ESTIMATION OF RATE OF RECOVERY OF DISTURBED SOILS FROM GROUND-BASED LOGGING IN PENINSULAR MALAYSIA

Kamaruzaman Jusoff

Faculty of Forestry, Universiti Pertanian Malaysia, Serdang 43400 UPM Selangor, Malaysia

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KAMARUZAMAN, J. 1996. Estimation of rate of recovery of disturbed soils from ground-based logging in Peninsular Malaysia. A field study was conducted to determine the rate of natural recovery of compacted soils in a logged-over hill forest area in Sg. Tekam, Pahang, Peninsular Malaysia. Based upon regression analysis, the estimated average times required for natural recovery of bulk density, total porosity, saturated hydraulic conductivity and resistance to penetration on skid trail, bush landing and secondary forest road to conditions found in the undisturbed soil are respectively listed in consecutive order as follows: (i) 22, 17 and 14 years; (ii) 24, 17 and 15 years; (iii) 52, 37 and 28 years; and (iv) 19, 14 and 12 years. The study showed that ground-based logging is most damaging to the skid trails, as the natural rate of recovery of such disturbed soils is exceedingly slow compared to bush landing and secondary forest road. Future research should focus on improved logging machine and systems that will lessen the damage on skid trails.

Key words: Rate of recovery - disturbed soils - ground-based logging

KAMARUZAMAN, J. 1996. Anggaran kadar pulih semula tanah terganggu daripada pembalakan berasaskan darat di Semenanjung Malaysia. Satu kajian lapangan telah dijalankan untuk menentukan kadar pulih semula tanah mampat di kawasan hutan bukit sudah kerja di Sg. Tekam, Pahang, Semenanjung Malaysia. Berdasarkan analisis regresi, anggaran purata masa kadar pulih semula untuk ketumpatan pukal, jumlah keronggan, kekonduksian hidraulik tepu dan ketahanan kepada penembusan di atas jalan gelungsur, matau sekunder dan jalan hutan sekunder berbanding dengan tanah tidak terganggu adalah masing-masing: (i) 22, 17 dan 14 tahun; (ii) 24, 17 dan 15 tahun; (iii) 52, 37 dan 28 tahun; dan (iv) 19, 14 dan 12 tahun. Kajian ini menunjukkan bahawa pembalakan berasaskan darat paling merosakkan jalan gelungsur, memandangkan kadar pulih semula tanah terganggu tersebut amat perlahan berbanding dengan matau sekunder dan jalan hutan sekunder. Penyelidikan masa depan seharusnya memberi tumpuan kepada mesin pembalakan dan sistem yang boleh mengurangkan kerosakan jalan gelungsur.

Introduction

The extent to which compacted soil will recover to its original natural condition depends on the soil type and the degree of compaction. Clay soils, which swell and shrink, may recover, or partly so, with subsequent wetting and drying. The most rapid rate of complete recovery so far reported was one year after tree-length skidding with rubber-tired skidders on relative dry, coarse-textured soil in Minnesota (Mace 1970). Ivanov (1976) found logging of spruce forest caused compaction and that restoration to original bulk density of semi-hydromorphic soils was 5 to 7 years. Hatchell *et al.* (1970) found no recovery one year after vehicular compaction in a loblolly pine forest, but reported that severely disturbed soils that had been logged over a 19-year period did recover slowly. In addition, they considered the average time of recovery for log decks and primary skid trails to be 18 years. Dickerson (1976) estimated that recovery of wheel-rutted and log-disturbed soils would take about 12 and 8 years respectively following tree-length skidding on soils ranging from loamy sand to silty clay loam in northern Mississippi.

Meaningful data on the rate of natural recovery of compacted forest soils in Peninsular Malaysia are lacking and such data are necessary to determine what extant preventive and curative measures are worthwhile. Therefore this study was designed to evaluate the rate of natural recovery of compacted, logged-over forest soils over a 10-year period in Sg. Tekam Forest Reserve Pahang, Malaysia.

