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# The Impact of Skid Trails on the Physical Properties of Tropical Hill Forest Soils

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**Key words: Skid trails; physical properties; hill forest soils.**

## ABSTRAK

*Satu kajian telah dikendalikan di Hutan Simpan Sungai Tekam di Pahang, Malaysia untuk menilaikan kesan-kesan jalan penarik ke atas beberapa ciri tanah. Keputusan kajian menunjukkan bahawa nilai ketumpatan pukal dan tahanan penyusupan telah naik, tetapi jumlah ruang rongga dan keupayaan pengudaraan turun. Kandungan air tersedia pulih kepada keadaan biasa hanya selepas dua tahun selepas penanaman pokok. Keputusan penyelidikan ini berguna kepada pengurus kawasan hutan dan tanah di dalam membentuk program penanaman semula pokok hutan supaya kepadatan dan hakisan tanah dapat dikurangkan di kawasan jalan penarik. Kajian harus dijalankan untuk mencari kaedah pembalakan yang sesuai supaya kerosakan ke atas ciri-ciri fizikal tanah di atas jalan penarik dapat dikurangkan.*

## ABSTRACT

*A field study was conducted in Sungai Tekam Forest Reserve of Pahang, Malaysia to evaluate the effects of skid trails on some selected soil properties. Results showed that bulk density and resistance to penetration increased while total pore space and aeration porosity decreased significantly. The available water holding capacity returned to normal after two years of exposure. This information is useful to forest and land managers who are attempting to manage soils to reduce soil compaction and erosion on skid trails and plan reforestation programmes. Research efforts should aim at reducing the alteration of some soil physical properties on skid trails by proper harvesting practices and reduction of skid trail related disturbances.*

## INTRODUCTION

The Malaysian logging industry has been operating on relatively low cost combinations of winch-lorries[1] and crawler tractors[2]. In this system, the crawler tractor gathers up to 50% of the felled trees (tree-length) in the easier operating terrain, rising to some 80% on slopes with gradients exceeding 40% and skids them to roadside loading points or landings using intensive trail patterns. Usually skid trails are built with a bulldozer crawler tractor (D7) having a minimum blade width of 4 m.

Serious environmental concern has been expressed about this ground-skidding operation on hilly or sensitive terrain. Skid trail network in particular are often critisized as being too dense and the source of soil erosion; they also have

[1] Winch-lorries are 6-wheel drive vehicles, having rear tandem axles and dual wheels.

[2] Crawler tractors are normally of Caterpillar D6 to D8 series with 90 to 185 flywheel horsepower.

poor regeneration qualities and cause soil compaction and disturbance. Smith and Wass (1985) reported that construction of contour skidroads on steep slopes causes deep gouging of the soil resulting in erosion, stream sedimentation and site deterioration. Brown and Krygier (1971) found that road-related landslides double the predicted annual sediment yield for one year from a coastal Oregon Watershed in the United States. In the Gombak area of Kuala Lumpur, Malaysia, Douglass (1967) showed a sediment production of about 62 $m^3/km^2$/year as a result of road construction and logging. Detrimental effects on the physical properties of soil and poor growth of coniferous seedlings in skid trails logging road were reported by Steinbrenner and Gessel (1955), Youngberg (1959), Dyrness (1965), Hatchell *et al.* (1970), Moehring and Rawls (1970), Wert and Thomas (1981) and Gent *et al.* (1983). Similar observations were also reported by Marn and Jonkers (1982) dealing with the natural regeneration of Mixed Hill Dipterocarp species in Sarawak, Malaysia.

In the Jengka forest of Pahang, Malaysia, a skid trail density of 0.02 to 0.06 km/ha occupied a normal logging operation with the winch-lorry crawler tractor logging system (Bahari 1986; pers. comm.) [3]. In a Mixed Hill Dipterocarp Forest of Sarawak, Marn and Jonkers (1982) reported a skid trail density of 0.14 to 0.17 km/ha with a similar logging method. They further indicated that the area occupied by skid trails and landings increased with increasing intensity of logging, from about 8% when extracting 2 trees/ha to some 13% when extracting 6 trees/ha.

