

CHAPTER 8

EFFECT OF PRE-EMERGENT HERBICIDE ON GERMINATION AND EARLY GROWTH

8.1 Introduction

Tree species vary in their tolerance to herbicides and while effective and safe pre-emergent herbicide treatments have been developed for many commercially important forest and orchard species, little is known of the tolerance of Australian natives to pre-emergent herbicides. In open-cut coal mine tree establishment, the main requirement is for herbicides that can be safely applied over newly planted trees or sown tree seed and which will give long lasting pre-emergent control of weeds.

8.2 Glasshouse Experiment 7. Effect of Two Pre-Emergent Herbicides on Germination and Early Growth.

8.2.1 Objective

To examine the effect of two pre-emergent herbicides (Surflan and Diphenamid), each at two rates, on the germination, survival and early growth of *E. maculata*, *A. saligna* and *C. glauca* on Topdressing (16) from Ravensworth No. 2 Mine.

8.2.2 Results

Relevant F values are shown in Appendix 2(vii).

Germination per cent was highly significantly affected ($P \leq 0.01$) by species and herbicide treatment. There was a highly significant interaction between species and herbicide (Figure 8.1). Diphenamid did not detrimentally affect the germination per cent of any of the species at either rate. However, it did significantly enhance the germination per cent of *E. maculata* at both rates. Surflan significantly reduced the

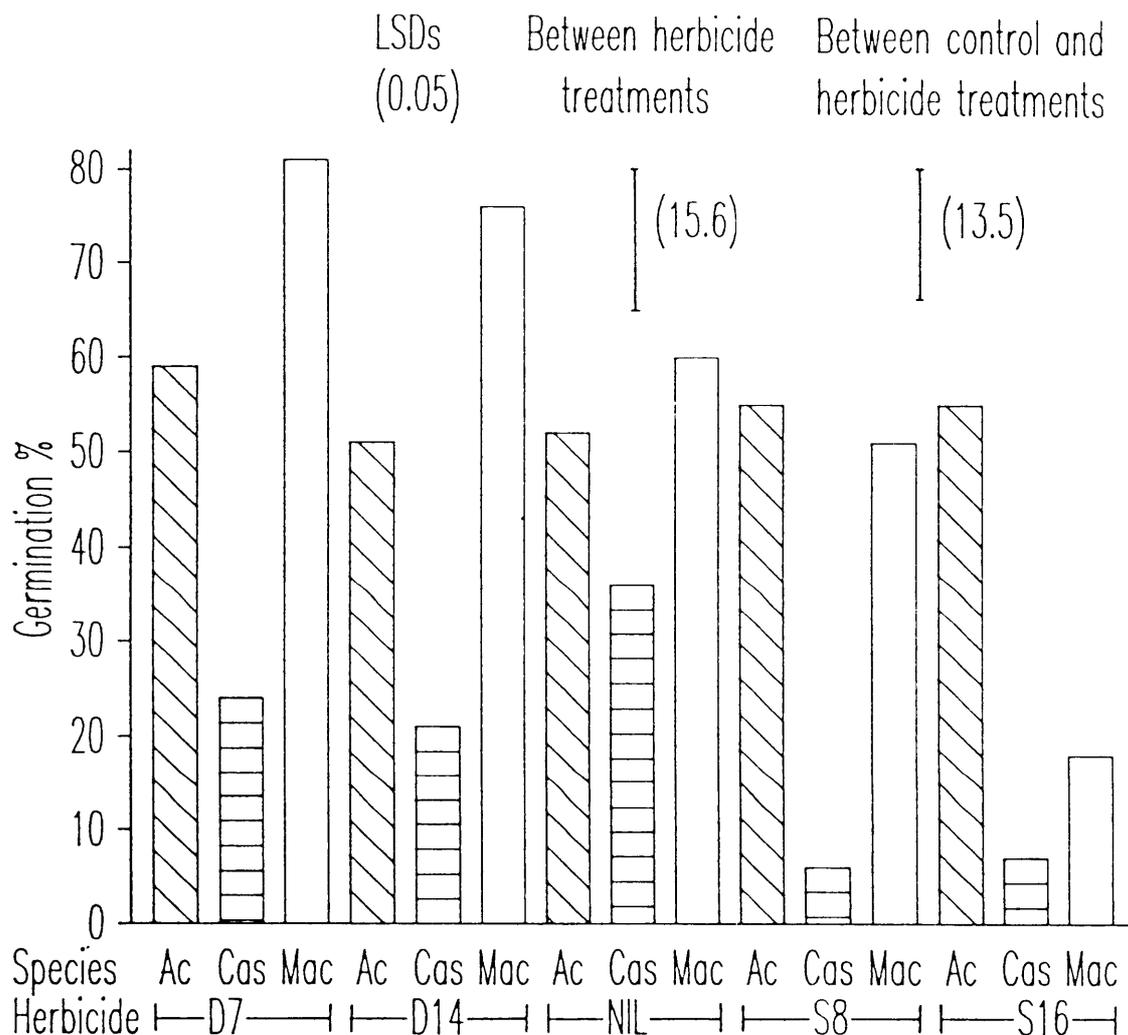


Figure 8.1 Effect of herbicide on the germination per cent of three native tree species sown into Topdressing (16) from Ravensworth No. 2 Colliery.

Ac = <i>A. saligna</i>	D7 = Diphenamid at 7 kg a.i.ha ⁻¹
Cas = <i>C. glauca</i>	D14 = Diphenamid at 14 kg a.i. ha ⁻¹
Mac = <i>E. maculata</i>	S8 = Surflan at 8 L ha ⁻¹
	S16 = Surflan at 16 l ha ⁻¹

germination per cent of *C. glauca* at both rates and *E. maculata* at the highest rate. *A. saligna* was not affected.

The results for germination energy paralleled those for germination per cent.

Survival following germination was affected by a highly significant species x herbicide interaction (Figure 8.2). The results indicate the incomplete picture presented by earlier germination results and reflect the dramatic detrimental effect Surflan had on the survival of all three species at both rates. Surviving seedlings after 169 days were small and unhealthy and unlikely to survive. Diphenamid significantly reduced survival of *A. saligna* and *C. glauca* seedlings but the effect was far less severe than for Surflan.

Shoot weight, root weight and total weight were all affected by a highly significant species x herbicide interaction. The effect was the same for all three growth parameters and the result for shoot growth is shown in Figure 8.3 as an example. The results largely reflected the poor survival induced by the application of Surflan noted earlier, and also indicated the general poor growth of *C. glauca* in all treatments. Diphenamid actually stimulated the growth of *A. saligna* at the lower rate and *E. maculata* at both rates, (Plates 8.1 and 8.2, respectively).

An examination of root/shoot ratio means indicates that treatment had little effect except for *C. glauca*. The result for *C. glauca* was probably an artefact caused by very low values for both root and shoot growth for this species.

The effect of Diphenamid at 7 kg a.i. ha⁻¹ on foliar N and P levels and on N:P ratio for *E. maculata* and *A. saligna* is shown in Table 8.1. For *E. maculata* and *A. saligna* there was no significant difference between Diphenamid at 0 and 7 kg a.i. ha⁻¹ for foliar N and P concentrations nor for the N : P ratio.