Methods and material

Location and description of study area

Study plots were located in Sg. Tekam Forest Reserve, Pahang (Figure 1). Details of logging operations under a selective management system for each site are presented in Appendix A. The study area is located approximately between longitudes 102° and 103°E and latitudes 4° and 5°N , about 200 km northeast of Kuala Lumpur. The area, about 121 400 ha, is composed of mixed hill dipterocarp forest located 450 km above sea level. Slope gradient ranges from nearly level to 45°. Annual precipitation is approximately 210 cm, occurring mainly in April to May and November to December. Mean annual temperature ranges from 20 to 31°C. The principal soil occurring on the study site belongs to the Durian Series (Order Ultisol) (Kamaruzaman 1987). The texture of the soil ranges from sandy loam to clay loam.

Methodology

Prospects for recovery were evaluated in a synoptic survey by examining some soil physical properties (bulk density, total porosity, saturated hydraulic conductivity and penetrometer resistance) on disturbed and undisturbed portions of 11 areas logged during the dry season at various times during a 10-year period. Sampling work was done on all 11 areas at the same time.

Five plots of 30 m^2 area were randomly selected in each logging compartment to represent four soil disturbance sources: skid trail, secondary or bush landing, secondary forest road and undisturbed. A set of five plots within a logging compartment was clustered to minimise site variation, and the soil profile on each plot was examined to ensure that the soil type was the same. In each of the five plots in each disturbance source, eight samples were randomly taken for determinations of bulk density, total porosity and saturated hydraulic conductivity.

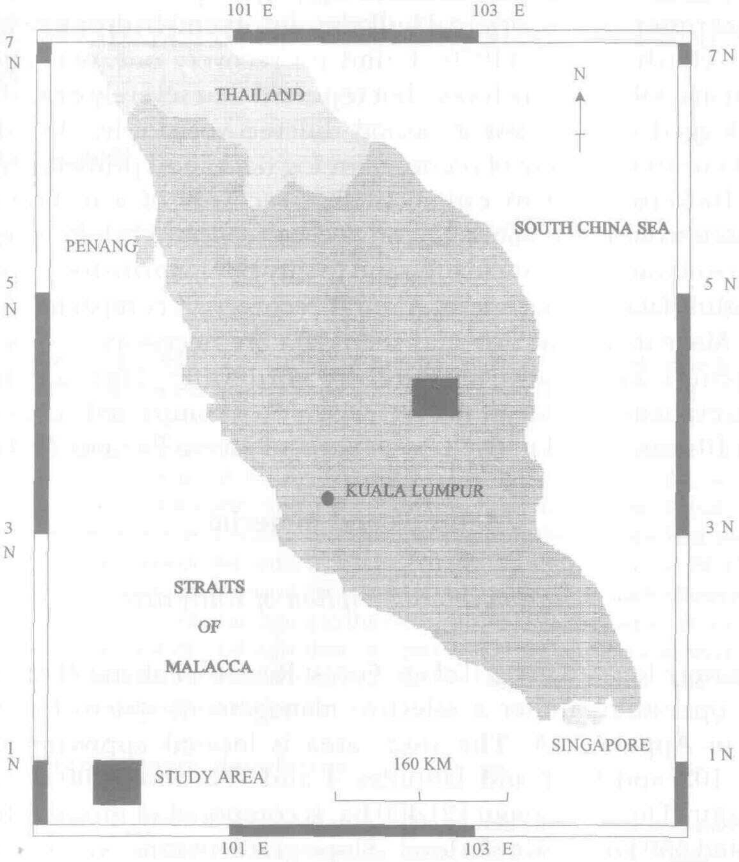

Figure 1. A map of Peninsular Malaysia showing the study area

Procedures and techniques were similar to those previously described for investigating logging disturbance (Kamaruzaman 1987). Metal core rings (181 cm^2) were used to determine bulk density, total porosity, and saturated hydraulic conductivity of surface soil of undisturbed soil, skid trail, landing and secondary forest road. A total of 10 determinations of penetrometer resistance were made in each plot with a pocket penetrometer at 0-15 cm depth after removing the organic matter. A total of 40 observations were made for each soil property (except 50 for penetration resistance) measured in each disturbance source for each year.

