil	0.37	13.4	2.2
Berm	0.24	8.8	0.7

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