

Report on SPP 95/0002

May 1996

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Emergence, survival and initial growth of karri (*Eucalyptus diversicolor*) on compacted and uncompacted soils

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SUMMARY

The emergence, survival and initial height growth of karri on uncompacted soil and on soil that had been compacted during timber harvesting operations were studied at two sites west of Manjimup, WA. Soil compaction was quantified in terms of shear strength using a vane tester. Quadrats on compacted and uncompacted soils were sown with karri seed in early May 1995 and monitored to determine emergence and survival during the following six months. A sub-sample of quadrats were protected with insecticide barriers to investigate the extent of seed loss due to harvesting by ants and other ground-dwelling invertebrates. Seedling emergence was very low, averaging only 4.1 per cent at Lindsay and 1.6 per cent at Graphite. Soil compaction had no statistically significant effect on emergence. Seven months after sowing 67 per cent of seedlings at Lindsay and 42 per cent of seedlings at Graphite were still alive. Only a few seedlings died over the summer and autumn months, despite below-average rainfall during this period.

Because of the very low emergence of sown seed during this study no firm conclusions can be drawn regarding the effects of soil compaction on emergence and survival. The limited data available on seedling growth indicated that the height of one-year-old seedlings was independent of soil compaction up to shear strengths of 70 kPa, which is more than four times the strength of uncompacted soil. The most likely explanation for the poor emergence is that seed was washed from some quadrats and buried too deeply for successful germination, or moved too far away from quadrats for emergents to be detected. To overcome this problem in future studies, seed could be broadcast over a larger area in order that seed losses from particular microsites might be compensated for by seed redistributed from other areas. However, broadcast sowing has the disadvantage that actual seeding rates on particular microsites, such as compacted soils, cannot be accurately controlled. Comparison of emergence on different seedbed types would therefore only be possible in general terms.

INTRODUCTION

Soil disturbance during timber harvesting operations can affect the establishment and growth of tree and understorey species. Light mechanical disturbance of the litter layer and surface soil may encourage the establishment of seedlings of many eucalypts, including karri (*Eucalyptus diversicolor*) (Breidahl and Hewett 1995). In some forest types, such as dry forests of silvertop ash (*Eucalyptus sieberi*) in south-eastern Australia, mechanical disturbance alone is sufficient to ensure successful regeneration after logging (Bridges 1983). More severe forms of soil disturbance which can occur during harvesting operations include compaction in-situ, gouging, puddling and mixing of soil profiles (Wronski 1984, Williamson 1990, Lacey 1993, Lacey *et al.* 1994). Severe forms of disturbance have been shown to adversely affect the growth of regenerating stands (Schuster 1979, Williamson 1990, Rab 1992, 1994, Maher 1993) and in extreme cases, disturbance may be so great as to prevent any effective regeneration. The effects of soil compaction can be ameliorated to some extent by ripping, and Schuster (1979) demonstrated that ripping improved the survival and growth of karri on log landings and snig tracks. Ripping does, however, represent an additional cost that could be avoided in most circumstances by restricting harvesting operations to dry weather conditions when soils do not become seriously compacted by trafficking.

Restrictions have been imposed on the extent of soil damage acceptable during harvesting operations (Dept. CALM 1996). In this context damage has been defined as removal of topsoil (A horizon), mixing of the topsoil and the subsoil (B horizon) which usually contains a high clay component, severe compaction that will affect germination or growth of plants, or a mixture of these effects. During the course of harvesting operations logging coupes and fallers blocks are surveyed to assess the extent of soil damage, and operations are halted if the specified damage threshold is exceeded. Topsoil removal and mixing of soil horizons can be readily recognised in the field, but compacted soil can be more difficult to identify particularly if it is not associated with landings and major snig tracks. Compaction can be quantified in terms of bulk density, penetration resistance and shear strength but the relationship between these variables and plant growth has not been widely investigated in Australia (Rab 1992, Lacey 1993). It is conceivable that even relatively superficial compaction of the topsoil may reduce its receptivity as a seed bed.

