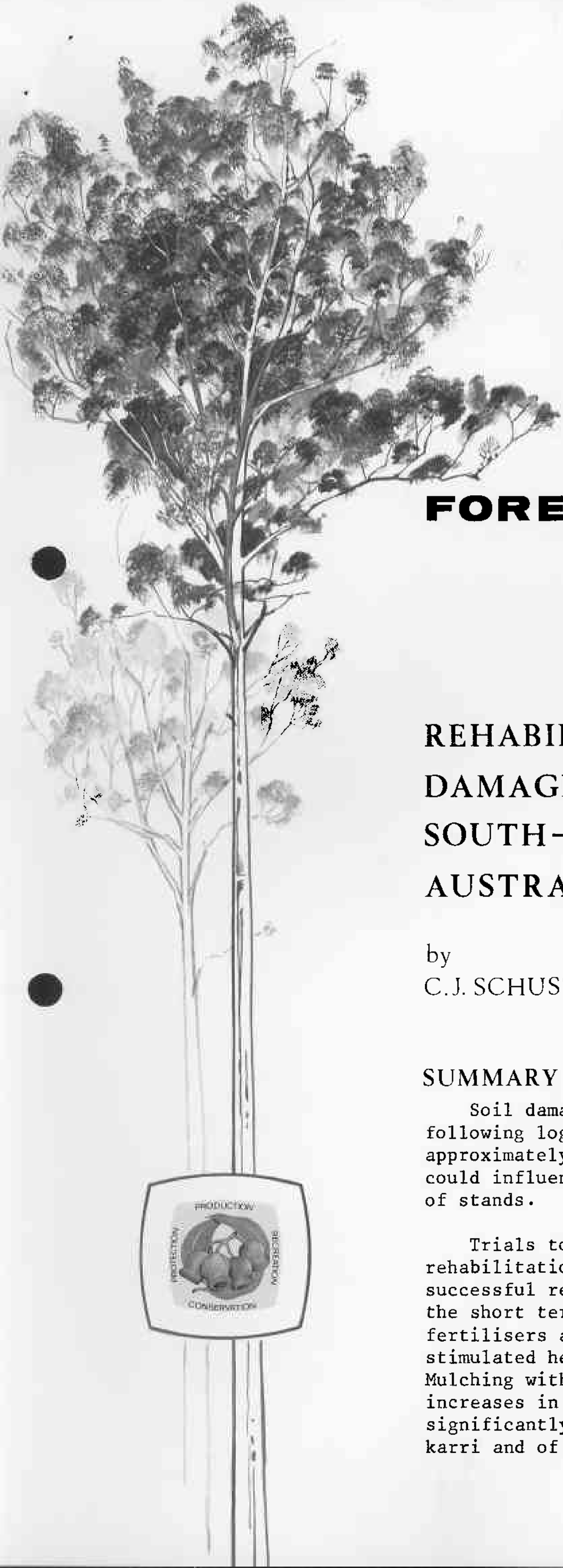

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REHABILITATION OF SOILS DAMAGED BY LOGGING IN SOUTH-WEST WESTERN AUSTRALIA

by
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SUMMARY

Soil damage (i.e. soil compaction and displacement) following logging, which may extend to a depth of approximately 40 cm in mixed karri and marri forest, could influence considerably the future productivity of stands.

Trials to monitor the effectiveness of various rehabilitation techniques on damaged sites indicate successful rehabilitation to be possible, at least in the short term. Deep soil ripping, the application of fertilisers and the formation of an ashbed all stimulated height growth increase in karri seedlings. Mulching with hammer-milled bark also produced slight increases in karri height growth. Deep soil ripping significantly improved the survival rate of planted karri and of a shrub species, *Acacia pulchella*.