Logging in the hill forest will become increasingly important in the near future and ground skidding will be the major logging system to be applied on the Malaysian steep hill slopes. As such, skid trails are deemed necessary and normally built close to the contour to provide a safe running surface for the crawlers. Such massive skid trail contruction inevitably upsets the ecological balance of the tropical hill forest and also causes destruction of surface soil structure, especially if the work is done in adverse weather conditions and with heavy machinery. Soils exposed on the skid trails often have degraded characteristics compared to the undisturbed adjacent soils (Gent *et al.*, 1983; Smith and Wass, 1985).

Efficient planning to minimize soil degradation and disturbances on skid trails requires a knowledge of the soils in the area to be managed (e.g. a soil survey), and the response of each soil to compaction. Although many temperate forests in Europe, United States and elsewhere have extensive soil resource inventories, the effects of skid trails on soil physical properties have not been sufficiently studied in the tropical hill forest of Malaysia. We seriously lack information required to justify or effectively plan rehabilitative measures such as compensatory planting and enrichment planting on skid trails. Therefore, it is important for the forest and land managers to understand and appreciate the damage to the soil resource when constructing skid trails.

The objective of this paper is to quantify the changes in some soil physical properties that are associated with skid trail construction and its recovery rate. The discussion is limited to the work done on the Mixed Hill Dipterocarp Forest soils of Jengka, Pahang in Malaysia.

## MATERIALS AND METHODS

### *Description of the Study Area*

The study was conducted in compartment C24 of Sungai Tekam Forest Reserve, located in Jengka of central Pahang, Malaysia *(Figure 1)*.

The study area, of 722 ha, lies roughly between longitudes 102° and 103° East and latitudes 4° and 5° North and has a rolling terrain with steep hills and mainly consists of mixed hill dipterocarp species. Elevation is 345

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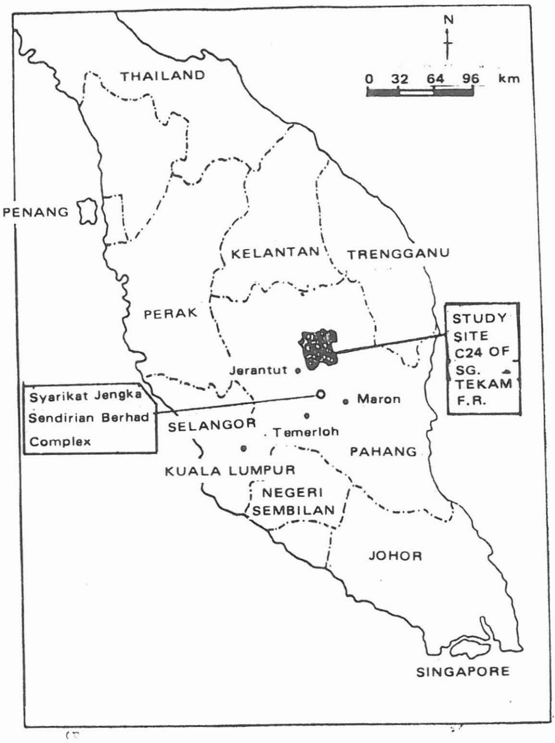


*Fig. 1: A map of the study area.*

m above sea level. The slope gradient ranges from 20 to 45°. Annual precipitation is approximately 205 cm, occurring mainly from April to May and September to December. Annual temperature ranges from 21 to 32°C.

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

*Experimental Design*

Crawler tractor skidding is the ground skidding technique examined in this study. It involves a two-year old skid trail left by debris avalanche and soil erosion for secondary succession.

The study was set up as a randomized complete block design. Two blocks were categorised on soils having skid trails in a logged-over forest and an adjacent undisturbed block of virgin forest as a control. Within each block, a 10 by 30 m plot was established and 10 sampling points were randomly selected within each treatment plot of 5 m by 10 m.

*Soil Sampling*

Ten soil samples were randomly taken with an ELE spring auger sampler from each treatment plot at the following depths: 0 – 15 cm, 15 – 30 cm and 30 – 50 cm. These depths were arbitrarily selected and had no relationship to the natural horizons.