Sampling and measurement were repeated on sandy to clay loam surface soil on each plot in 11 logged areas (logged from 1975 to 1985) in April 1985. Recovery rates were predicted by regression analysis. In order to reduce the influence of annual variations in bulk density and total porosity, differences between the actual values of disturbed and undisturbed soil physical properties were analysed. Because of appreciable differences in permeability of various soil horizons, soil surface conditions and moisture content affecting saturated hydraulic conductivity (Baver 1956), evaluation of the trends towards recovery of saturated hydraulic conductivity was based upon the hydraulic conductivity of disturbed soils expressed as a proportion of that found on undisturbed soil. A linear relationship of recovery and time was assumed, and it was also assumed that all soils recover at the same rate.

Results and discussion

Bulk density

Except for soils under skid trails, a trend indicating a gradual recovery of disturbed soils with time was noted by plotting bulk density values in the disturbed soils versus time since logging (Figure 2). The linear relationships are significant at the 5 % level and evidently, the number of observations made (40) have provided a reliable estimate of recovery time on skid trail, bush landing and secondary forest road. Bulk densities for disturbed soils decreased sharply two years after logging, but increased gradually after three years and then decreased slowly after seven years and later (Table 1).

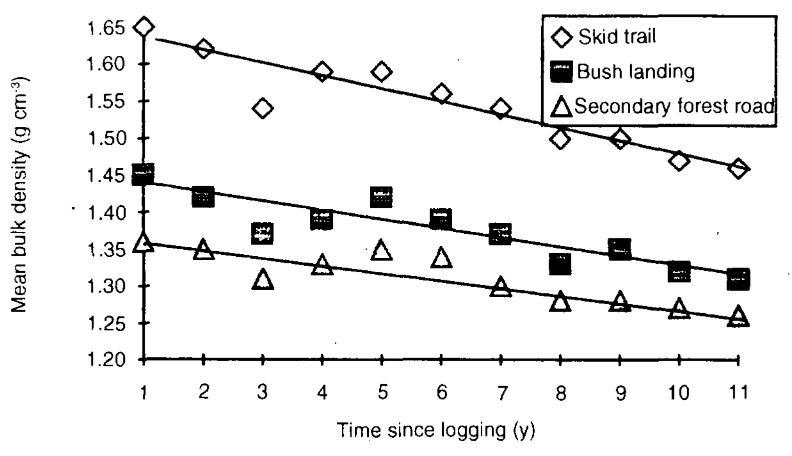

Figure 2. Recovery of mean bulk density on skid trail, bush landing and secondary forest road as related to time since logging. Lines are fitted visually to best fit.

The sharp decrease in bulk density two years after logging could be possibly due to the root decaying process which form small soil voids and the subsequent increase to the filling of such voids by roots of secondary vegetation. Ten years after logging, the average bulk densities of skid trail, bush landing and secondary forest road soils were 21, 8 and 4 % greater than the values of the undisturbed samples (Table 1). Partial recovery of soils under skid trails was not apparent during

Table 1. Mean bulk densities of surface soil following ground-based logging for a 10-year period[a]

Disturbance source	Year[b]											Linear regression equation	Covariance	Goodness of fit	Regression coefficient
	1985	1984	1983	1982	1981	1980	1979	1978	1977	1976	1975				
Skid trail	1.65 ± 0.01	1.62 ± 0.02	1.54 ± 0.02	1.59 ± 0.02	1.59 ± 0.02	1.56 ± 0.02	1.54 ± 0.02	1.50 ± 0.02	1.50 ± 0.02	1.47 ± 0.01	1.46 ± 0.01	Y = - 2.03R + 0.45	- 0.22	0.98	- 0.99[c]
Bush landing	1.45 ± 0.03	1.42 ± 0.02	1.37 ± 0.02	1.39 ± 0.02	1.42 ± 0.03	1.39 ± 0.02	1.37± 0.02	1.33 ± 0.01	1.35 ± 0.01	1.32 ± 0.02	1.31 ± 0.01	Y = - 1.51R + 2.25	- 0.17	0.98	0.99[c]
Secondary forest road	1.36 ± 0.04	1.35 ± 0.04	1.31 ± 0.02	1.33 ± 0.03	1.35 ± 0.02	1.34 ± 0.02	1.30 ± 0.02	1.28 ± 0.02	1.28 ± 0.02	1.27 ± 0.02	1.26 ± 0.01	Y = - 1.26R + 0.18	- 0.14	0.96	- 0.98[c]
Undisturbed	1.19 ± 0.01	1.19 ± 0.02	1.15 ± 0.01	1.18 ± 0.01	1.21 ± 0.02	1.21 ± 0.01	1.20 ± 0.01	1.19 ± 0.01	1.21 ± 0.02	1.20 ± 0.01	1.21 ± 0.02				