INTRODUCTION

The area of pure karri (*Eucalyptus diversicolor* F. Muell.) stands being logged in Western Australia is decreasing whilst that of mixed karri-marri (*E. calophylla* R. Br. ex Lindl.) stands is steadily increasing. In the main these stands are found on podsolic duplex soils with heavy clay near the surface, type Dy3.62, as distinct from the deeper red loam soils of the pure karri stands, types Gn2.14 and Gn2.15 (McArthur and Clifton, 1975).

The process of logging appears to damage the podsolic soils more severely than the red loam soils, particularly during winter, when high soil moisture levels occur. This difference may be attributed not only to the differences between the physical properties of the two soils, but also to the higher intensity of logging of both karri and marri on podsolic soil sites compared with logging of pure karri on the red loam sites. Various authors (for example, Moehring and Rawls, 1970) have confirmed the increase in problems of compaction and soil displacement resulting from logging on wet soils.

The rehabilitation trials reported here were confined to the podsolic soil types since they are the more susceptible to damage. However, the results should be applicable to the red loam soil types also.

Effects of soil damage

Damage through logging activity degrades the structure of a soil, altering it physically and hindering normal plant growth. The soil changes include an increase in bulk density (Hatchell and Ralston, 1971) caused by compression of the soil, and a concomitant decrease in soil pore space. These result in reduced root growth (Aubertin and Kardos, 1965) and increased resistance to water infiltration (Sharda, 1977).

Furthermore, after puddling occurs on these soils, the clay brought to the surface may harden, making the site's nutrients unavailable to plant roots because of the impermeability of the soil aggregate.

The practical significance of soil damage through logging depends on its severity and on the proportion of the logged coupe affected. Up to 20 to 35% of the ground surface of a coupe may be disturbed by logging operations, but the proportion of this that could be classed as damaged varies with the season of logging and from site to site. In a survey of 60 logging coupes in the Piedmont region of the United States, Campbell *et al.*, (1973) found that, on average, 23% of a logging coupe was disturbed by logging with rubber-tyred skidders, and that 5 to 10% of the soils in the coupe undergo changes that could affect tree growth.

Concern as to the possible effects of soil damage on stand regeneration, aesthetics and future productivity prompted the initiation of research into soil rehabilitation methods. However, rehabilitation on a large scale is both expensive and difficult, and efforts are currently being made to reduce the amount of soil disturbance and damage through a modification of logging techniques.

Natural amelioration of soils

Various researchers have studied the processes of natural amelioration of compacted soils. The major agents of amelioration include wetting and drying cycles, freezing and thawing, plant root growth and soil fauna activity (Garner and Telfair, 1954; Hatchell and Ralston, 1971). However, not all of these are important factors in restoring the compacted soils of the karri forest.

Freezing and thawing are not relevant factors in Western Australia owing to the relatively mild winter seasons, and furthermore, as one of the studies described in this paper shows, root penetration into the compacted soils is very limited.

Studies made in other countries have shown that natural amelioration of soils damaged to the same degree as those in the karri forests may take from 20 to 40 years (Hatchell and Ralston, 1971).

Although natural amelioration may lead to recovery of both the soil and the understorey vegetation before the second rotation logging, it is unlikely that karri will establish itself because the species is intolerant of shade in its juvenile stages. Hence all sites may require some degree of rehabilitation for full tree stocking.

This paper reports the results of investigations into soil damage and of rehabilitation trials.

METHOD

Extent of soil compaction

A total of 16 soil cores were taken from two severely compacted and two non-compacted podsolic sites in the karri forest to determine the depths to which soil compaction caused by logging was evident. Bulk density was used as a measure of soil compaction.

Root growth in compacted soil

To compare root development on compacted and non-compacted sites, three karri trees growing on the edge of snig tracks in a ten-year-old regeneration area on a red loam soil type were selected. Root trenches were dug beside them into the compacted and non-compacted soils. The compacted soil was of similar bulk density to those compacted soils mentioned in the previous section of this paper.