In each plot, 17 soil cores were also collected at a 15 cm depth with metal core rings 7.6 cm in diameter and 4 cm high. A depth of 15 cm was chosen because variability in soil physical properties was greater in the surface layer than in the lower horizons (Gent *et al.*, 1983). Furthermore, the surface layer is important for water infiltration during short-duration high-intensity rainstorms because it has a high hydraulic conductivity and high water storage capacity, both of which may be greatly reduced by compaction (Hill and Jakobsen, 1982). This zone also contains 70 to 90% of the total root mass and is by far the most important storage zone for tree nutrients (Kalela, 1949 and Kostler *et al.*, 1968).

Both ends of the cores were fitted with plastic covers to reduce the loss of water by evaporation. These undisturbed samples were used to determine bulk density, moisture retention characteristics (pF curves), available water holding capacity (AWC) and aeration porosity.

A self-registrating penetrometer or Penetrograph type Stiboka (made in The Netherlands) equipped with a 1 $cm^2$ (cone number 1) base surface cone was used to measure resistance to penetration on the skid trail and in the undisturbed soil. The resistance to penetration test is commonly selected to measure soil strength or root penetration resistance since soil engineering tests for shear strength, such as the triaxial and direct shear tests have limited use due to the larger number of samples and tests required to obtain an adequate degree of precision in structured soils (Bradford, 1980). With the penetrometer test, the soil resistance was transformed via a spring mechanism, causing a pin to mark a graphical card. The registration of soil resistance was automatic and continous with direct availability of the graphs as the penetrograph was driven into the soil at a constant speed. 50 replicates of each probe were made in each of the treatment plots.

*Laboratory Analysis*

The soil physical properties determined were moisture content, bulk density, total pore space, aeration porosity, water retention characteristics, soil strength and particle-size distributions. These properties were chosen as parameters because they reflect the degree of the alteration of physical soil properties caused by skid trails. Furthermore, these soil properties were most affected by skidroad construction (Garrison and Rummel, 1951; Youngberg, 1959 and Hatchell *et al.*, 1970).

Disturbed soil samples were prepared for laboratory analysis by air-drying for about 24 hours and passed through a 2 mm sieve for moisture content determination. Core samples density and total pore space determinations.

Moisture content was determined by the gravimetric method. Bulk density was determined using tension table and pressure plate extractors. Total porosity was computed from were oven-dried at 105°C for 24 hours for bulk the bulk density using a micro-computer programme developed at Universiti Pertanian Malaysia, Serdang. Aeration porosity, which was considered to be the air-filled pore space at 0.1 bar suction, was calculated from the following relationship (Mbagwu *et al.*, 1983):

$$S_a = S_t - Q_v(0.1)$$

where,

$S_a$ = macro porosity/aeration porosity

$S_t$ = total pore space

$Q_v(0.1)$ = percentage volume of water held at 0.1 bar suction

The AWC was computed as the differences between moisture retention at 0.1 bar (taken as field capacity) and 15 bars suction (Lal and Akinremi, 1983). Particle-size distribution of samples was determined by the pipette method.

*Statistical Analysis*

The data were subjected to a one-way analysis of variance (ANOVA). Duncan's New Multiple Range Test was run on the SPSS-X computer programme to separate significant differences in soil moisture content among depths and between treatments. Other soil properties data were subjected to a paired t-test which was also run on the SPSS-X computer programme to find significant differences in the properties between treatments.

## RESULTS AND DISCUSSION

*Soil Moisture Content*

The average soil moisture content on the gravimetric basis of the skid trail and undisturbed plot are given in Table 1.

Duncan's New Multiple Range Test showed that there was no significant difference in moisture content among depths and between treatments ($P \leqslant 0.05$). However, soils on skid trail had a higher moisture content at all depths than on the undisturbed soils, because of differences attributable to soil water retention characterictics and also differences in various water balance component, e.g. drainage, interception and evapotranspiration.