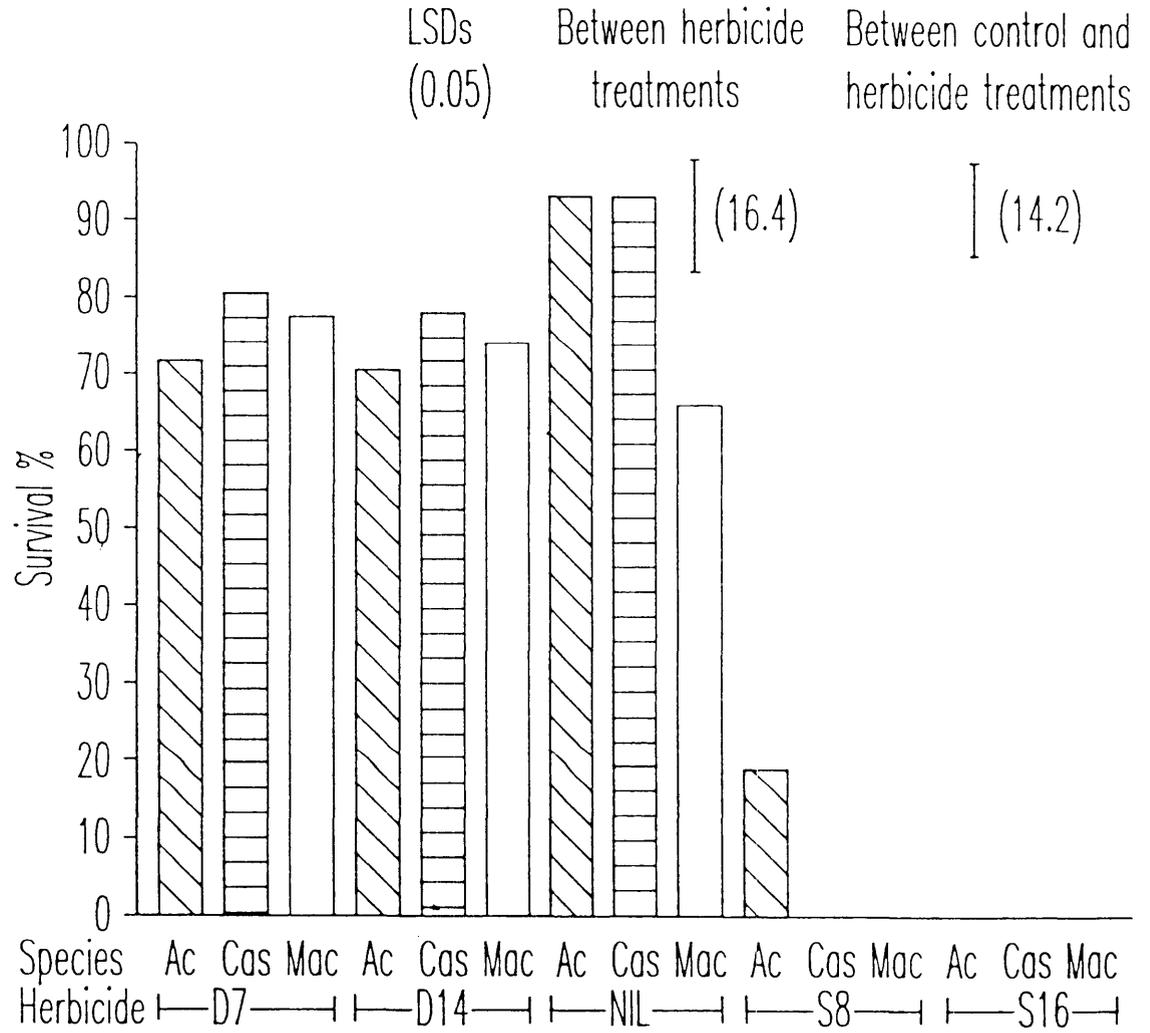


Figure 8.2 Effect of herbicide on the survival per cent of three native tree species sown into Topdressing (16) from Ravensworth No. 2 Colliery.

Ac = *A. saligna*
 Cas = *C. glauca*
 Mac = *E. maculata*

D7 = Diphenamid at 7 kg a.i.ha⁻¹
 D14 = Diphenamid at 14 kg a.i. ha⁻¹
 S8 = Surflan at 8 L ha⁻¹
 S16 = Surflan at 16 L ha⁻¹

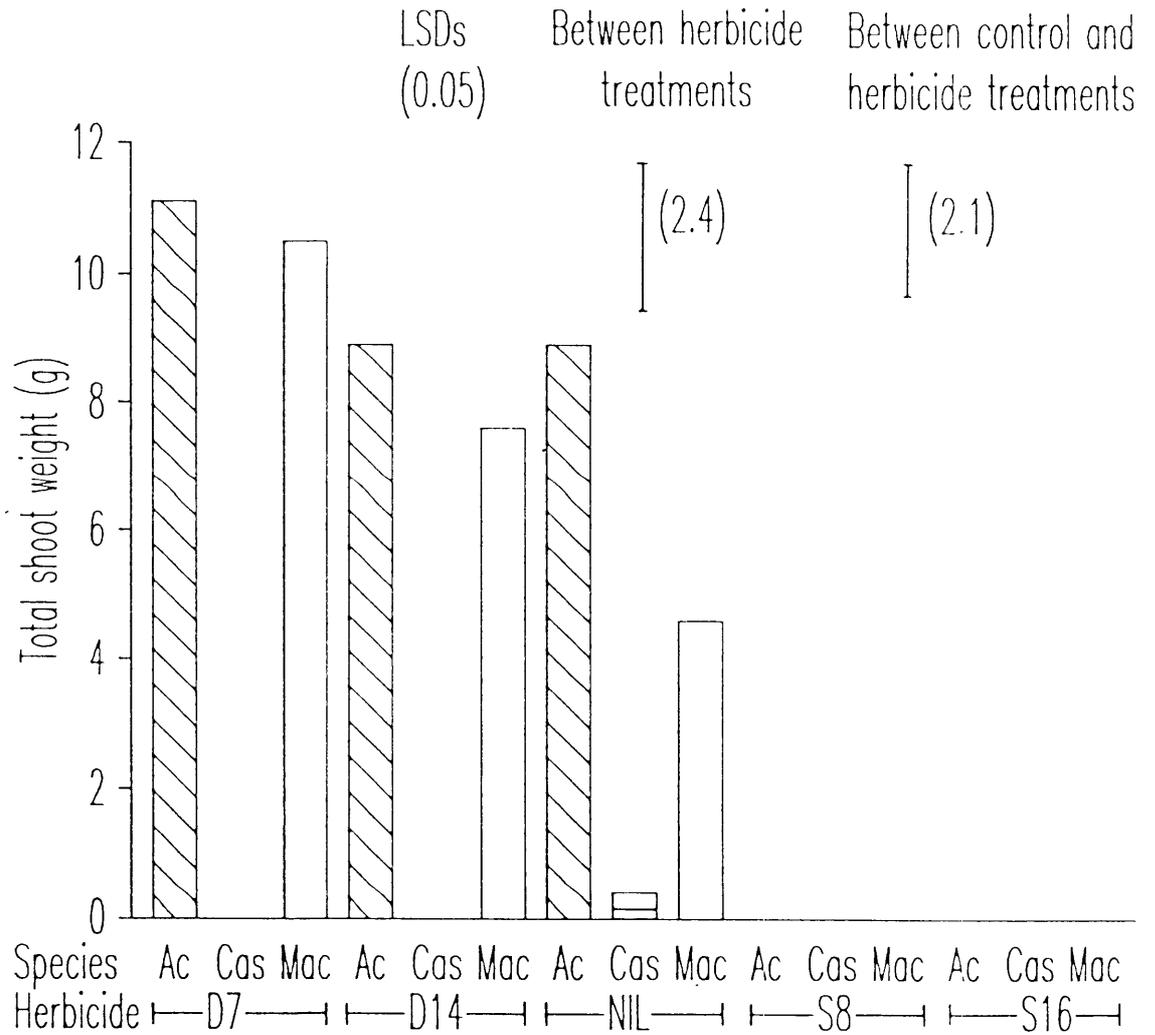


Figure 8.3 Effect of herbicide on the total shoot dry weight of three native species sown into Topdressing (16) from Ravensworth No. 2 Colliery.

Ac = <i>A. saligna</i>	D7 = Diphenamid at 7 kg a.i.ha ⁻¹
Cas = <i>C. glauca</i>	D14 = Diphenamid at 14 kg a.i. ha ⁻¹
Mac = <i>E. maculata</i>	S8 = Surflan at 8 L ha ⁻¹
	S16 = Surflan at 16 L ha ⁻¹



CONTROL	SURFLAN	DIPHENAMID
	16 ha ⁻¹ 81 ha ⁻¹	14kg 7kg
		a.i. ha ⁻¹ a.i. ha ⁻¹

Plate 8.1 Effect of two pre-emergent herbicides, Surflan and Diphenamid, each at two rates, on directly sown *A. saligna* on Topdressing (16) from Ravensworth No. 2 Mine 169 days after sowing.