Successive soil samples measuring 20 cm in depth, with a width of 15 cm and a length of 100 cm (total volume 0.03 m^3), were removed in successive stages to a depth of 120 cm from the cleaned face of each root trench closest to the sample tree. The sampled face in each case was approximately 1 m from the tree.

The samples were sieved on site using a 2 mm sieve, to separate all the live plant roots. These were then oven dried at 105°C.

Log landing rehabilitation trials

To determine the effectiveness of ripping in soil rehabilitation, a split plot factorial experiment was carried out on three compacted log landings on a podsolic soil type in Poole Block, approximately 30 km south of Manjimup. Logging had taken place eight years previously, and virtually no vegetation, except isolated shrub species, had established since then.

One half of each landing was ripped to a depth of approximately 1 m, and the other half was left compacted. Karri seedlings were then planted on each landing at a spacing of 3 m x 2 m, and the following treatments were applied.

(1) Bark mulch was spread to a radius of 15 cm around the stem, and to a depth of 5 cm. The mulch consisted of hammer-milled marri bark slivers, to which nitrogen in the form of ammonium nitrate was added at the rate of 0.0018 kg nitrogen (52 g of the commercial fertiliser "Agran") for each kilogram of air-dry bark. Water was then added to the bark to give a moisture content of 60%

The nitrogen was added firstly to encourage the growth of fungi and thereby promote the mulching process, and secondly to provide an immediate source of nitrogen for plant growth.

(2) A mixture of phosphorus and nitrogen fertilisers was applied at the rate of 60 g per plant (Christensen, 1974). The mixture consisted of superphosphate (22% P_2O_5) and urea (46% N) in a ratio of 5:1, to give an actual P:N ratio of 1:1.

(3) *Acacia pulchella* R. Br. seed was first boiled in water for two minutes and then spread at the rate of approximately 0.5 x 10^6 seeds per ha, in an attempt to provide a quickly established ground cover as well as a long-term supply of nitrogen for the karri seedlings (Shea and Kitt, 1976).

Snig track rehabilitation trials

Trials concerned with the rehabilitation of snig tracks were established in Sutton Block, approximately 30 km south-east of Manjimup. Combinations of the following treatments (four treatments in all) were applied to snig tracks.

(1) Deep ripping to a depth of approximately 1 m.

(2) Heaping and subsequent burning of logging debris over the snig tracks to provide an ashbed. Debris accumulation ranged from 1500 to 1900 $t \cdot ha^{-1}$ over the plots, and generally this was reduced by 60% after the burn.

Karri seedlings were then planted at a spacing of 2 m x 1 m, and their height, growth and survival were monitored.

After burning, estimates of seedfall were made using 1.2 m x 1.2 m seed trays, and the numbers of naturally regenerated karri seedlings and their height growth were monitored.

RESULTS

Extent of soil compaction

Figure 1 shows bulk density (as a measure of soil compaction) through the soil profile on damaged and undamaged sites.

Soil compaction extends to a depth of approximately 40 cm on a severely damaged site. On non-compacted sites the trend is for a steady increase in bulk density from 10 to 40 cm depth. At depths greater than this, soil bulk densities appear to be similar on damaged and undamaged sites. The bulk densities at only the 0 to 10 cm depth were significantly different at the 0.01 level.

Root growth in compacted soil

Compaction of the soil as a result of logging activity caused a marked decrease in root development (Fig. 2).