This report describes an experiment conducted as part of a study intended to quantify the limits of acceptable change to soil attributes during timber harvesting operations. The main hypothesis tested by the experiment was that soil compaction, as measured by soil shear strength, reduces the emergence, survival and growth of karri from seed. A secondary hypothesis tested during the experiment was that insect harvesting reduces the quantity of seed available for germination.

METHODS

Study areas

The experiment was replicated at two sites (Lindsay block Compartment 32 and Graphite block Compartment 5) located respectively 15 km and 25 km west of Manjimup. At both sites tall open forest of karri and marri (*Eucalyptus calophylla*) had been clearfelled in winter 1994 without retention of seed trees, and then burnt in April 1995 to remove logging slash in preparation for planting. The stand at Lindsay contained both mature trees and regrowth approximately 50 years old, and smaller trees were harvested with a rubber-tyred forwarder prior to the final cut. At Graphite the stand consisted largely of mature trees which were harvested with a rubber-tyred skidder.

Both sites were on the Crowea landform unit of Churchward (1992) which comprises broadly convex ridge crests and the flanks of gentle upper slopes and ridges. Elevation ranged from about 200 m ASL at Graphite to 260 m ASL at Lindsay. Churchward (1992) mapped the soils at Lindsay as the brown sub-unit of the Crowea landform, characterised by a brown, gravelly A horizon up to 1 m deep above a mottled clay B horizon with a dominant hue of 7.5YR (Dy2.61, Dy2.62). Soils at Graphite were mapped as the yellow sub-unit which has a pale grey-brown sandy loam A horizon up to 0.4 m thick above a mottled yellow to grey clay horizon with a general hue of 10YR.

Experimental Procedures

On 26 April 1995 a series of 24 1 m x 1 m quadrats were demarcated at each site. Twelve quadrats were located on soil that had been undisturbed by machine traffic, and the other 12 on soil that had been compacted by machine traffic, but not displaced or puddled. This level of disturbance corresponds to the Secondary damage category defined by Wronski (1984) and Williamson (1990). Quadrats were located on ground from which all leaf litter and woody debris had been removed by the post-harvest burn, but none were on deep mineral ashbed. Steel fence droppers and wire pins were used to mark quadrat locations.

At the time of demarcation, soil shear strength was measured in the top 5 cm of the A horizon with a GEONOR vane tester. Measurements were made in the four corners of each quadrat to avoid disturbing the seedbed. Readings that were obviously affected by fine roots, or that were considered unreliable because of soil fracture during insertion of the vane were repeated to obtain a consistent value representative of the overall seedbed condition within the quadrat. For undisturbed soils at both sites the largest of the test vanes was used (factor x 0.5), while for compacted soils the intermediate vane (factor x 1) was used at Lindsay and the smallest vane (factor x 2) was used at Graphite. The use of the smallest vane was necessitated by the generally greater level of compaction at Graphite. Soil shear strengths were measured in units of kPa. Samples of the top 5 cm of soil were also collected for moisture content determination. Samples were initially screened to remove any large fragments of charcoal or roots, oven dried at 105°C for 24 hours,

and then sieved through a 2 mm mesh to separate the gravel fraction. Gravimetric moisture contents were calculated for the non-gravel fraction of the soil.

On 28 April half the quadrats from each class of soil disturbance at each site had a 0.3 m wide buffer strip sprayed around them with chlorpyrifos insecticide (Trade name DURSABAN) to discourage seed harvesting by ants and other ground-dwelling invertebrates. Application rate was 3 l per 10 m² of ground area with a dilute solution containing 50 ml of DURSABAN in 10 l of water.

One hundred karri seed were sown in each quadrat on 2 May 1995. The seedlot used was 92025, collected from Graphite 6 compartment. Laboratory tests conducted by the Department of Conservation and Land Management Seed Centre indicated 72 per cent viability for this seedlot. Weather conditions at the time of sowing were cool (16-18°C), clear and dry with a moderate strength southerly breeze. The only live vegetation apparent at either site at the time of sowing were occasional emerging fronds of bracken (*Pteridium esculentum*) or zamia palm (*Macrozamia reidli*), and pyrophilous fungi.