CONTROL	SURFLAN	DIPHENAMID
	16 kg ha ⁻¹	14kg 7kg
		a.i. ha ⁻¹ a.i. ha ⁻¹

Plate 8.2 Effect of two pre-emergent herbicides, Surflan and Diphenamid, each at two rates, on directly sown *E. maculata* on Topdressing (16) from Ravensworth No. 2 Mine 169 days after sowing.

Table 8.1 Effect of the pre-emergent herbicide Diphenamid applied at 0 and 7 kg active ingredient ha⁻¹ on foliar N and P concentrations (%) and on the N : P ratio for *E. maculata* and *A. saligna* seedlings 169 days after sowing and treatment.

Nutrient or Ratio	<i>E. maculata</i>		<i>A. saligna</i>	
	Diphenamid Rate=		Diphenamid Rate=	
	0 (kg a.i. ha ⁻¹) (Mns.of8)	7 (Mns.of4)	0 (Mns.of8)	7 (Mns.of4)
N	1.71(A)	1.51(A)	2.74(A)	2.64(A)
P	0.19(A)	0.15(A)	0.21(A)	0.22(A)
N : P	9.0(A)	10.1(A)	13.0(A)	12.0(A)

L S D's	<i>E. maculata</i>			<i>A. saligna</i>		
	N	P	N:P	N	P	N:P
P ≤ 0.05	Not.sig.	Not.sig.	Not.sig.	Not.sig.	Not.sig.	Not.sig.

Note: For each species values in the same row with the same letter are not significantly different for $P \leq 0.05$.

8.2.3 Discussion

Surflan reduced the germination per cent and germination energy of *C. glauca* and *E. maculata* at one or both rates. This result probably related to, and pre-empted, the poor survival and growth of all three species following treatment with this herbicide. It was apparent that the toxic effects of Surflan were being expressed immediately after emergence of the radicle. The fact that the germination of *A. saligna* was not affected by Surflan did not indicate its resistance to Surflan. Rather, the larger seed size of *A. saligna* appeared to impart greater germination energy which resulted in earlier emergence than the other, smaller seeded species, giving any herbicide present less time to act.

Diphenamid had no effect on the germination of *A. saligna* and *C. glauca* and actually enhanced both the germination per cent and germination energy of *E. maculata*. The enhanced effect on germination energy probably relates to the general enhanced effect of Diphenamid on growth discussed later. The reason for the enhanced effect on germination per cent is less clear but may relate to a reduction in pre-emergent damping-off, again as a result of the enhanced effect on growth following germination.

Surflan caused high mortality and resulted in poor growth of surviving seedlings for all three species. It was considered unsuitable for further use with native tree seed at either rate.

Diphenamid resulted in a marginal reduction in the survival of *A. saligna* and *C. glauca* seedlings. However, this disadvantage did not extend to growth and Diphenamid actually stimulated the growth of *A. saligna* and *E. maculata* seedlings at one or both rates. The effect on growth was more pronounced at the lower rate. This could be an experimental artefact or more likely an example of the stimulatory effect of sublethal doses of herbicide, the so-called Arndt - Schulz rule (Wiedman and Appleby, 1972). This effect was also noted by Hall (1985) in grass species using a mixture of propazine and chlorthal, and by Rice *et al.* (1963) using Simazine. However, the actual mechanism is unclear.

In this experiment, enhanced growth was not matched by any significant increase in foliar N or P concentrations, nor a significant improvement in the N/P ratio. This implies that increased N and P uptake is not involved, although other elements may be. These results differ from those of Rice *et al.* (1963) who related increased growth in response to Simazine to increased N absorption. However, if there was a strong N and P dilution effect due to increased foliage volume, increased N or P uptake may still be a factor.

C. glauca seedlings did not grow well in the control despite reasonable germination and survival. This was obviously a response to the growing medium and/or glasshouse conditions and resulted in the effect of herbicide on this species not being adequately tested.

This experiment did not test the effectiveness of either herbicide on weed control, although the effectiveness of both on grass control is well documented (Rice *et al.* 1963). Some broadleaved weeds did emerge during the experiment although these were quickly removed by hand. The inability of either herbicide to control broadleaf weeds is seen as the major limitation in their effective use. On re-formed coal mines, this problem would be more apparent for topdressing material which normally has a higher inherent component of all weed types than other substrates.

8.2.4 Summary

1. Diphenamid at both rates was suitable for use with the three species tested although the effect on *C. glauca* needs further testing. Surflan at both rates was unsuitable for use with any of the species.

8.3 Field Experiment 6. Effect of Two Pre-Emergent Herbicides on the Growth of Planted Seedlings.

8.3.1 Introduction

This field experiment followed from glasshouse experiment 7 and used the same two pre-emergent herbicides at the same rates as in glasshouse experiment 7.

8.3.2 Objectives

(1) To examine the effect of two pre-emergent herbicides (Surflan and Diphenamid), each at two rates, on seedling growth and survival of four native tree species (*E. maculata*, *E. punctata*, *C. glauca* and *A. saligna*) planted into three substrates (Topdressing (16), Sandstone (17) and Topdressed and grassed (18)) at Ravensworth No. 2 Mine.

(2) To examine comparative survival of each species on each substrate.

8.3.3 Results

There was no significant difference between Surflan and Diphenamid treatments when adjusted for per cent ground cover over 12 months of growth. Generally, weed competition was minimal and was not considered to have imposed constraints on plant growth and/or survival. This result confirmed the effectiveness of both herbicides in controlling sown pasture competition.

Herbicide treatment had no significant effect on growth (i.e. height at 0, 6 and 12 months and basal area) or survival for any of the three substrates. Since there was little weed competition in the trials, this is good evidence that the chemicals are not toxic to any of the species. If there had been weeds any toxic effects may have been masked by the releasing effect of the herbicides.

The growth of the different species was very significantly different ($P \leq 0.001$) by substrate. This was mainly due to variation in the growth of *A. saligna*.

The per cent survival of the different species differed significantly between Topdressing (16) and Topdressed and Grassed (18). On both these sites *E. punctata* had the poorest survival, while on the Topdressed and Grassed (18) site *A. saligna* had significantly better survival than the other species. There was no difference in survival between species on Sandstone (17).

8.3.4 Discussion

Both herbicides at both rates were considered suitable for use with the four species involved. Comparing these results with those for glasshouse experiment 7, it was apparent that Diphenamid can be safely sprayed over both sown seed and six month old planted seedlings for those species tested with the possible exception of sown *C. glauca*. However, there appears a clear cut-off point for Surflan. Newly germinated seedlings were killed, while planted 6 month old seedlings were not affected. This result may express a change in sensitivity by developing seedlings to Surflan. However, as both herbicides act on root cell division the effect may also be due to the less accessible root system of field planted seedlings, i.e. applied herbicides may have been bound in the surface substrate layers or simply did not leach down in effective quantities to the bulk of the root system of planted seedlings in the field.

Both herbicides appeared to prevent sown pasture competition adequately over the duration of the experiment. However, this effect was masked by a distinct dry period following planting which may have contributed to pasture and weed control generally. There was no difference in weed control effectiveness between rates. Consequently, the lower, more cost efficient rates would be more suitable for large scale use.

Although differences in species survival were apparent on individual substrates, the differences were not dramatic, and all species were considered suitable for large scale planting on the three substrates tested.

8.3.5 Summary

Both Diphenamid and Surflan at both rates were suitable for use with planted seedlings of the four species used.