[a] Data are average of 40 samples ± standard deviation (in cm^{-3}).
[b] Year of logging for each of the 11 areas sampled.
[c] Significant at $p = 0.05$.

the 10-year period. However, partial recovery of compacted soils were evident during a 10-year period on soils of bush landing and secondary forest road. Initial bulk density values observed were significantly different ($p< 0.05$) for the aforementioned soils but not for soils under skid trails over the 10-year period.

'Moderately' disturbed soils such as those found on bush landing and secondary forest road, logged at various times over a 10-year period did recover slowly. However, severely disturbed soils below the skid trail showed a slow tendency to return to previous level over a 10-year period. The average time required for bulk density on skid trail to return to original density of undisturbed soils was estimated by regression analysis to be 22 years. On bush landing and secondary forest road, the recovery rates are 17 and 14 years respectively. Despite the high volume of the dipterocarp roots, soil faunal activity all year long and rapid decomposition of litter in the tropical forest, the recovery of disturbed soils is much slower in the tropical forest than in the temperate forest of North America. In addition, the large and heavy logs skidded by the logging machines and the high intensity of rainfall in the tropical forest undoubtedly cause serious soil compaction (Kamaruzaman 1987).

In North Mississippi, Duffy and McClurkin (1974) reported that initial bulk densities of 1.42 and 1.55 g cm^{-3} for log-disturbed and wheel-rutted soils, respectively could be detrimental to the establishment and growth of loblolly pine.

Total porosity

The average total porosities for disturbed soils were highest at 10 years after logging (Table 2). Ten years after skidding, the average total porosities of soils under the skid trail and bush landing were 18% and 7% respectively below those of the undisturbed samples. Secondary forest road had an average of 4% lower total porosity than the undisturbed soils.

Figure 3 shows the recovery of mean total porosity for the disturbed soils in relation to time. Assuming a linear relationship, total porosities of disturbed and undisturbed soils were observed to have a similar trend to that of bulk density linear model. However, soils under the skid trails would require two years longer to return to their original conditions, compared to only 22 years for bulk density of soils under the skid trail.

As in the case of bulk densities, the initial total porosities of disturbed soils could be detrimental to tree establishment and growth. For instance, gaseous diffusion becomes extremely limited when the volume of air-filled pores is less than 10-15 % (Smith & Wass 1994). The air pore space also affects the availability of certain nutrients both directly and indirectly. For example, under water-logged conditions, there is a reduction of iron and an increase in readily soluble phosphorus (Smith & Wass 1994).

Table 2. Mean total porosities of surface surface soil following ground-based logging for a 10-year period[a]

Disturbance source	Year[b] 1985	1984	1983	1982	1981	1980	1979	1978	1977	1976	1975	Linear regression equation	Covariance	Goodness of fit	Regression coefficient
Skid trail	37.53 ± 0.53	38.96 ± 0.62	41.85 ± 0.69	39.82 ± 0.75	39.82 ± 0.75	41.11 ± 0.74	41.85 ± 0.79	43.29 ± 0.57	43.29 ± 0.57	44.53 ± 0.55	44.87 ± 0.43	Y = 1.29R + 0.69	0.14	0.94	0.97[c]
Bush landing	45.30 ± 1.27	46.57 ± 0.78	48.12 ± 0.82	47.47 ± 0.88	46.59 ± 1.04	47.39 ± 0.80	48.13 ± 0.83	49.90 ± 0.48	48.92 ± 0.46	50.31 ± 0.77	50.75 ± 0.57	Y = 1.04R + 0.82	0.11	0.96	0.98[c]
Secondary forest road	48.58 ± 1.58	49.01 ± 1.52	50.69 ± 0.84	49.71 ± 1.13	49.14 ± 0.92	49.55 ± 0.80	50.80 ± 0.81	51.73 ± 1.16	51.72 ± 0.63	52.19 ± 0.64	52.35 ± 0.52	Y = 8.18R + 0.88	0.99	0.96	0.98[c]
Undisturbed	58.23 ± 0.81	55.23 ± 0.81	56.60 ± 0.76	55.40 ± 0.72	54.47 ± 0.85	54.48 ± 0.72	54.71 ± 0.56	55.08 ± 0.92	54.47 ± 0.67	54.87 ± 0.49	54.44 ± 0.72				

[a] Data are average of 40 samples ± standard deviation (in %).
[b] Year of logging for each of the 11 areas sampled.
[c] Significant at p = 0.05.