Other researchers relate soil moisture content to bulk density and consequently soil porosity. For example, David and Ike (1970) reported that in wet soil surface, the bulk density in the 0 to 5 cm layer of skidroads was 13% greater than on the adjacent undisturbed area. Consequently, total pore space and macropore space were decreased by 11 and 49%, respectively.

TABLE 1
Moisture content (per cent) for the 0 – 15 cm, 15 – 30 cm and 30 – 50 cm layers under undisturbed soil and skid trail

| Depth (cm) | Moisture content* (%) | |
|---|---|---|
| | Undisturbed soil | Skid trail |
| 0 – 15 | 11.7 ± 0.48§ | 12.2 ± 1.65 |
| 15 – 30 | 11.8 ± 0.27§ | 12.4 ± 1.56 |
| 30 – 50 | 11.8 ± 0.29§ | 12.7 ± 1.46 |

*Data are mean of 10 replications ± standard deviation of the mean.

§All means in each row and column are not significantly different at the 0.05 level as determined by Duncan's New Multiple Range Test.

*Bulk Density, Total Porosity; Aeration Porosity and AWC*

The results on the effects of skid trails on bulk density, total pore space, macro porosity and AWC are shown in Table 2.

The bulk density of soils on the skid trail was significantly different compared to the original undisturbed condition (Table 2). The bulk density of soil on the skid trail (1.27 g/cm$^3$) exceeded by 0.12 g/cm$^3$ (about 12%). A 20% increase in bulk density of soils in wheel ruts of rubber-tired skidders over that of the adjacent undisturbed soil was recorded by Raghavan *et al.* (1976) in Quebec, Canada and Hatchell *et al.* (1970) in Mississippi, United States due to repeated traffic compaction and exposure of the denser subsoil to logging activities.

Due to higher bulk density, soils on the skid trail had significantly lower pore space than the undisturbed soils (Table 2), a reduction amounting to 5% over the undisturbed soil.

In addition to the above two factors, skidding also significantly reduced macropore space of skid trail soil to about 4.7% that of the undisturbed soil. Macropore space of the undisturbed soil and the skid trail was about 54.3 and 49.6%, respectively. Skid trail soil was compacted resulting in a total porosity of below 52%, a level considered far from critical for aeration need of many forestry crops (Baver *et al.*, 1972; Vomocil and Flocker, 1961 and Grable, 1971).

The AWC given in Table 2 indicated a non-significant difference between undisturbed and skid trail soil ($P \leqslant 0.05$). However, the available water in the skid trail was 14% lower by volume to that of the undisturbed soil.

TABLE 2
Bulk density, total porosity, aeration porosity and available water holding capacity for 0 – 15 cm layer in soils of undisturbed plot and skid trail*

| Treatment | Bulk density (g/cm$^3$) | Total porosity (%) | Aeration porosity (%) | AWC (% v/v) |
|---|---|---|---|---|
| Undisturbed soil | 1.15 ± 0.09§ | 57.0 ± 3.42§ | 54.3 ± 3.58§ | 9.4 ± 2.67§§ |
| Skid trail | 1.27 ± 0.21§ | 52.0 ± 8.03§ | 49.6 ± 8.43§ | 8.0 ± 2.72§§ |

*Data are mean of 17 replications ± standard deviation of the mean.

§Means in each column are significantly different at the 0.05 level as determined by a paired t-test.

§§Means in each column are not significantly different at the 0.05 level as determined by a paired t-test.

The pF curves in *Figure 2* show that the soil from the skid trail generally has greater moisture retention at all suctions than those of the undisturbed soil. However, the trend from both plots indicates a decrease in water content with increasing suction.

The results in Table 2 indicate that changes in the physical properties of the skid trail are inter-related. For example, the increase in soil bulk density of the skid trail is related to the reduction of the total pore space. Considering bulk density as a measure of soil compaction (Hill and Jakobsen, 1982), the sandy loam soils on the skid trail studied could be considered as compacted. A bulk density exceeding 1.20 g/cm$^3$ for Preacher soil, in the Coast Range of Oregon, was indicated as heavily compacted by Wert and Thomas (1981). In severely compacted soils, most of the previous pore space has been filled up by soil solids, hence resulting in a reduction of macropore space and giving a higher bulk density. The decrease in macropore space also reduces the infiltration capacity of the soil because it destroys the non-capillary pore space of the soil, hence rendering the moisture pathway more tortuous. This can result in reduced percolation rate and consequently increase run-off and erosion (Dickerson, 1975). Steinbrenner and Gessel (1955) found that a 15% increase in the bulk density of skidroad soils resulted in a 95% loss in permeability.