CHAPTER 9

GENERAL DISCUSSION AND CONCLUSIONS

The major aim of the research described in this thesis is to investigate the suitability of a range of substrates for native tree establishment and to develop practical, low cost tree establishment techniques. Nutrition and substrate physical characteristics were considered critical to plant establishment, and preliminary glasshouse studies concentrated on examining nutrient deficiencies and other characteristics of substrates. Field experiments were designed to verify the results of glasshouse experiments and to examine the effect of different substrates and treatments on germination, survival and early growth. Being the first extensive investigation of tree establishment on reformed open-cut coal mines in the Hunter Valley, the study was intentionally broad in its approach and attempted to provide practical recommendations and highlight problems and areas requiring further attention.

9.1 Glasshouse Experiments

Effect of Substrate on Germination

Glasshouse experiment 1 demonstrated significant differences in germination among substrates. Shale (3) had consistently superior germination, while Topdressing (1) had consistently inferior results. The reasons for these differences were not readily apparent at that stage although surface crusting was observed on some pots. There was sufficient evidence from other coal mine spoil studies to suggest that surface crusting may have contributed to differences in germination.

Glasshouse experiment 2 examined the effect of three additives likely to ameliorate surface crusting and hence reduce germination differences. The type of soil conditioner had no effect on germination per cent. This suggested that surface crusting was not a critical factor

in substrate germination differences. The enhanced effect of Terrasorb on germination energy was considered to be a result of either improved imbibition, a reduction in surface crusting or a more general decompaction of the surface. Penetrometer measurements of crust strength in glasshouse experiment 2 were not feasible because it would have interfered with germination, so this aspect was followed-up in a subsequent experiment.

Glasshouse experiment 3 measured changes in soil strength (as an indication of crusting), pH and conductivity in the surface layers (5 mm depth) of Topdressing (4), Sandstone (5) and Shale (6). Due to the destructive nature of sampling it was not possible to use vegetative material in this experiment. As near as possible the same substrates were used as those in glasshouse experiments 1 and 2 in order to relate effects observed in glasshouse experiment 3 with germination results in glasshouse experiment 1. However, due to the time elapsed between experiments 1 and 3 (12 months) it was not possible to use materials at the same stage of weathering and this is a confounding factor in making direct linkages among the experiments. Within this limitation, the results of glasshouse experiment 3 revealed distinct effects which may help explain the results of glasshouse experiment 1.

In glasshouse experiment 3 Shale (6) had the highest level of surface crusting, Sandstone (5) was intermediate while Topdressing (4) had the lowest. If a strong crust were considered detrimental to germination then the relative levels of germination observed in experiment 1 should correlate with the levels of surface crusting. This was not the case. Surface crusting does not appear to be a limiting factor in germination for these substrates.

Sandstone (5) became strongly alkaline upon watering. Topdressing (4) became only moderately alkaline while Shale (6) gave an intermediate result. It would be reasonable to assume that if pH was a contributing factor affecting germination, Sandstone (5) would be the most unfavourable medium, while Topdressing (4) would be the most favourable. The pH response was confounded by variation in the pH of the

town water supply. Original substrate pH levels and consequent pH changes upon watering did not coincide with germination trends observed in glasshouse experiment 1; pH therefore did not appear to be a limiting factor in germination.

The general changes in salinity following watering were similar to those observed by Emmerton (1983). These effects may be more severe on plant material than would at first be indicated by measurement of salinity of the bulk substrate. However, all levels were relatively low and well below the critical salinity level of 1.58 mS cm⁻¹ found by Elliott and Hannan (1980) to be limiting to plant growth. However, Elliott and Hannan's limit referred to pasture establishment and may not be relevant to native tree species. In addition chemical limits to growth may be much higher than those for germination and establishment.

Due to the regular watering programme implemented in glasshouse experiment 1, water availability was not considered a limiting factor in glasshouse germination. However, the results shown in Figure 6.6 suggest that substrate water holding characteristics may be critical in field germination and survival.

None of the substrate characteristics measured in glasshouse experiment 3 adequately explained substrate germination differences observed in glasshouse experiment 1. In glasshouse experiment 1, reduced germination per cents were probably due to pre-emergence mortality since excavation of seeds revealed that many of the radicles had died after breaking through the testa. Other seedlings died soon after emergence, the symptoms which preceded death resembled damping-off or seedling blight caused by pathogenic soil-inhabiting fungi. Both Ting (1945) and Richards (1961) indicate that biological factors and particularly the promotion of damping-off by the soil pathogen *Fusarium*, can affect germination in glasshouse studies. This suggests that differences in the microbiology of substrates may have been responsible for germination differences in glasshouse experiment 1, and possible other germination experiments. The higher per cent of post emergent losses in Topdressing

(1), which could be expected to be more biologically active than the other originally deeper profile substrates, supports this explanation.

Effect of Substrate and Species on Early Plant Growth and Survival

Substrate materials used in glasshouse experiments 4 and 6 were from similar locations on C.S.R. Lemington Mine. However, unlike Shale (12) in glasshouse experiment 4, Shale (15) in glasshouse experiment 6 was not highly saline and did not exhibit toxic effects on *E. maculata* seedlings. This result emphasized the extent to which surface characteristics could vary within small areas.

Substrate differences were again the major cause of growth differences. The results in glasshouse experiment 6 were consistent with those in glasshouse experiments 4 and 5 with the topdressing material producing superior growth, while the sandstone material produced inferior growth. In glasshouse experiments 5 and 6 the shale material gave an intermediate growth response. Differences in growth response between substrates may possibly be related to the effect of pH on nutrient availability. Acidic topdressing materials had higher water soluble P (Table 5.1) than did the more alkaline shale and sandstone materials. These latter materials were also characterized by relatively high exchangeable Mg and Na. Physical factors may also be involved. In glasshouse experiment 6 poor growth and survival appeared to be related to poor infiltration capacity and hard setting conditions, particularly for Sandstone (14) and Shale (15). Penetrometer studies in glasshouse experiment 3 also indicated that the sandstone and shale materials developed stronger crusts than the topdressing material, and also set harder below the level of crust formation. While the two studies cannot be directly compared, it is possible that hard setting and/or poor infiltration capacity in substrates may be related, and that both could lead to a reduction in growth and possible higher mortality under glasshouse conditions. Allison (1968) stated that soils with weak internal aggregate forces may consolidate into a hard mass. Weak aggregate forces may be caused by mechanical disruption, low organic

content (Allison 1968), the decomposability of organic material (Tisdall *et al.* 1978), textural differences (Kemper and Noonan 1970) and the nature of the clay component e.g. illite or montmorillonite (Corbett 1969). McHenry and Russell (1943) found that soils became less aggregated with decreasing clay content. Generally, topdressing materials were less prone to aggregate destruction and repacking due to better initial aggregate structure, higher decomposable organic content, and for Hunter Valley No. 1 materials, more favourable texture. Better aggregate composition would reduce the tendency of spoil to disperse and surface seal under regular glasshouse watering and could be expected to result in better aeration of the potted material. This could be expected to improve growth and, possibly, survival.

Effect of Fertilizer

Glasshouse experiments 4 and 5 revealed a wide range of nutrients limiting to tree seedling growth. The results were often specific to individual substrates. Topdressing materials showed the least number of deficiencies and, where they occurred, to a lesser degree. P and to a lesser extent N, were the two most common and debilitating deficiencies. Fertilizer, at the rates used in these two experiments did not offset substrate differences. Glasshouse experiment 6 showed that for all three substrates the lowest rates of N and P needed to optimize total weight of *E. maculata* seedlings were 50 kg N ha⁻¹ and 25 kg P ha⁻¹. However, possibly due to the presence of other nutrient deficiencies or physical factors, or inadequacy of experimental design, substrate growth differences were not ameliorated. Further factorial experiments are needed to determine the optimum rates of each deficient element for each substrate. If other chemical and/or physical effects were limiting, as was suggested in other experiments, optimizing nutrition would not eliminate disparate growth although improved root growth in response to added P could have an ameliorative effect.