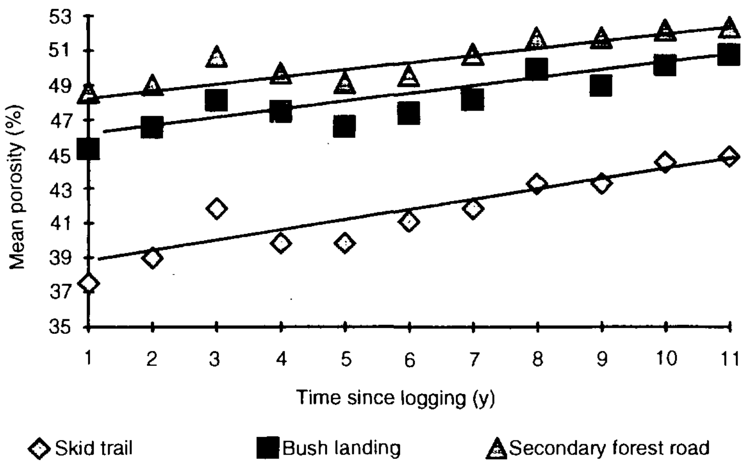

Figure 3. Recovery of mean total porosity on skid trail, bush landing and secondary forest road as related to time since logging. Lines are fitted visually to best fit.

Saturated hydraulic conductivity

Best fitted lines of mean saturated hydraulic conductivity in the disturbed soils were plotted over time since logging (Figure 4). Slight consistent trends toward recovery of saturated hydraulic conductivities on skid trails, bush landings or secondary forest roads are illustrated in Table 3. A much slower recovery of saturated hydraulic conductivity was found on skid trails while secondary forest roads show a relatively faster recovery. Bush landings have an intermediate period of recovery.

After the skid trail and bush landing had been abandoned for 10 years, the saturated hydraulic conductivities were 83 and 69 % respectively lower than that on undisturbed soil (Table 3). During the same period, secondary forest road had only 39 % lower saturated hydraulic conductivity than the of undisturbed soil.

If changes in mean saturated hydraulic conductivity in the disturbed soils remain linear, saturated hydraulic conductivity of soils under the skid track will approximate that of the undisturbed soils in about 52 years after logging. Bush landing and secondary forest road would require about 37 and 28 years respectively to return to their original conditions.

The slight trend towards complete recovery of saturated hydraulic conductivities on disturbed soils may be due to limited sampling points and this introduces a large sampling error (Table 3). Perhaps, the use of a double ring infiltrometer or increasing the number of samples would have substantially reduced the sampling error.

Table 3. Mean saturated hydraulic conductivities of surface soil following ground-based logging for a 10-year period[a]

Disturbance source	Year[b]											Linear regression equation	Covariance	Goodness of fit	Regression coefficient
	1985	1984	1983	1982	1981	1980	1979	1978	1977	1976	1975				
Skid trail	1.51 ± 0.30	2.06 ± 0.30	3.16 ± 0.64	5.76 ± 0.92	2.62 ± 0.64	5.62 ± 0.84	5.44 ± 1.03	7.69 ± 0.62	7.49 ± 0.46	7.70 ± 0.60	8.71 ± 0.55	Y = 1.83R + 4.41	0.20	0.87	0.93[c]
Bush landing	6.90 ± 0.94	9.06 ± 1.48	10.67 ± 1.41	11.92 ± 1.50	9.17 ± 1.40	10.53 ± 1.08	13.60 ± 1.22	14.57 ± 1.03	15.77 ± 0.85	17.69 ± 1.15	14.15 ± 1.08	Y = 2.14R + 2.10	0.24	0.94	0.97[c]
Secondary forest road	14.21 ± 1.09	16.89 ± 0.85	18.17 ± 0.95	17.27 ± 0.89	17.69 ± 0.75	17.55 ± 0.76	21.76 ± 0.78	23.08 ± 1.22	22.48 ± 0.81	25.23 ± 0.86	22.13 ± 0.66	Y = 2.15R + 0.41	0.21	0.89	0.94[c]
Undisturbed	34.50 ± 0.82	41.20 ± 0.75	39.50 ± 0.77	41.12 ± 0.70	32.76 ± 1.00	35.10 ± 0.79	38.86 ± 1.00	40.47 ± 0.78	39.43 ± 1.03	42.76 ± 0.80	36.28 ± 0.93				