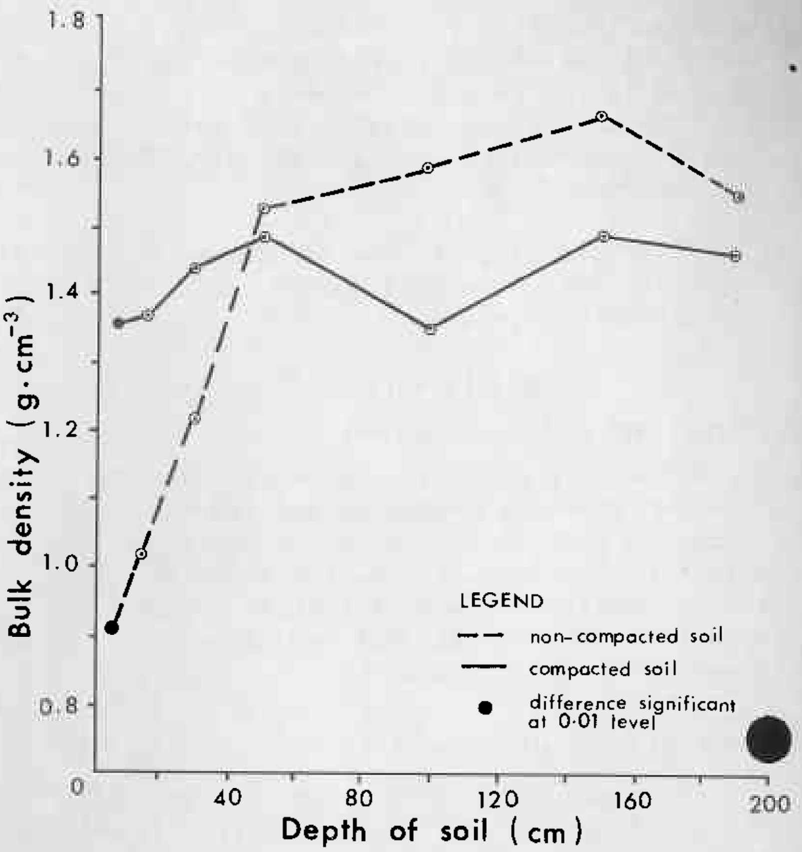

FIGURE 1: Mean bulk densities of compacted and non-compacted soils. (Significance of differences tested using Students t test).