In glasshouse experiments 4 and 6, *E. maculata* was more responsive to both substrate and fertilizer treatments than *C. glauca*. For this reason, and the fact that *Eucalyptus* species are the predominant

species used in rehabilitation, *E. maculata* was considered a more useful indicator of future field fertilizer requirements.

Seed Versus Seedlings

Effect of Substrate

Substrate differences caused considerable variation in both germination and subsequent growth, and in the growth of dibbled seedlings. Comparison of similarly termed substrates, e.g. topdressing materials, was difficult due to variations in physical and chemical characteristics of those materials. However, broad trends were observed.

Topdressing materials gave inferior germination results under glasshouse conditions when compared to sandstone and shale materials. However, the growth of seedlings in topdressing was consistently superior to the other two substrates. This suggests that factors limiting germination are different in nature and/or scale to those affecting seedling growth.

None of the physical or chemical factors tested in glasshouse experiment 3 adequately explained differences in germination between substrates. There was some evidence to suggest a biological cause (damping-off). Differences in growth between substrates were not adequately explained but may relate to variable moisture, aeration and compaction under glasshouse conditions, as well as nutrient availability.

There was little variation in the root/shoot ratio of directly sown, as opposed to dibbled seedlings in similar substrates from the same colliery. Consequently, up to the age of plants grown in these experiments, and under the conditions imposed, neither form of plant establishment could be considered more field hardy.

Effect of Fertilizer

Differences in substrate characteristics, and particularly those from different collieries, makes comparison of the empirical fertilizer requirements of dibbled seedlings and seedlings germinated *in situ* difficult. *E. maculata* seedlings germinated *in situ* (H.V. No. 1 substrates) had lower N and P growth requirements (N10 P10) than dibbled seedlings (N50 P25) (C.S.R. Lemington substrates). These rates were the same for all substrates for each particular mine. This implied that for *E. maculata* optimum fertilizer rates for either sown or planted seedlings need only be colliery specific. Investigation of the requirement of other *Eucalyptus* species will be necessary to assess to what extent the observed optimum rates can be generalized.

Extrapolation of Results to the Field

Prior to the addition of fertilizer, selecting the most suitable substrate is therefore a compromise between adequate germination per cent and good survival and growth. Germination per cent would be the most practical of these three parameters to manipulate and low germination per cent as was apparent for Topdressing (1) could be readily compensated for by using heavier sowing rates.

While Terrasorb increased germination energy none of the soil amendments significantly affected germination per cent. Consequently, the use of soil amendments did not ameliorate differences in germination per cent or growth between substrates. Differences in early survival could also be readily adjusted by similarly increasing sowing rates. Fertilizer could be applied to promote growth. However, fertilizer did not adequately compensate for growth deficiencies, particularly on sandstone materials. For these reasons topdressing and to a lesser degree shale materials, were the most preferred substrates.

Substrate water characteristics varied significantly and may be the most important physical characteristic affecting field germination

and survival. The higher sand content in Sandstone (2) and Shale (3) indicates there will be less available water than in Topdressing (1). This is consistent with the lower observed field moisture contents of Sandstone (2) and Shale (3) (Figure 5.1) throughout July 1985.

Care must be taken when extrapolating these glasshouse results to the field. For instance, in the field, topdressing material is only spread in a layer approximately 30 cm thick. Consequently, the bulk of a mature tree's roots would ultimately reside in lower overburden material. Initially, a young seedling, having most of its roots in the topdressing material, would be predominantly affected by the characteristics of this material. However, as the tree aged and the roots ramified deeper into a different substrate, the initial effect of the topdressing material would decline and the characteristics of underlying substrates would begin to assert themselves. However, the topdressing material could still indirectly assert an effect through such factors as water infiltration and nutrient release.

Variation in the optimum rates of N and P for the growth of *E. maculata* and *C. glauca* seedlings would mean that the higher fertilizer rates, i.e. normally those for *E. maculata*, would be applied when both species were established together in the field. Similarly, when topdressing material existed only as a thin surface veneer, the higher fertilizer requirements of the lower substrate should be met for planted seedlings unless supplementary maintenance dressings are economically feasible.

The root/shoot ratio can be considered a guide to field survival. Plants with a higher ratio could be expected to be more immune to drier conditions although optimum root/shoot ratios have not been determined for most species. The root/shoot ratios of seedlings grown in Topdressing (1) were considerably inferior to the root/shoot ratio of seedlings in the other two substrates in glasshouse experiment 1. However, the result for Sandstone (2) was largely a consequence of poor shoot, rather than good root development. A high ratio in this case confers little advantage. This was a feature of most of the glasshouse

experiments although glasshouse experiment 6 showed that root development could be promoted at high rates of P. This is one mechanism by which field hardiness may be increased.

The thickness of the topdressing layer in the field and the volume of roots in this layer would again be important in determining the root/shoot ratio and hence drought tolerance of establishing plants at any particular stage of their development. A topdressing material which discouraged root ramification into lower strata and encouraged surface rooting through differential moisture availability or other factors, would reduce drought tolerance and hence survival ability in times of drought.

9.2 Field Experiments and Broadacre Field Trials

Effect of Substrate on Germination and Survival.

The effect of substrate on germination varied between field experiments. Variation even occurred between adjacent experiments on apparently the same substrate. This variability made explanation of germination results difficult. Variation in germination may reflect differences in the physical and chemical characteristics of a particular treatment, or some other experimental artefact. Artefact effects were quite possible and were evident in field experiment 1 (site preparation/mulch trial) which had a 70% higher stocking rate after 2 years than the adjacent soil amendment trial established on the same day. The effect was consistent across substrates. Where substrate did have a significant effect on field germination per cent and germination energy (e.g. in field experiments 1 and 2) the results were similar to those of earlier glasshouse results using the same substrates. In those experiments Topdressing (1) produced inferior germination to Sandstone (2) and Shale (3). A similar result also occurred in field experiment 7 and broadacre field trial 1 where Topdressing (19) had greatly reduced germination per cent and germination energy after 12 months compared to Overburden (20). Irving (1986) showed a similar trend at Tarong coal mine in Queensland, where overburden material had twice the actual

density of *Eucalyptus* seedlings after 4 months compared to soil. However, Irving related his results to increased pasture competition on soil. In glasshouse experiment 1 increased 'damping-off' appeared to explain lower germination percentages. Such an effect would also reduce germination energy. However, it is unlikely that damping-off would be a problem in exposed, relatively low moisture, field situations. There was no visual evidence to support its occurrence. This suggests that factors affecting germination in the field are most likely different from those in the glasshouse.

Temperature may be a critical factor in field germination counts if mortality occurs prior to emergence or when seedlings are small and their death not easily detected. Hawkins (1958) found that 88.8% of *E. crebra* mortality at a site in western Queensland was due to insolation and only 1.7% due to drought. In Figures 5.3 and 5.4 Topdressing (1) was shown to have higher unshaded temperatures at certain times of the day and year, while Sandstone (3) had consistently lower temperatures. The effect probably related to greater heat reflection and hence the lower heat absorbing capacity of the lighter coloured sandstone material. Related substrate temperature effects may be critical to early seedling survival.

Variation in depth of seed burial between substrates due to differences in surface tilth may also explain germination differences between substrates in the field. However, there was no evidence to support such variation and Irving (1986) showed that differences in surface tilth did not relate to differences in germination.

Germination differences did not parallel substrate moisture characteristics shown in Figure 5.1 for Hunter Valley No. 1 substrates. However, the results in Figure 5.1 do not reflect the effect of rock on short term moisture availability in the field. A high rock content such as that found in sandstone and shale materials may increase short term moisture availability in close proximity to seed and hence increase germination. Chemical characteristics did not appear to affect germination.

The effect of substrate on survival also varied in the field. In field experiments 1 and 3 Topdressing (1) produced superior seedling survival, while in field experiment 2 the same substrate produced inferior survival to the other two substrates. There was no difference in substrate survival in field experiment 5. As field experiment 1 had higher numbers of seedlings this experiment can be considered a better reflection of substrate trends. As such, higher survival of seedlings on Topdressing (1) parallels the more favourable substrate water characteristics of this substrate shown in Figure 5.1. However, differences in substrate moisture characteristics were much smaller than differences at many Queensland mines (Irving 1986, Emmerton 1983). Consequently, differences in spoil moisture characteristics could be expected to be less important in plant establishment on Hunter Valley coal mines than at some Queensland mines.