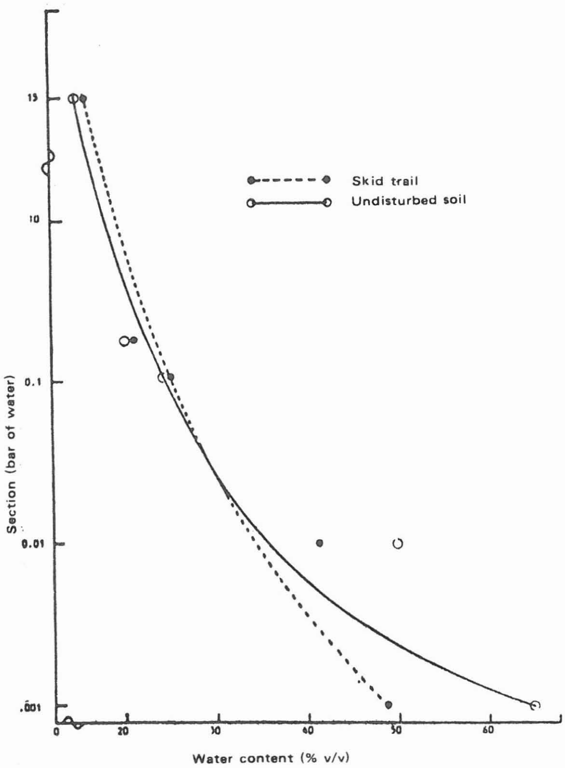


*Fig. 2: Water retention curves (pF) for skid trail and undisturbed soil.*

A higher bulk density in the skid trail may also be due to the exposure of the denser suboil during the initial process of ground skidding. In the process of ground skidding of logs from the stump to landing, the moving logs towed by the crawler tractor tore out vegetation, displaced litter and scraped into the soil along their path. The forward end of the logs seriously plowed the soil. This became even more serious when the logs were allowed to trail far behind the tractor. With repeated use, the denuded skid trails were deepened, the soil compacted and the excavated materials moved out to form berms along the sides of the trails, leaving behind the bare denser suboils.

There was a reduction of total porosity on skid trail because the soil structure tends to be destroyed and compacted by repeated passage of tractor during ground skidding. Several studies on soil disturbance by logging showed similar effects on total porosity. For example, Steinbrenner and Gessel (1955) found that there was a 53% loss in macroscopic pore space on tractor roads. The percentage of air space volume also decreased.

Dyrness (1965) found that the percentage of air space volume or aeration porosity in skid trail soil was lower than undisturbed soil (63 versus 77%, respectively).

The results from the above changes in soil physical properties of skid trail could alter the normal soil forming process and also bring about detrimental effects to plants or regeneration on the affected sites. According to a generalized productivity curve compiled by Froehlich (1978), a 10% increase in soil bulk density would correspond to a decrease of about 10% in seedling height growth. In our study, the reduction in height growth of the dipterocarp seedlings would be expected to be greater since there was a 12% increase in soil bulk density on the skid trail, assuming the other soil properties and growth requirements of dipterocarps are similar to those conditions of Froehlich. Youngberg (1959) found a highly significant decrease in the growth of planted Douglas-fir seedlings on compacted tractor roads as compared to seedlings in other cutover locations. This may be due to restricted soil aeration which limits the development of an extensive root system, impairs the essential process of respiration of an established root system and retards both water and nutrient absorption. It also prevents the orderly functioning of essential biological processes associated with good soil fertility.