Quadrats were inspected weekly during June, July and August and then at three to five week intervals up to 21 December to monitor seedling emergence and survival. Seedlings were considered to have emerged once their cotyledons had unfolded and were visible from 0.5 m, consistent with the procedure employed by Stoneman (1994). Individual seedlings were marked with coloured sticks so that cohorts from different germination events could be distinguished. Early in the course of the experiment it became apparent that seed had been washed from some quadrats and re-distributed on the soil surface or buried. Seedlings which emerged outside of quadrats could only have originated from the artificially-sown seed as no seed trees had been retained at either site, and the quadrats were placed far enough away from uncut forest to make seed dispersal from this source unlikely. Seedlings which emerged outside of quadrats were recorded if it was clear which quadrat they had originated from. Quadrats were re-assessed on 20 May 1996 and the height to growing tip measured on all surviving seedlings.

The proportion of seed which emerged during the course of the experiment was calculated from the known number of seed sown (2400) at each site. Seedlings which emerged both inside and outside of demarcated quadrats were included in this figure, as to have considered only those within quadrats would have substantially under-estimated the total numbers of seedlings at each site. However, seedlings which emerged outside of quadrats were excluded from the data set used to compare emergence and height growth on uncompacted and compacted soils, because the condition of the seedbed on which these seedlings occurred was not quantified. The effects of soil compaction and insecticide barriers on emergence were tested using two factor analysis of variance. Emergence data were normalised by log transformation prior to analysis.

A storage rain gauge was established at Graphite on 2 May but stolen from the site on 16 May. Storage rain gauges were subsequently placed at both sites on 2 June, although the replacement gauge at Graphite was also stolen in September. Gauges

were read in conjunction with assessments of seedling emergence. Total rainfall from 2 July to 31 August was 527 mm at Lindsay and 524 mm at Graphite. A further 256 mm was recorded to 21 December at Lindsay. Rainfall during the summer and autumn period was well below average throughout the district, with only 59 mm recorded at Manjimup between 1 January to 30 April compared to the long term average of 123 mm.

RESULTS

Soil shear strength

Soil shear strength was measured prior to the commencement of the winter rains, and consequently the topsoil was still relatively dry, with mean moisture contents of 9 per cent at Lindsay and 7 per cent at Graphite (Table 1). The shear strength of uncompacted soils at both sites was similar (12-15 kPa), but compacted soils were on average almost twice as strong at Graphite as at Lindsay (Table 1). Compacted soils at Graphite also exhibited much greater variability in shear strength than did compacted soils at Lindsay. The highest average (mean of four measurements) shear strength for a quadrat was 91 kPa at Lindsay and 167 kPa at Graphite, and individual measurements indicated shear strengths of up to 260 kPa on the most compacted soils.

TABLE 1 NEAR HERE

Seedling emergence, survival and growth

The proportion of sown seed which emerged was very low, averaging only 4.1 per cent at Lindsay and 1.6 per cent at Graphite. Seedbed compactness and insecticide barriers had no statistically significant effect on emergence at either site (Table 2).

TABLE 2 NEAR HERE

First emergents were recorded at both sites in mid-June (Day 50 after sowing), and the number of emergents increased steadily during July (Fig. 1). From late July (Day 79) to late August (Day 121) no further seedlings emerged, and some of those which had emerged died. Mortality was mainly due to localised waterlogging and to deposition of soil on small germinants following heavy rain. A further cohort of seedlings emerged during September and October (Days 121-171 after sowing).

Seven months after sowing survival of emergents was 67 per cent at Lindsay but only 42 per cent at Graphite. Corresponding figures for one year after sowing were 61 per cent and 39 per cent respectively. Mortality during summer and autumn was therefore quite low, despite below average rainfall.

The height of surviving seedlings at Lindsay one year after sowing was plotted in relation to the average soil shear strength measured on the quadrats in which seedlings occurred (Fig. 2). The mean height of seedlings on uncompacted soil (296 cm, $n=7$) was very similar to that of seedlings on compacted soil (284 cm, $n=22$) and

seedlings exhibited comparable variation in height range on both categories of seedbed. The compacted soils had average shear strengths up to 70 kPa. There were too few seedlings within quadrats at Graphite to warrant analysis of height growth.