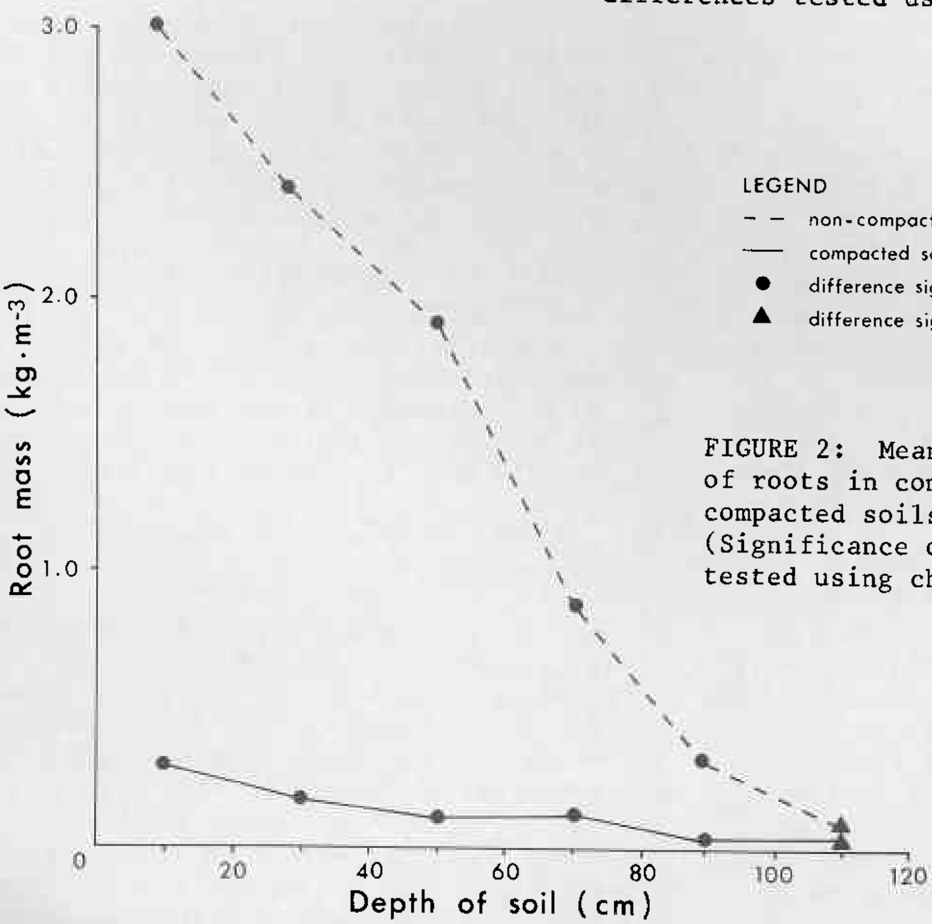

FIGURE 2: Mean oven-dry weights of roots in compacted and non-compacted soils. (Significance of differences tested using chi-square test).

The reduction in root growth in compacted soils compared with non-compacted soils was statistically significant at all depths sampled.

Since most fine plant roots are normally in the top 60 cm of the soil, compaction of this zone would clearly have a serious effect on plant growth.

Log landing rehabilitation trials

Height growth - Seedling heights were analysed by calculating 95% confidence intervals about the mean. Where the confidence intervals of a treatment do not overlap it is assumed there is a significant difference between the treatments.

The heights of karri seedlings subjected to the various treatments (ripping, bark mulching and fertiliser), measured at age two years, are compared in Table 1. Since analysis of the karri height data showed the effects of the presence of *A. pulchella* seedlings to be negligible, these data were grouped together with those for the plots not sown with *A. pulchella* to provide another replicate of every treatment combination.

Growth is promoted most effectively when ripping, fertiliser and bark mulching treatments are all applied. Ripping and fertilising each increase height growth individually, but mulching results in a trend towards better height growth only when in combination with the other two treatments.

Survival - If soil rehabilitation is to be undertaken operationally, a satisfactory rate of plant survival must be obtained as well as satisfactory growth. The plant survival counts for the Poole Block trials are expressed in Table 2 as confidence intervals of percentages.

Ripping was the only treatment to increase survival ($p = 0.05$). Both fertilising and mulching tended to decrease seedling survival slightly, perhaps because of an excess of nitrogen fertiliser applied at the base of the plants. All treatments, however, resulted in survival rates that are acceptable when compared with those obtained in normal Forests Department regeneration plantings. The sowing of *A. pulchella* seed was shown to have no effect on karri survival, and consequently was not included in this table.

TABLE 1

Height growth (cm) of karri seedlings under various treatments on compacted log landings

	R_0	R_1
F_0M_0	45.5 ± 7.6*a	73.8 ± 14.8 b
F_0M_1	48.3 ± 20.1 ab	67.7 ± 14.4 b
F_1M_0	75.6 ± 22.0 bc	157.7 ± 11.1 d
F_1M_1	135.7 ± 41.8 cd	195.7 ± 59.7 d

F = fertiliser R = ripping 1 = present
M = mulching 0 = absent
*denotes a 90% confidence interval about the mean
Data notated with the same letter are not significantly different at $p = 0.05$

TABLE 2

Percentage survival of karri on compacted log landings

Treatment	0	1	Significance
R	92.9 ± 1.8*	97.8 ± 1.0	0.05
M	97.3 ± 1.1	93.7 ± 1.6	0.05
F	97.3 ± 1.1	93.5 ± 1.8	0.05

F = fertiliser R = ripping 1 = present
M = mulching 0 = absent
* denotes a 90% confidence interval about the mean

Seed germination - The germination and survival rates of *A. pulchella* on the log landings are indicated in Table 3 by the figure given as plant per cent, which is the percentage of seeds sown that develop into one-year-old plants.

TABLE 3

Plant per cent of *A. pulchella* on ripped and unripped log landings

	R_o	R_1
Plant per cent	2.46	3.77

R = ripping o = absent 1 = present
Data significantly different at p = 0.01

Clearly, if the artificial regeneration of log landings with shrub species is to be considered, then ripping of the sites is necessary to increase the rate of germination and survival.