*Resistance to Penetration*

Resistance to penetration was significantly higher on the skid trail than on undisturbed soil at 5 to 70 cm depths (Table 3) at $P \leqslant 0.05$. Penetrometer readings generally increased with depth for both soils. This is to be expected since the subsoil is more compact than the surface soil. The tracing of the penetrograph recordings shown in *Figure 3* demonstrates the effect of the skid trail on the soil strength. The average penetrometer resistance or cone indices of the soil profile for the upper 15 cm zone of the skid trails and undisturbed soils are approximately 70 and 100 $N/cm^2$, respectively (Table 3).

The highest average cone index for the skid trail occured at a depth of 65 cm. For undisturbed soil, the maximum cone index recorded was 132 $N/cm^2$ at a depth of 70 cm.

On the skid trail, the soil subsequently remolded and consolidated. Large pores were destroyed as a result of compaction by the crawlers, thereby increasing soil strength as well as soil bulk density (Table 2). Hatchell *et al.* (1970) reported that skid trail disturbance

TABLE 3
Resistance of penetration (penetrometer readings)
at various depths for undisturbed soil and skid trail*

| Depth (cm) | Penetration resistance ($N/cm^2$) | |
|---|---|---|
| | Undisturbed soil | Skid trail |
| 5 | 48.5 ± 46.08 | 102.9 ± 125.98 |
| 10 | 69.2 ± 61.50 | 103.7 ± 104.10 |
| 15 | 69.6 ± 58.55 | 99.7 ± 101.37 |
| 20 | 75.2 ± 54.92 | 112.5 ± 112.29 |
| 25 | 70.4 ± 50.69 | 112.2 ± 106.01 |
| 30 | 68.8 ± 43.80 | 115.3 ± 113.46 |
| 35 | 75.8 ± 47.62 | 116.6 ± 112.48 |
| 40 | 90.8 ± 52.21 | 128.0 ± 94.89 |
| 45 | 100.8 ± 53.93 | 119.4 ± 71.28 |
| 50 | 117.6 ± 63.11 | 127.8 ± 71.76 |
| 55 | 100.3 ± 41.41 | 148.3 ± 68.70 |
| 60 | 101.8 ± 53.58 | 145.0 ± 64.81 |
| 65 | 128.5 ± 69.26 | 174.0 ± 48.14 |
| 70 | 132.0 ± 90.56 | 172.0 ± 28.84 |

*Data are mean of 50 replications ± standard deviation of the mean.

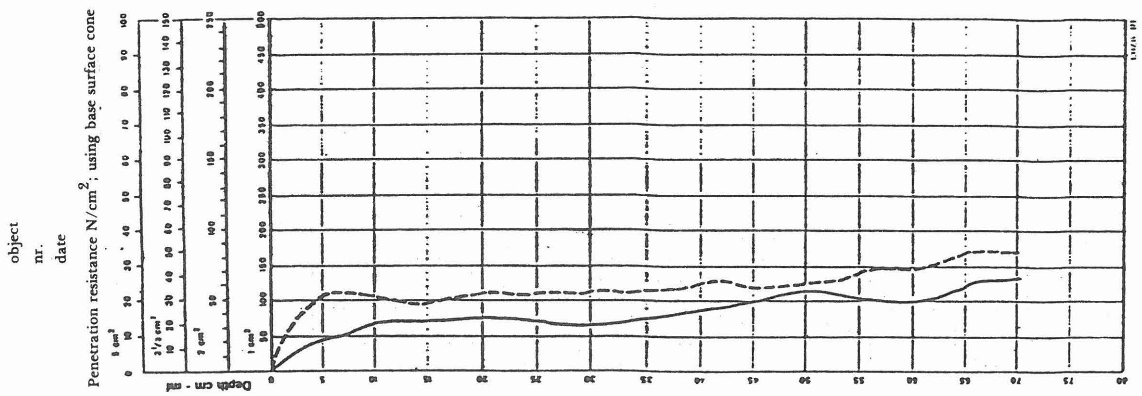

*Fig. 3: Penetrograph recordings on a graphical card of skid trail (broken lines) and undisturbed soil (solid lines).*

caused a substantial increase in soil strength and a drastic reduction in soil infiltration capacity. Greacen and Sands (1980), and Smith and Wass (1985) also reported an increase in penetrometer resistance compared with undisturbed areas down to 50 cm soil depth on a logging road with sandy soil texture.

