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THE COMPACTABILITY OF NEW ZEALAND FOREST SOILS

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Fig. 1 - Extreme example of soil disturbance on a skidtrail crossing a clay soil. Note the great width of this skidtrail

INTRODUCTION

Agricultural engineers have long been so concerned about soil compaction caused by farming machinery that a large amount of research has been carried out on the relationship between agricultural soils and equipment used on them. Interest in the type of forest soil disturbance caused by logging equipment, and its consequences for tree growth, is comparatively recent.

Damage to the soil by agricultural machinery quickly becomes noticeable because of the short interval between harvests. With logging, the corresponding interval is long, which should be of advantage in allowing the soils to recover. Nevertheless, evidence is accumulating that harvesting-related soil disturbance can seriously depress tree growth. In North America, the figures reported for tree growth losses caused by soil disturbance range from 5% to 55% (Perry 1964; Moehring and Rawls 1970; Froehlich 1979). Evidence already exists in New Zealand that Pinus radiata planted on landings and skidtrails does not grow as well as on undisturbed areas (Ballard 1978; Murphy 1984).

Different soils react in different ways to harvesting traffic. Indeed the interaction between soils and machinery is complex, with characteristics such as soil moisture, organic matter content, soil texture, wheel load and size, slippage, tyre pressure, and vehicle vibration all affecting the type and severity of disturbance created. Soil disturbance (Fig. 1) caused by harvesting machinery takes three main forms:

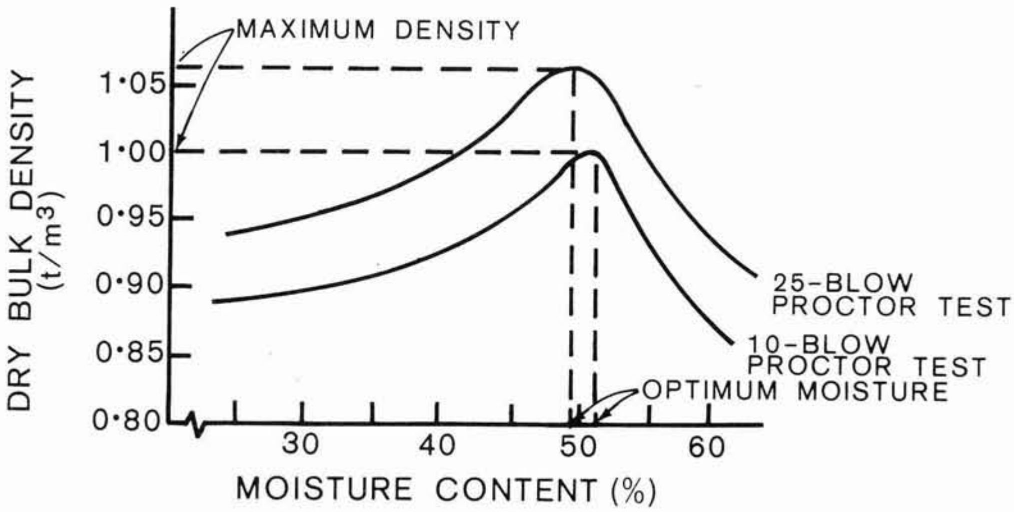
Perry, T.O. 1964 : Soil Compaction and loblolly pine growth. Tree Planters' Notes 67 : 9
Moehring, D.M. and I.K. Rawls 1970 : Detrimental effects of wet weather logging. Journal of Forestry 68 (3) : 166-7
Froehlich, H.A. 1979 : Soil compaction from logging equipment. Effects on growth of young ponderosa pine. Journal of Soil and Water Conservation 34 (6) : 276-8

- Compaction of the soil. This leads to increased bulk density and mechanical impedance to root growth, and to reduced aeration, infiltration, and mycorrhizal growth.
- Deformation of soil structure. This further reduces infiltration and leads to puddling of the topsoil.
- Removal of topsoil. This leads to reduced nutrient availability.

This Report deals primarily with the first of these.

STANDARD COMPACTION CURVES FOR NEW ZEALAND FOREST SOILS

Civil engineers for many years have used a testing procedure, commonly known as the Proctor test, to help obtain the maximum possible degree of compaction with the least expenditure of energy. The test is designed to determine the optimum soil wetness at which compaction of a given soil can be achieved most effectively by a given compactive effort.