Superior survival of seedlings in Topdressing (1) in the field does not correspond with the very low root/shoot ratio of seedlings in this substrate in glasshouse experiments 1, 2 and 5. In this case, glasshouse determined root/shoot ratios were not good indicators of likely field survival.

Considerable weed growth occurred on Topdressing (1) in the field and, although weeds were killed regularly with carefully applied herbicide, it was possible that this dead growth may have sheltered native tree seedlings at critical times. Weed establishment on Sandstone (2) and Shale (3) was far less prolific than on Topdressing (1).

Both germination per cent and survival per cent peaked after 9 months for seed sown at Hunter Valley No. 1 Mine in June, 1985. Survival then declined slowly until 24 months after which further losses were minimal. These results suggest firstly that seed of those species sown does not have the potential to remain dormant for periods much longer than 9 months. The result was expected for *Eucalyptus* species and Irving (1986) showed a similar result and noted negligible increase in *Eucalyptus* stem density after 11 months. This accords with the generally accepted view that the seed viability of this relatively soft-seeded

genus declines relatively rapidly when in contact with the ground. Usually, most germination occurs between 2-6 months, and very little occurs after 12-18 months (Cremer *et al.* 1984). More protracted germination of *Acacia* species has been shown in other studies e.g. Irving (1986), but this did not occur in this study. The relationship between seed longevity and moisture content of seed has received little investigation, but it is thought to be critical (Boland *et al.* 1980). Grose (1965) found that imbibed seed of the vast majority of 70 Victorian eucalypts was killed at 40°C. Maximum ground temperatures regularly reach this level between October and April (Figure 5.3), especially on the darker topdressing and shale material.

The decline in survival after 9 months probably reflects below average rainfall experienced in the first half of 1986 and the inability of young seedlings to establish adequate root systems prior to the onset of dry conditions.

Effect of Substrate on Growth

Irving (1986) showed that height provided an acceptable estimate of biomass yield. Timber volume tables incorporating stem basal area and height provide a routine method of estimating stem volumes (Jacobs 1955). Therefore, the use of average plant height and average stem basal area were considered reasonable estimators of plant yield. As such, direct comparison between shoot dry weight determined in glasshouse experiments, and plant growth in the field, as measured by average height and average basal area was considered reasonable.

The effect of substrate on growth in field experiments was much less consistent than in glasshouse experiments. In field experiments 5 (Hunter Valley No. 1) and 7 (Bloomfield), seedlings on topdressing material had superior average height and average basal area. In field experiment 2 (Hunter Valley No. 1) topdressing material produced inferior growth, while in field experiments 1 and 3 (Hunter Valley No. 1) substrate had no significant effect on growth for equivalent species. Irving (1986) also showed no significant difference in the growth of *E.*

maculata seedlings on different substrates at Tarong coal mine in Queensland. This was despite differences in native tree stocking densities and in shoot dry weight observed in earlier glasshouse experiments for this species.

Variation in substrate growth response between glasshouse and field experiments may relate to a variation in the coarse fragment in equivalent substrates. In glasshouse experiments, coarse gravel and rock components greater than 5 mm diameter were removed by sieving. The sieved material was thoroughly mixed and regular and optimum watering was undertaken. These differences between field and glasshouse substrates have obviously been important to growth. The effect of glasshouse substrate preparation is effectively to reduce physical differences between substrates. This would in turn emphasize substrate chemical differences. In glasshouse experiments, differences in growth between unamended substrates were largely attributed to nutrient availability. In the field, the much higher gravel and rock component of sandstone and shale substrates, compared to topdressing, would have introduced a considerable potential for physically-induced growth variation. The degree of rock, particularly near the surface, would be affected by the length of time substrates had been exposed and the degree of weathering. Physical breakdown of shale and mudstone material can be rapid, while sandstone breaks down less rapidly. (Doubleday 1974). This has also been noted by the author on mines in the Hunter Valley. High levels of rock could affect growth in a variety of ways. One effect of large quantities of rock in spoil is to increase available water for the short term by reducing particle surface area, and hence the water retention ability of spoil. In the long term, the amount that can be stored and hence made available to plants is reduced (Wilson 1985). However, an increase in the proportion of smaller particles could be expected as rocks weather. It is difficult to predict the effect of changes in short and long term water availability on germination and growth. However, excavations of the root system of five year old trees at Drayton Colliery indicate that roots ramify readily through substrates with high rock components (Plates 9.1 and 9.2). At this site deep root growth was matched by healthy and vigorous shoot growth.



Plate 9.1 Root growth of five year old *E. punctata* planted into spoil material at Drayton Mine. Height of tree 6.5 m, base diameter of trunk 180 mm, depth of tap root 1.75 m+, apparent surface root spread 2.1 m.



Plate 9.2 Root growth of five year old *E. cladocalyx* planted into spoil material at Drayton Mine. Height of tree 7.0 m, base diameter of trunk 70 mm, diameter of root at 1.8 m was 7.8 mm, apparent surface root spread 2.8 m.

There was no significant difference between sandstone and shale substrates for either average height or average basal area in field experiments at Hunter Valley No. 1 Mine. This was despite substantial differences in the particle size composition of those substrates demonstrated in Table 6.13. Both substrates had high rock components in the field and this may have been more critical in affecting growth than finer particle sizes. This further supports the importance of the coarse rock fragment in affecting growth.

Growth differences between topdressing material and other substrates will also be dependent on the depth of topdressing and the nature of the underlying substrate. Trial excavation, using a post hole auger, demonstrated variation in the depth of topdressing material on experimental sites at Hunter Valley No. 1 between 10 cm and 40 cm. Greater variation in depth may have occurred. This variation in topdressing thickness highlights the limitations of pot trials containing 100% of various surface substrates, in predicting field growth responses. Variable topdressing thickness may also explain variation in growth between adjacent field experiments.

If differences in the depth of topdressing have affected growth then variation in the growth of plants on topdressing between field experiments suggests a critical depth of this material may exist. Dyson (1985) showed that where topdressing has produced differences in growth, the effect may only be temporary. He showed superior growth of a variety of native tree species on topdressing at Ravensworth No. 2 Mine compared to an adjacent non-topdressed substrate for up to three years. At this time the difference in the average height of trees was much smaller than at 12 months. The study suggested an initial beneficial but declining effect of topdressing on plant growth over time. Further measurement of trees has not been undertaken to see if the positive, but declining effect of topdressing on growth has turned into a detrimental effect over time although observation suggests this has occurred. This is a critical point and Hanman (1981) raised the question as to whether the replacement of 'topsoil' over reshaped spoil dumps actually assists or hinders natural soil forming processes and, by inference, plant growth.

The above discussion highlights some of the problems of using spoil physical characteristics as a guide in predicting plant growth. In regard to spoil moisture availability, one might question the assumption that the quantity of available water a substrate can hold is limited to the water held between field capacity and the permanent wilting-point. In the first place, plants have varying abilities to extract water from soil (Russell, 1961). In the second place, the actual values for the available water are determined on the fine fraction material after drying and passing through a 2 mm sieve and not when it is in its natural condition. There is also the assumption that the moisture content of the soil at its permanent wilting-point is independent of the actual structure of the soil. Russell (1961) states that the assumption will fail whenever the plant roots cannot ramify throughout the soil zone sufficiently uniformly to extract all the usable water fairly rapidly. Work by Furr and Taylor (1939) and Oppenheimer and Elze (1941) on fruit trees showed the assumption also fails for light textured soil.