Penetrometer resistance (which can be taken as a measure of resistance to root penetration) increased on the skid trail because the soil was compacted, and this is associated with an increase in bulk density and a decrease in the soil-air volume (Table 2). Sands *et al.* (1979) found that penetrometer resistance increased exponentially with increasing soil density. They indicated that even a small increase in soil density, as a result of an increasing number of machine passes in the same track, may bring it into the range where soil resistance is critical for root penetration. Roots cannot ramify freely through the soil if the pores through which they grow are destroyed by heavy consolidation at the critical point of root penetration.

### *Particle Size Distribution*

Table 4 shows the textural composition of the soils under the skid trail and undisturbed sites at 0 – 15, 15 – 30 and 30 – 50 cm depths.

The most interesting result of the textural composition is that the clay fractions at all depths on the skid trail were higher than those of the undisturbed soil. The non-significant increase of the clay fraction on skid trail can be clearly seen from a bar chart drawn in *Figure 4.*

TABLE 4

Mechanical analysis of soil in 0 – 15, 15 – 30, and 30 – 50 cm depths in skid trail and undisturbed soil*

| | Coarse sand (%) (2.0 – 0.1 mm) | | Fine sand (%) (0.1 – 0.05 mm) | | Silt (%) (0.05 – 0.002) | | Clay (%) (below 0.002 mm) | |
|---|---|---|---|---|---|---|---|---|
| Depth (cm) | Skid trail | Undist. soil | Skid trail | Undist. soil | Skid trail | Undist. soil | Skid trail | Undist. soil |
| 0 – 15 | 51.6 | 49.7 | 25.7 | 29.4 | 5.1 | 12.2 | 17.6 | 8.7 |
| 15 – 30 | 53.0 | 48.2 | 24.4 | 31.1 | 4.5 | 12.0 | 18.1 | 8.7 |
| 30 – 50 | 50.6 | 48.2 | 24.5 | 30.2 | 5.7 | 12.8 | 19.2 | 8.8 |

*Data are mean of replications for each depth and treatment.

§All means in each row and column are not significantly different at the 0.05 level as determined by Duncan's New Multiple Range Test.