[a] Data are average of 40 samples ± standard deviation (in cm h^{-1}).
[b] Year of logging for each of the 11 areas sampled.
[c] Significant at $p = 0.05$.

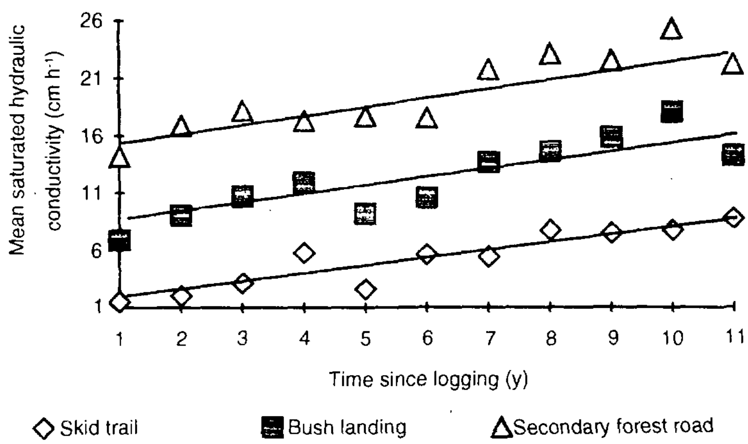

Figure 4. Recovery of mean saturated hydraulic conductivity on skid trail, bush landing and secondary forest road as related to time since logging. Lines are fitted to best fit.

Resistance to penetration

The average penetrometer resistance values for each disturbance source are shown in Table 4. Resistance to penetration values were lowest at 10 years after logging in each soil disturbance source. After 10 years of logging, the average penetrometer resistance of soils under the skid trails was about seven-fold higher than that of the undisturbed soil. For bush landing and secondary forest road, the resistances were four-fold higher than the penetrometer resistance of the undisturbed samples (Table 4). Differences in resistance to penetration between undisturbed and those of soils below skid trails, bush landings and secondary forest roads decreased with time (Figure 5).

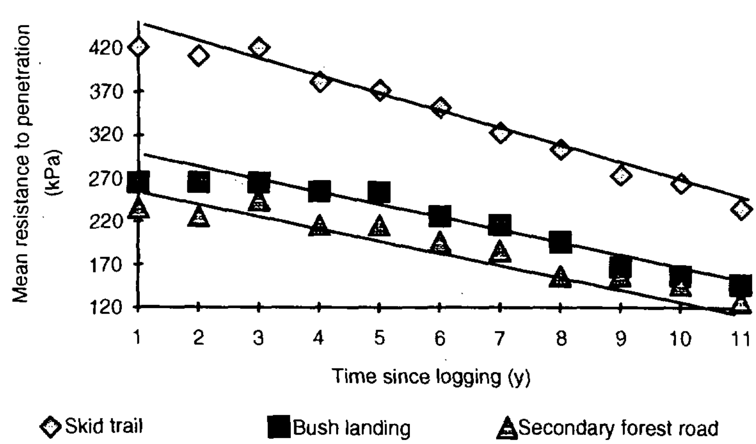

Figure 5. Recovery of mean resistance to penetration on skid trail, bush landing and secondary forest road as related to time since logging. Lines are fitted visually to best fit.