SOURCE : Sidle, R.C. and D.M. Drlica (1981) Soil compaction from logging with a low-ground pressure skidder in the Oregon Coast Ranges. Soil Sci. Soc. Am. J. 45 : 1219-24

Fig. 2 - Example of effect of test conditions on a clay loam soil

Figure 2 illustrates the general trend for two levels of compactive effort. As soils become wetter, they compact progressively easier up to a point. That corresponding moisture content is the optimum for road building and other such activities. Beyond this point, it becomes progressively more difficult to compact the soil and the soil tends to puddle.

The reasons for the curve's shape are several. Interlocking of particles, particle-to-particle bonding, and frictional resistance prevent compaction in a dry soil. As the soil becomes wetter, the moisture films weaken the interparticle bonds, cause swelling, and reduce internal friction by lubricating the particles; allowing the particles to slide together and compact by squeezing out air. As soil nears saturation, there is very little air left to squeeze out, so soil compactability is limited. At saturation the non-compressibility of liquids prevents further compaction. However, it could be expected that logging machinery may sink and bog at this stage.

For each level of compactive effort there is a separate compaction curve. With higher compactive effort, the curve is shifted upward and leftward, indicating that a higher bulk density is attained at lower soil moisture contents.

Ballard, R. 1978 : Use of fertilisers at establishment of exotic forest plantations in New Zealand. N.Z. Journal of Forestry Science 8 : 70-104

Murphy, G. 1984 : Pinus radiata survival, growth, and form four years after planting on and off skidtrails. N.Z. Journal of Forestry 28 (2) : 184 - 193

TESTING OF NEW ZEALAND SOILS

Soil laboratories in New Zealand have adopted the New Zealand Standard Compaction test (NZS 4402) which is similar to the American standard; it uses a compactive effort of 27 blows on each of three layers with a 2.5 kg rammer dropped from a height of 300 mm. This laboratory test was used by the Forest Research Institute to examine soils collected from fifteen forest locations around New Zealand. The soils were selected, firstly , from forests which are currently being (or will shortly be) harvested and, secondly, to cover a range of soil texture types.

Considerable differences were found in the maximum bulk densities and the optimum moisture contents at which the maxima occurred. The shape of the compaction curves indicated the texture difference between sites.

Soils most at risk from compaction are clay soils with low organic matter contents, which display steeply peaked curves; with increasing sand and organic matter content soils become less susceptible to compaction and exhibit flat curves.

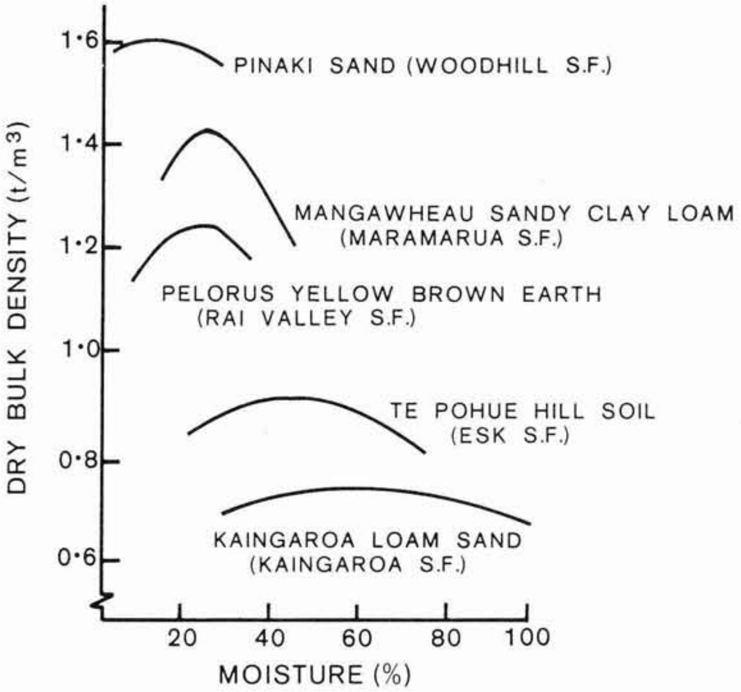


Fig. 3 - Examples of standard compaction curves for five forest soil types.

Figure 3 shows example curves for five forest soil types. Table I gives the test results for all fifteen soils analysed for the top two soil horizons (where applicable). As well as showing the optimum moisture content, Table 1 also gives a relative measure of compactability. We have used the term "compaction" index to indicate the difference between the dry bulk density at 10% moisture content and at the optimum moisture content for the standard compaction test; the lower the compaction index the greater the difficulty in creating large increases in bulk density. For example, the Pinaki sand (from Woodhill State forest) can be compacted only with difficulty, whereas the Mangawheau sandy clay loam hill soil (from Maramarua State forest) can be compacted with relative ease.