Effect of Treatments

In field experiment 1 deep-ripping improved germination per cent but had no effect on germination energy, survival or growth after 2 years. The effect on germination per cent did not appear to relate to decompaction or improved spoil moisture availability. If reduced exposure of seedlings within the ripline was the cause, this could also have been expected to affect survival favourably. Survival was not affected by site preparation. As riplines were located along the contours, superior germination per cent may have resulted from riplines restricting seed movement downhill and possible burial off-site. Cultivation, having a less permanent effect on surface roughness, produced no increase in germination per cent. The strong concentration of seedlings in riplines apparent on all three substrates, supports the apparent seed trapping ability of riplines along the contour. This effect was also noted in broadacre field trial 2. The proposed effect would be more critical to seed retention on steeper slopes, and highlights the likely role of deep-ripping along the contour in short term erosion control. These likely benefits justify the further use of

ripping in large scale direct seeding programmes, although there may be scope for reducing the depth of ripping (Pegg 1987) and hence reduce the amount of rock brought to the surface. Under current coal mine legislation, surface rock above 50 cm diameter should be removed from the surface.

The enhanced effect of straw and to a lesser extent chitter mulch on germination per cent may relate to enhanced moisture availability under the mulches. Organic mulches have been used to improve spoil structure, the microclimate, infiltration and reduce run-off and evaporation (Doyle 1976). While these advantages may apply to the straw mulch, the chitter mulch was very thin and provided only a partial ground cover at the applied rate (60 tonnes ha⁻¹). This, combined with the enhanced surface and sub-surface heating (Figure 7.1) make it difficult to visualize improved moisture availability under chitter. The effect may be similar to that observed for deep-ripping, and may relate to improved seed retention on plots.

The failure of deep ripping or cultivation to improve growth suggests that compaction on the experimental sites was not limiting to the growth of directly sown seedlings.

None of the soil amendments used in field experiment 2 had any effect on plant establishment. The advantageous effects of Terrasorb, apparent in glasshouse experiment 2, were not repeated in the field. This suggested that either glasshouse effects were an artefact of glasshouse conditions or that appropriate conditions in the field were not reached. The failure of gypsum to affect germination or survival suggested that surface crusting, was not due to unfavourable sodic properties.

The failure of applied N and P to affect growth in field experiment 3 varied from the positive response of directly sown seedlings, and particularly *E. maculata* seedlings, to increasing rates of N and P in glasshouse experiment 1. The difference between the growth of direct sown seedlings in glasshouse and field experiments to applied N

and P most likely relates to the longer duration of field experiment 3 (2 years) compared to glasshouse experiment 1 (98 days). It is possible that a growth response by field sown seedlings may have occurred soon after germination. However, if such a response did occur it was not apparent after 2 years. The lack of any field response to applied N and P did not appear to relate to species differences between glasshouse (2 species) and field experiments (5 species). Optimum glasshouse fertilizer rates largely reflected the strong response of *E. maculata*, rather than *C. glauca*, in glasshouse experiment 1. As *Eucalyptus* species constituted 70% of the total stocking number in field experiment 3, the combined species response in field experiment 3 was considered representative of *Eucalyptus* response. If we assume that the three field sown *Eucalyptus* species responded similarly (as suggested by Irving 1986) a direct comparison with glasshouse results is realistic.

It is possible that the failure of seedlings to show a growth response to applied N may relate to the standard cultivation treatment all experiments received prior to sowing. Cultivation may have resulted in an increase in the mineralization of soil N. Even though the total content of all three substrates was low, sufficient N might be mobilized to prevent plant response to added N for a short time (Richards 1961). Beneficial effects of cultivation on plantation trees have been observed in forestry, but it is often held that these effects are ephemeral. If the main purpose of cultivation is to promote mineralization of N it would be unlikely to have lasting effect, unless supplemented by the use of N fertilizers.

Irving (1986), when dealing with directly sown seedlings, also showed a different response to applied N and P between glasshouse and field experiments. He showed a highly significant growth response to applied N and P by a range of *Eucalyptus* species on sandstone and siltstone substrates in glasshouse experiments. However, in the field and on the same substrates, total *Eucalyptus* yield after 17 months was significantly affected by applied N at 100 kg ha⁻¹, but not by applied P. He showed no response at 20 kg N ha⁻¹ which was the highest rate used in field experiment 3 in this study and the highest optimum rate (for

growth) shown in glasshouse experiment 1. These findings suggest that the optimum rates of N and P determined in glasshouse experiment 1 may not be optimum for growth of directly sown seedlings under field conditions. Both glasshouse and field N and P experiments in this study suggest that there is no growth advantage in applying N and P at the same time as native tree seed is sown. However, split fertilizer applications in the field at the 6-10 true leaf stage and at higher rates of N and P, as suggested in glasshouse experiment 6, may be more suitable. This requires further examination.

The absence of any response to applied N and P in field experiment 3 and to applied P in field experiments by Irving suggests that nutrients were quickly made unavailable to plants. This agrees with the findings of Elliott (1983b) who showed a rapid conversion of soluble forms of P to less soluble forms using alkaline overburden materials from Hunter Valley coal mines. Elliott also showed that the depth of movement of P can be quite shallow and that applied fertilizers do not leach below 4-5 centimetres. While young seedlings, particularly in confined pots, may have access to this zone, larger trees in the field with deeper root systems would have less access. Near surface rooting would also be impeded by surface drying in the field. Optimum watering in the glasshouse would tend to encourage deeper leaching of nutrients than in the field.

To overcome rapid conversion of applied nutrients to less soluble forms, luxury amounts of fertilizer may need to be applied to the surface before deeper rooted plants obtain any benefit. A field experiment using planted seedlings and higher factorial combinations of N and P was designed in this study, but mine access was restricted immediately prior to establishment and the experiment did not proceed. Such a trial should be established.

The only advantage of adding fertilizer in conjunction with sown seed in field experiment 3 was to improve survival of seedlings in Sandstone (2). Adding fertilizer actually decreased the survival of seedlings in Topdressing (1) and Shale (3). The latter result parallels

decreasing root/shoot ratios of seedlings in these substrates with increasing N and P rates in glasshouse experiment 1. The reduction in field survival may be a direct result of lower root/shoot ratios in Topdressing (1) and Shale (3) as a result of the addition of N and P, leading to reduced field hardiness and lower survival. The increase in survival of seedlings on Sandstone (2) may relate to an improvement in root weight noted in response to added P in glasshouse experiment 6. In glasshouse experiment 6, *E. maculata* seedlings grew poorly in sandstone material and seedlings had much lower root (and shoot) weights than seedlings in the other two substrates. Under low nutrient conditions, some plants allocate a much greater proportion of their assimilate to root growth (Bowen 1981). This may have been the case for seedlings in Sandstone (2) and may have resulted in improved field survival. However, as discussed earlier, there was no apparent shoot growth response to applied N and P, making root/shoot ratio responses difficult to envisage.

The above results raise many questions, including the value of glasshouse pot trials in predicting field nutrient responses and the source of nutrients responsible for the good growth of unfertilized sown and planted native trees observed on controls in all three substrates in field experiment 3 and on other experiments. The last point is particularly relevant and brings into question the validity of applying critical levels of soil nutrients established for agricultural crops, to native tree species. There is some evidence to suggest that native tree species may have greater access to fixed soil nutrients than agricultural crops. Mulette *et al.* (1974) showed that *E. gummifera* exhibited a marked response to insoluble phosphates and explained the response as an adaptive process developed by plants which have evolved on soils low in P.

The study showed that pelletizing native tree seed in the manner described can have detrimental effects on germination and survival. Further testing of lower rates of N and P is necessary before any conclusion on the value of pelletizing seed in this manner can be made. Further field nutrient studies employing split fertilizer dressings and higher fertilizer rates also need to be undertaken to

clarify the role of nutrients, and particularly N and P, in the growth of directly sown seedlings.

Field experiment 5 indicated there was no optimum month (of those tested) for sowing native tree seed. This conclusion differs from basic agricultural experience in the Hunter Valley which indicates that successful crop establishment is more likely in autumn. The results of experiment 5 must be viewed with considerable caution. The experiment needs repeating over a large number of months and annually for at least five years for meaningful sowing time predictions to be made.