DISCUSSION

Emergence of seed sown at Lindsay and Graphite (4.5 & 1.6 per cent respectively) was lower than expected from the results of previous studies of direct seeding in comparable circumstances. Christensen and Schuster (1979) reported that emergence of seed sown in autumn on clearfelled coupes averaged 7.6 (range 5.4-9.7) per cent on red loam soils and 7.0 (range 3.9-10.2) per cent on yellow podzolic soils, while Loneragan (1979) reported emergence of 7-32 per cent on favourable seedbeds following autumn sowing. Gartrell (1993) reported emergence of 23-26 per cent for karri seed sown in May in rehabilitated bauxite pits and in jarrah forest near Dwellingup.

In contrast to the low emergence observed in the experimentally-sown quadrats, a clearfelled coupe immediately adjacent to the study site at Graphite was successfully regenerated from seed trees following post-harvest burning in 1995, with 83 per cent of survey points stocked to at least 1666 seedlings ha^{-1} and 50 per cent stocked to greater than 3000 seedlings ha^{-1} after six months (D. Maher, pers. comm., May 1996). This suggests that the poor results of the experimental sowing were due to factors other than seasonal conditions.

The success of emergence following direct seeding may be influenced by a variety of factors including the sowing rate and technique, and the extent of seed losses due to insects, fungi, or other types of physical damage. High sowing rates may lead to better percentage emergence through predator satiation (O'Dowd and Gill 1984), although it is questionable whether this mechanism could be invoked in the case of small quadrats where the seed is concentrated in a very localised area. The sowing rate used in this study (100 m^{-2}) was selected to represent the seedfall likely to occur from retained karri seed trees following a high intensity regeneration burn. This rate was arrived at by adding an arbitrary margin of approximately 20 per cent to the average seedfall (82 seed m^{-2}) reported from an operational scale trial of karri regeneration techniques (White 1971). Sowing rates used in small plot experiments by Christensen and Schuster (1979) and Gartrell (1993) were considerably higher (250 m^{-2} and 250 m^{-2} respectively). Light raking of the seedbed following sowing would also tend to improve the success of emergence by reducing the extent of seed harvesting and re-distribution following rain (Stoneman and Dell 1994), and probably contributed to the relatively high level of emergence reported by Gartrell (1993). No attempt was made to alter the condition of the seedbeds in this experiment because it would have conflicted with the primary aim of comparing the receptivity of uncompacted and compacted soils.

Losses due to insects have been shown to substantially reduce the level of seed emergence of eucalypts in tall open forests including karri (Christensen and Schuster

1980) and mountain ash (*Eucalyptus regnans*) (Cunningham 1960). The lack of any effect of insecticide barriers in the present experiment suggests that some other factor was primarily responsible for seed loss. Vertebrates have been shown to be responsible for substantial seed harvesting in jarrah forest (Stoneman and Dell 1994), but their role as seed harvesters in clearfelled karri forest has not been investigated. However, it is reasonable to assume that the relatively small size of karri seed and the dark colour of the seedbed following the post-harvest burn would limit the extent of losses due to vertebrates.

The most likely explanation for the poor emergence is that seed was washed from quadrats and buried too deeply for successful germination, or moved too far away from quadrats for emergents to be detected. To overcome this problem in future studies, seed could be broadcast over a larger area in order that seed losses from particular microsites might be compensated for by seed redistributed from other areas. However, broadcast sowing has the disadvantage that actual seeding rates on particular microsites, such as compacted soils, cannot be accurately controlled. Comparison of emergence on different seedbed types would therefore only be possible in general terms.

The limited data available on seedling growth at Lindsay indicated that the height of one-year-old seedlings was independent of soil compaction up to shear strengths of 70 kPa, which is more than four times the strength of uncompacted soil. Increased soil bulk density caused by compaction during harvesting operations has been shown to reduce the height and diameter growth of seeded mountain ash (Rab 1994) and the height growth of planted karri seedlings (Maher 1993). Different techniques were employed to quantify soil compaction in each study, preventing direct comparison of the results. The original intention was to measure soil bulk density on each quadrat in this experiment, but in view of the poor emergence and low number of seedlings this was not warranted. A possible explanation for the lack of any obvious effect of compaction on height growth in this study is that the relationship between soil strength (or bulk density) and plant growth is not linear, and instead is characterised by a threshold level below which growth is unaffected.