Snig track rehabilitation trials

Height growth - The figures for height growth (at age two years) for planted and naturally regenerated seedlings on snig tracks treated with combinations of ripping and debris heaping and burning are shown in Tables 4 and 5.

For karri height growth, similar results were obtained in both the log landing trials and the snig track trials. On the snig tracks, both ripping and debris heaping and burning greatly increased height growth over that for the untreated control.

TABLE 4

Height growth (cm) of planted karri on snig tracks

	R_o	R_1
B_o	50.2 ± 9.6* a	80.1 ± 6.9 b
B_1	123.4 ± 35.1 c	166.9 ± 28.9 c

R = ripping o = absent 1 = present
B = debris heaping and burning
* indicates a 95% confidence interval about the mean
Data notated with the same letter are not significantly different at p = 0.05

TABLE 5

Height growth (cm) of naturally regenerated karri on snig tracks

	R_o	R_1
B_o	24.0 ± 10.6*a	96.7 ± 22.7 b
B_1	206.7 ± 118.0 bc	330.8 ± 93.8 c

R = ripping o = absent 1 = present
B = debris heaping and burning
* indicates a 95% confidence interval about the mean
Data notated with the same letter are not significantly different at p = 0.05

Ripping by itself was also effective. However, the two treatments combined produced large increases in growth for both planted and naturally regenerated seedlings.

Survival - The survival rates for planted karri and the plant per cent of the naturally regenerated karri in the snig track trials are shown in Table 6.

Ripping the compacted areas increases both the percentage survival of planted seedlings and the plant per cent for natural regeneration in comparison with the untreated controls. The debris heaping and burning technique tends to decrease the survival rate of planted stock when compared with survival on the sites that were ripped only.

Both ripping alone and the combination of both treatments gave operationally acceptable survival rates.

DISCUSSION

The results presented in this paper show logging to have some detrimental effects on podsolic soils in the karri forest. These effects must be seen in perspective, however, since even wet-weather logging disturbs only 20 to 35% of a coupe. Damage to this extent is nevertheless likely to result in regeneration difficulties, loss of productivity and aesthetic degradation of stands.

Although improved logging techniques may reduce the problem to some extent, logging on wet podsolic soils will always

TABLE 6

Percentage survival of planted karri and plant per cent of naturally regenerated karri on snig tracks

	R_oB_o	R_oB_1	R_1B_o	R_1B_1
Survival, planted karri	75 ± 8*a	67 ± 11 a	91 ± 3 b	80 ± 8 ab
Plant per cent, naturally regenerated karri	0.15 a	5.86 b	7.55 b	6.73 b

R = ripping o = absent 1 = present B = debris heaping and burning
* indicates a 90% confidence interval about the mean
Data notated with the same letter are not significantly different at p = 0.01 for both survival and plant per cent

result in some deterioration of site quality unless suitable rehabilitation techniques are used. These trials indicate that successful rehabilitation of damaged soils is possible, at least in the short term (to two years of age).

All the treatments applied during the trials on both log landings and snig tracks resulted in satisfactory plant survival rates. However, optimum early growth was achieved in each case only by using a combination of all the experimental treatments.

The good height growth sustained in the snig track plots that had been subjected only to debris heaping and burning may be a short-term effect. Burning releases a flush of nutrients into the topsoil (Hatch, 1960), and it is possible that this is sustaining the good early growth of karri on these plots.

In any case, the trials have shown that root penetration of these severely compacted soils is very limited, and problems resulting from both water stress and soil penetration difficulties may occur as these trees, growing older, place a greater strain on their environment.

CONCLUSION

Successful rehabilitation of soils damaged by logging activity is possible, to two years of age, using both tree and understorey species. The most successful rehabilitation technique is the application to damaged areas of a combination of soil ripping, fertilising and bark mulching, or if possible of soil ripping and the redistribution and burning of logging debris.

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