Table 4. Mean penetrometer resistances of surface soil following ground-based logging for a 10-year period[a]

Disturbance source	Year[b]											Linear regression equation	Covariance	Goodness of fit	Regression coefficient
	1985	1984	1983	1982	1981	1980	1979	1978	1977	1976	1975				
Skid trail	421.70 ± ± 16.67	411.89 ± ± 21.31	421.70 ± ± 18.49	382.47 ± ± 13.28	372.67 ± ± 19.86	353.05 ± ± 24.90	323.63 ± ± 20.18	304.02 ± ± 24.66	274.60 ± ± 19.61	264.79 ± ± 18.52	235.37 ± ± 26.07	Y = - 0.16R + 2.91	- 1.72	0.97	- 0.99[c]
Bush landing	264.79 ± ± 14.06	264.79 ± ± 14.62	264.79 ± ± 14.47	254.98 ± ± 14.76	254.18 ± ± 17.30	225.56 ± ± 15.37	215.75 ± ± 15.51	196.14 ± ± 16.01	166.72 ± ± 16.67	156.91 ± ± 12.23	147.11 ± ± 7.24	Y = - 0.96R + 1.33	- 1.06	0.98	- 0.99[c]
Secondary forest road	235.37 ± ± 10.54	225.56 ± ± 12.48	245.18 ± ± 15.85	215.75 ± ± 16.85	215.75 ± ± 18.75	196.14 ± ± 11.88	186.33 ± ± 15.47	156.91 ± ± 16.96	156.91 ± ± 15.88	147.11 ± ± 13.44	127.49 ± ± 16.70	Y = - 7.81R + 0.96	- 0.86	0.93	- 0.97[c]
Undisturbed	34.50 ± 9.47	41.20 ± 9.75	39.50 ± 12.40	41.12 ± 11.37	32.76 ± 11.13	35.10 ± 12.23	38.86 ± 10.13	40.47 ± 13.44	39.43 ± 10.13	42.76 ± 9.75	36.28 ± 9.30				

[a] Data are average of 40 samples ± standard deviation (in kPa).
[b] Year of logging for each of the 11 areas sampled.
[c] Significant at p = 0.05.

From the regression equations developed for each disturbed soil and assuming linear models, the resistance of soils on secondary forest road would require about 12 years to return to their original conditions. Soils under the skid trail would require a relatively longer time (19 years) to reach complete recovery compared to an intermediate rate of recovery (14 years) for soils on bush landings. The longer period for skid trail soils to recover from penetrometer resistance is because of its higher degree of compaction initially.

The small sampling error undoubtedly indicates that the number of probes made during the penetration test was adequate. It may appear that resistance to penetration (or soil strength) is another reliable indicator of recovery from soil compaction apart from bulk density.

This investigation was conducted with the assumption that any association of time since logging with the properties of disturbed soils, relative to those of undisturbed soils, could account for observed differences in soil properties, as time trends are related to the type of logging machine used in logging operations. Wheel or rubber-tired skidders were used on the older logging areas, while the later sites were recently logged with crawler tractors. Since track-type tractors are known to have a lower pressure on the soil, a shorter period of recovery than that indicated by the older logging areas may be required under current logging practices. Locating plots within soil disturbance source is subjective. Consequently, in this study many plots on skid trails, bush landings and secondary forest roads may not represent typical disturbed soil conditions. The differences in the number of vehicular trips or passes were unknown for the older plots. These were problems which could not be completely avoided in an attempt to provide some insight into the rate of natural recovery.

Although wetting and drying cycles have a role in the early stages of natural restoration, biological factors are likely to be far more effective. The actions of burrowing animals and insects and the gradual upheaving of soil by tree roots are commonly credited as forces altering the bulk density and macroporosity of the surface layer of forest soils. Allen (1985) reported that the pressure exerted by roots growing in non-aggregated soil is associated with aggregate formation with a consequent increase in pore space and reduction in bulk density.

Conclusion

Despite differences in the initial compaction level, the study showed that the soils under skid trails took a longer period to recover from soil compaction. Minimising the area covered by skid trails and tilling to loosen the soil are possible alternatives for retaining or restoring soil productivity. A more positive approach would be to encourage development or improve design of the logging machine with low bearing pressure using crawlers to minimise the degree of soil disturbance and compaction. It can be implied from this study that even after 10 years of logging, bulk density of soils under the skid trails would possibly interfere with adequate seedling survival and tree growth if species such as compensatory forest plantations species are planted in the tropical hill forest, assuming the other soil factors remain unchanged. It also appears that bulk density is a more reliable indicator of recovery rate from soil compaction.

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