Williamson (1990) noted that although bulk density and soil strength were generally higher on soil profiles disturbed during logging, there was no clear indication of which physical factors were most significant in reducing stocking and growth. He concluded, on the basis of both field studies and glasshouse experiments, that reduced growth was not solely due to compaction, and that displacement or mixing of surface soil horizons was more significant.

CONCLUSION

Because of the very low emergence of sown seed, no firm conclusions should be drawn from this study regarding the effects of soil compaction on emergence and survival. Although limited, the data available from this study indicated that the growth of karri seedlings was not adversely affected by moderate levels of soil

compaction. However, this conclusion should only be regarded as tentative until tested with a more extensive set of observations.

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TABLE 1

Shear strength and moisture content of uncompacted and compacted soils at Lindsay and Graphite blocks on 26 April 1995. Data are means with standard deviations shown in brackets.

SOIL ATTRIBUTE	LINDSAY	GRAPHITE
Shear strength (kPa)		
- uncompacted soil	12 (3)	15 (5)
- compacted soil	56 (23)	102 (65)
Moisture content (%)	9 (4)	7 (3)

TABLE 2

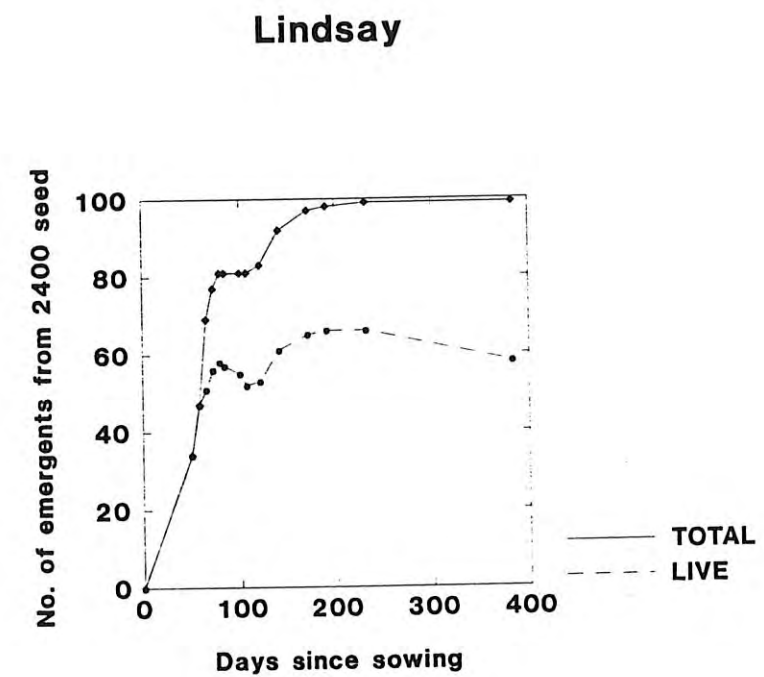
Total number of emergents from 100 seed sown per 1 m² quadrat on uncompacted and compacted seedbeds, with or without insecticide barriers. Data are means for six quadrats with standard deviations shown in brackets. Within each site, none of the means were found to be significantly different ($p < 0.05$) using two factor analysis of variance.

TREATMENT	LINDSAY	GRAPHITE
Uncompacted/ - insecticide	3.2 (3.0)	1.8 (1.7)
Uncompacted/ + insecticide	2.7 (1.5)	2.7 (2.1)
Compacted/ - insecticide	4.3 (3.2)	0.8 (1.6)
Compacted/ + insecticide	6.2 (6.1)	0.8 (0.8)
Mean for all seedbed types	4.1 (3.8)	1.6 (1.7)