USE OF THE SOIL COMPACTION CURVES

Compaction curves have been used by some logging managers in North America to help make decisions about whether machines should be permitted to work at certain critical soil moisture conditions. However, in one recent American study (Froehlich et al. 1980) where actual compaction by normal ground extraction logging equipment was compared with that achieved by the laboratory Proctor test, it was found that the laboratory test was too severe and that as a result the moisture content at which maximum damage would have occurred was underpredicted. A modified version of the test with only 8% of the compactive effort provided a reasonable estimate of actual skidtrail densities after 20 round-trip passes with logging machines. That the standard compaction test gave erroneous results was not unexpected; the standard test is designed to show what you can do if you really try to compact the soil. Provided a logging manager recognises this difference, the compaction curves are still of considerable use; they give very strong indications of soils which are

New Zealand Standards (1981) - NZS 4402 Part 2 P - Soil Compaction and Soil Density Tests.
Froehlich, H.A.; Azevedo, J. : Cafferata, P. : and D. Lysne 1980: Predicting Soil Compaction on Forested Land. USDA, Forest Service, Equipment Development Centre, Missoula, Montana.

particularly sensitive to compaction and will help us to identify forest soils that need care at the time of logging. Where soil moisture measurements are difficult to obtain accurately, a conservative estimate of the soil conditions may be an advantage, particularly on very sensitive soils.

D.S.I.R. soil surveys and maps cover most of New Zealand. Soil type boundaries and descriptions of the soils tested and reported here can be easily obtained (Soil Bureau Bulletin 26 (3)). Forest managers, concerned about soils not reported here, could contact Soils and Site Amendment, Forest Research Institute, Rotorua.

Table 1 - N.Z. Standard Compaction Test Results for Selected Soils from 15 forests

Forest	Soil type*	Horizon**	Texture class	Optimum+ moisture content (%)	Compaction‡ index t/m³
Woodhill	Pinaki Sand	B	Sand	12	0.02
Kaingaroa	Kaingaroa loam	A	Sand	61	0.07
	sand	B	Sand	25	0.02
Mohaka	Tuai sandy loam	A	Loamy sand	59	0.10
		B	Sand	40	0.10
Esk	Te Pohue hill	A	Sand	42	0.07
	Soil	B	Sand	41	0.06
Long Mile	Arawa sandy	A	Sand	39	0.03
(FRI)	loam	B	Sand	30	0.16
Lismore	Pohangina	A	Sandy loam	30	0.13
	steepland soil	B	Silt loam	18	0.16
Eyrewell	Lismore yellow grey earth	B	Sandy loam	18	0.10
Tairua	Wharekawa soil	A	Loamy sand	52	0.05
	(podzolised)	B	Loamy sand	70	0.01
Mangatu	Wanstead clay	A	Sandy loam	37	0.10
	loam	B	Silt loam	24	0.15
Golden	Spooner yellow	A	Clay loam	24	0.15
Downs	brown earth	B	Clay loam	24	0.15
Conical	Kaikuku yellow	A	Clay loam	24	0.18
Hill	brown earth	B	Silt loam	19	0.12
Ngaumu	Ngaumu fine	A	Clay loam	32	0.16
	sandy loam	B	Clay	24	0.16
Riverhead	Waikarei	A	Clay loam	26	0.15
	silt clay loam	B	Silty clay loam	26	0.13
Rai Valley	Pelorus podzolised yellow brown earth	B	Clay loam	22	0.09
Maramarua	Mangawheau sandy	A	Silty clay loam	22	0.14
	clay loam hill soil	B	Silty clay	29	0.18

* Soil Bureau Bulletin 26 (3). Soils of New Zealand. Part 3
\+ The moisture content of maximum bulk density.
‡ Compaction index is the difference between dry bulk densities at 10% moisture content and optimum moisture content.
** A = Topsoil
B = Subsoil

CONCLUSIONS

There are considerable differences between forest soil types in their compactability as indicated by standard laboratory compaction tests. The standard test can be used as an indicative tool for determining expected soil compaction by ground extraction machinery. It should also provide useful information which will help forest managers to avoid seriously damaging the forest soil and possibly impairing future tree growth. Investigations are continuing at the Forest Research Institute to quantify the effect of various degrees of soil compaction on the growth of radiata pine.

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