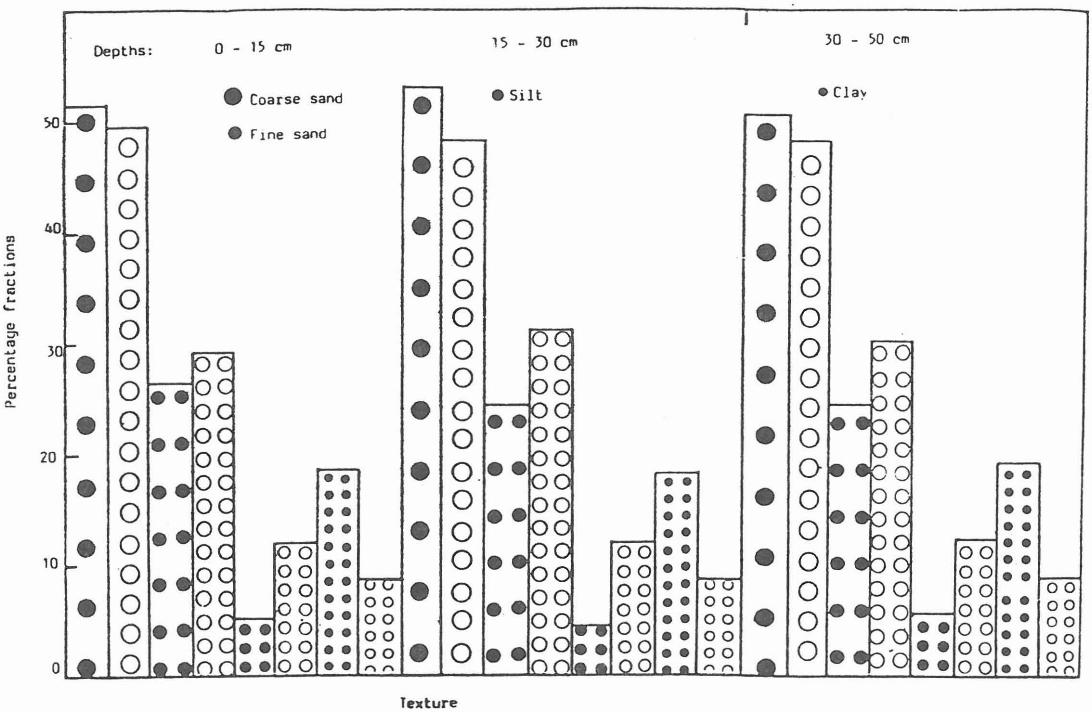


*Fig. 4: A histogram of the particle size distribution for skid trail (solid circles) and undisturbed soil (clear circles).*

The fact that clay content is higher not only at the surface, but also at a depth of 30 – 50 cm, suggests that the differences existed before logging, because differences attributable to surface erosion would presumably be greater near the surface than at lower depth.

The increase in clay percentage of skid trail soil could also be attributable to a decrease in the degree of erosion within the skid trail area as a result of the presence of some vegetative growth *(Figure 5)*.

These secondary successional plants absorbed the impact of the raindrops and therefore minimized the destructive effect of the beating action of rain on soil structure. Furthermore, the presence of some litter under the vegetative growth allowed a high proportion of the rainfall to infiltrate so that there was little run-off. In addition, part of the intercepted water hardly reached the soil but was evaporated directly from the leaves and stems. This water therefore, cannot contribute to run-off and was not a factor causing erosion on this particular skid trail.

Under the conditions of higher clay content on skid trail and subsequently little erosion, clogging of the larger pores of lower soil layers by the fine clay particles did not occur. Inspection of ***Figure 2*** **suggests that higher clay contents**

***Fig. 5:*** ***Secondary succession on the skid trail following abandonment for two years.***

seen in Table 4 can presumably be associated with the higher 15-bar water content resulting in a lower AWC of the skid trail soil (8.0% by volume) compared to the undisturbed soils (9.4% by volume), although their difference was not significant.

While no satisfactory explanation could be offered for the non-significant difference in the AWC between the skid trail and undisturbed soil, the AWC showed a tendency to return to pre-skid trail level. This is probably due to the establishment of secondary vegetation which involves the establishment of a rooting zone and biological activity. Aubertin (1971) attributed such recovery to small soil voids from root decay and the subsequent increase to the filling of the voids by the roots of establishment secondary growth.

*Rate of Recovery*

How long it will be before the other physical properties (besides AWC) of the skid trail will recover fully to its original state of undisturbed level is not definitely known. However, from this study, a time period of two years only provided the AWC to recover slowly from further deterioration on the skid trail.

Certain forest soil management practices such as enrichment planting, agro-forestry practice or managed forest fallow could restore or avoid the other deterioration in skid trail soil property losses such as bulk density, total porosity, aeration porosity, and soil strength. Nevertheless, because of their inherently degraded physical properties discussed earlier, these soils were likely to require larger inputs of fertilizers, or longer fallows in order to achieve a high level of productivity

To reduce the detrimental effects of skid trail construction on soil physical properties, forest managers should minimize compaction during tractive logging activities. Some of the recommendations are (1) pre-plan and confine skidding to a low density trail network, (2) winch logs to the trail instead of travelling to each log, (3) locate skid trail on the driest available soil and along contours, (4) carry load off the ground to minimize shear forces on the soil and (5) use machines that have large soil contact areas and low weight.

When forest managers have no choice among sites, they can manage soils on these skid trails productively; but the incremental effort or investment per unit area required to achieve sustainable increase in production on these sites will be much greater.

## CONCLUSIONS

The most important effect of skid trail construction on forest soil physical properties resulted mainly from compaction processes during traction. Significant changes in bulk density, total porosity, aeration porosity and resistance to penetration can be observed from compacted soil compared to the undisturbed soil. Recovery from AWC on skid trail surface has taken place. Obviously, the soil damage on skid trail is of economic importance, and measures should be taken to reduce skid trail damaging effects to a minimum.

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