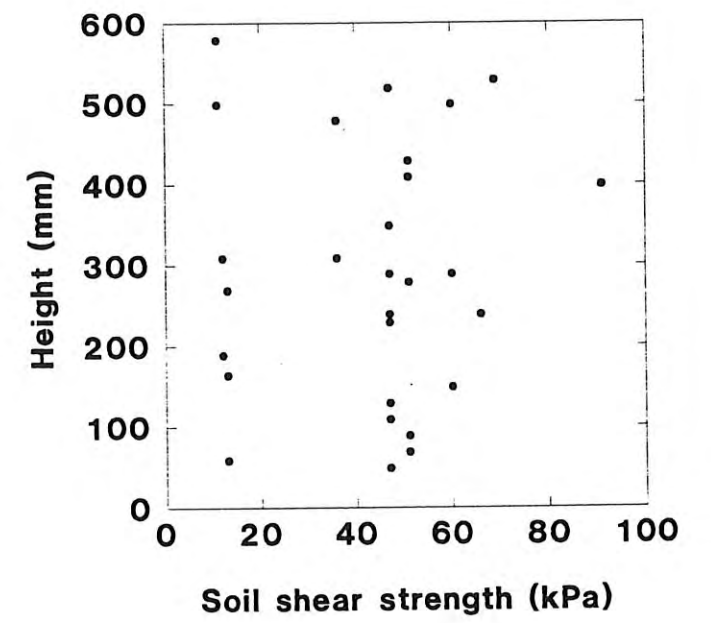
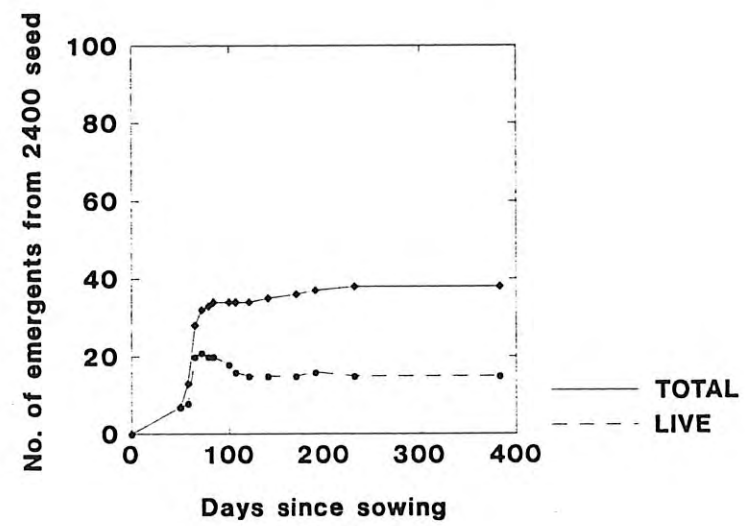
Captions for Figures.

Figure 1. Total number of, and number of live emergents from 2400 seed sown on 2 May 1995 (Day 0). Data are from (a) Lindsay block, and (b) Graphite block.

Figure 2. Height of surviving one-year-old seedlings in relation to average soil shear strength measured in quadrats at Lindsay block.



Graphite



Lisa

DEPARTMENT OF CONSERVATION AND LAND MANAGEMENT

Memorandum

DATE: May 31, 1996
TO: See distribution list
FROM: Lachie McCaw
RE: Report on study into effects of soil compaction on emergence and growth of karri

Christine Farrell, SID Woodwa^{C97}
Attached is a progress report on SPP 95/0002 for the relevant file. I have also sent a copy to the Forest Science Library.

L. McCaw
19-7-

Attached is a copy of a draft report on a study conducted to investigate the effects of soil compaction on emergence, survival and initial growth of karri. This work was conducted as part of SPP 95/0002.

I would appreciate your comments on the report, and your suggestions as to where future investigations into soil disturbance and its effects should be targetted. I will not be in a position to commence any further work in this area until April 1997 when I will be released from the requirement to work on an ANCA-funded project on Banksia fire ecology.

Lachie McCaw

Lachie McCaw
Senior Research Scientist

CC: ✓ Dr P Christensen, SID Manjimup
✓ Dr J. McGrath, SID Busselton
Dr R. Harper, SID Como
Dr G. Stoneman, Crawley
Mr J. Bradshaw, FMB Manjimup
Mr A. Seymour, SFRBU Manjimup
Ms D. Maher, SFRBU Manjimup
Mr W. Tiedemann, Manjimup District

Bob } Please read and return ✓
John } to me for filing.

D.R.