Field experiment 7 indicated that Japanese millet failed to establish in adequate densities on Overburden (20). Millet established better on Topdressing (19) and improved with increasing rates of millet. Irving (1986) also noted better establishment of Rhodes grass (*Chloris gayana* cv. Pioneer) and annual white French millet (*Panicum miliaceum*) on soil material than on overburden. It is not known what minimum dry matter production gives adequate protection against erosion on mined land. The critical value is likely to depend on slope, the erodibility of the substrate, the plant species and rainfall intensity. Marshall (1973) generalized that, in a non-mined land situation, water erosion is quite low when ground cover exceeds 40%, but increases rapidly below 20%. The poor establishment of Japanese millet on Overburden (20) makes erosion control using this pasture species difficult on this substrate. On Topdressing (19) the maximum millet rate of 20 kg ha⁻¹ achieved a 30% ground cover. Obviously higher rates of millet will need to be applied to achieve the 40% cover proposed by Marshall. Figure 7.2 suggested that millet competition will reduce native plant growth but that higher rates of millet above 10 kg ha⁻¹ will not result in further reductions in average plant height or average basal area for native tree species.

Millet has the advantage over other cover crops such as Rhodes grass in that it reaches a maximum yield very quickly within 2-4 months (Irving 1986). The establishment of vegetative cover within 2-4 months as in this case on erodible substrates such as recontoured spoil has obvious advantages.

The effect of cover crop competition has been qualitatively related to native species establishment in sandmine rehabilitation situations (Atkinson 1971, Lewis 1977 , Piccone 1982). Other studies e.g. Irving (1986), related the effect of increasing cover crop yield to decreasing density of native tree seedlings. However, cover crop yields in field experiment 7 were apparently insufficient to affect native plant density although plant growth was affected. Decreasing growth with increasing rates of millet did not appear to relate to spoil moisture availability, as increasing rates of millet were apparently responsible for increasing gravimetric water content (Figure 7.3). This response was attributed to a reduction in surface evaporation, probably as a consequence of reduced wind velocity and insolation with increasing rates of millet. The reduction in average height and average basal area with increasing rates of millet was probably related to competition for spoil nutrients, and in particular, N. The joint sowing of millet and native tree species also produced non-significant but substantial increases in the germination per cent and germination energy of native tree species (Table 7.12). This effect was particularly pronounced for Topdressing (19) which had higher millet cover and the result supports the 'nurse crop' effect of millet on newly germinated native plants proposed earlier. Survival of native plants was also superior on Topdressing (19) and may have been related to the higher millet cover on this substrate than on Overburden (20).

The two herbicide experiments showed a difference in herbicide effect between directly sown seedlings under glasshouse conditions and planted 6-month-old seedlings in the field. Under glasshouse conditions, Diphenamid at both rates proved suitable for use with *E. maculata* and *A. saligna* seed. The lower rate would be more cost efficient. The effect on the growth of sown *C. glauca* was uncertain due to poor growth on the control. Surflan at either rate was considered unsuitable for use with native tree seed. Further testing on a wider range of species under field conditions should occur before large scale use of Diphenamid with sown native species proceeds. Both Surflan and Diphenamid at either rate were suitable for use with the four native species planted into three substrates at Ravensworth No. 2 Mine. This suggests that wider use of

either herbicide with planted seedlings of other species in the three genera represented, could be safely achieved.

In all field experiments and trials and for germination in particular, there was no specific physical or chemical substrate characteristic that could be related unequivocally to germination response. There appeared to be a range of factors that can affect germination although isolation of the important characteristic(s) was often difficult.

Field experiments and broadacre field trials demonstrated that successful establishment of direct sown native tree species can be achieved on a wide range of bare overburden and replaced topdressing materials on coal mines within the Hunter Valley. This, combined with the lower per hectare and per tree cost of direct seeding compared to planted seedlings, is sufficient to justify continued, large scale use of direct seeding. Other advantages of direct seeding include the ability to locate trees and species on sown sites at random; establishment of a dense understorey / overstorey stand in one operation and establishment of large numbers of N-fixing species such as *Acacia*, *Allocasuarina* and *Casuarina*. These N-fixing plants will assist in nutrient cycling and obviate the possible need to rely on what Jehne and Bowen (1981) term the 'nutrient addition strategy' of repeated N additions. In addition, the establishment of large numbers of trees of varying mature height will result in quicker canopy closure, more leaf litter and reduced potential for erosion.

The study demonstrated little advantage in using topdressing material in the establishment of native plants. When topdressing material did produce superior plant establishment, results on nearby alternative substrates were still considered adequate. The decision whether to prestrip, stockpile and respread topdressing material should be based on sound economic and biological considerations. The main advantages of topdressing material in this study have included the superior establishment of pasture crops such as Japanese millet and the superior growth and survival of native tree seedlings in some field

situations. However, the variable survival and growth results appear to testify as much to variation in the thickness of respread topdressing as to variations in its quality. The ability of topdressing material at Bloomfield Colliery to successfully support cover crops such as Japanese millet may be important to long term surface stability. Disadvantages in the use of topdressing materials for tree establishment have included occasional lower stocking rates resulting from either lower germination per cent and/or survival and the high cost of prestripping and respreading the topdressing, estimated at approximately \$4,500 ha⁻¹. The need to preserve a valuable resource is recognized and the Soil Conservation Service of N.S.W. (Elliott and Venness 1981) have developed techniques to identify topsoils worthy of prestripping and respreading for a predominantly pasture establishment. With the area of tree establishment on open-cut mines in the Hunter Valley increasing, the suitability of surface materials must be viewed in a wider context. A similar set of criteria to those developed by Elliott and Venness for pasture needs to be developed with tree establishment requirements as an objective.

The much poorer growth of tree seedlings evident on non-topdressing materials in glasshouse experiments was not supported by field results. Despite apparent differences in growth between substrates in some field experiments, dominant seedlings in the field on all substrates and in all experiments had good leaf colour and crown vigour.

9.3 Further Research

Topics of particular importance to future research include :-

(1) Further detailed field investigation of optimum fertilizer composition and rates for directly sown and planted seedlings on a wider range of substrates.

(2) Effect of directly sowing native tree seed onto acid Greta Seam substrates.

(3) Effect of the joint sowing of native tree seed and ephemeral cover crops with emphasis on critical minimum ground cover levels.

(4) Effect of degree of substrate weathering on nutrient and water availability and native plant growth.

(5) Effect of time on tree stand composition, soil forming processes under tree stands and the long term ability of substrates to support stand development. Most field experiments will be maintained by collieries. These experiments provide a unique opportunity to study long term processes and, in doing so, to acquire the knowledge needed to improve on current tree establishment practices.

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APPENDIX 1

GENERAL SOIL PROFILE DESCRIPTIONS
FOR HUNTER VALLEY NO. 1 MINE

(After van de Graaf (1963))

Solonetzic Soils

- A₁ # Very dark greyish brown to yellowish brown; coarse to moderately fine-textured; usually of massive structure; may be friable when moist, often hard when dry; usually slightly acid to neutral (pH 6.1-7.3).

Usually clear transition

- A₂ Sometimes absent; similarly textured; colours lighter, e.g. very light grey or brownish grey or even more bleached, dry colours often very light; massive structure usually slightly acid to neutral (pH 6.1-7.3).

Abrupt Transition

- B₁ Fine-textured; wide range of colours from black, very dark greyish brown, dark brown, grey-brown, reddish brown, and yellowish brown or intermediate shades, often mottled; strong grade or subangular blocky, blocky, prismatic, or more rarely columnar structure; very hard when dry plastic when wet; moderately to strongly alkaline (pH 7.9-9.0); lime often present.

- C Weathering material derived from colluvium or alluvium and in situ from bed-rock.

The A horizon generally varies between 2 and 12 in. in thickness, but is mostly about 6 in. thick.

Podzolic Soils

- A₁ * Surface soil of coarse to moderately fine texture; colours ranging from very dark brown, very dark greyish brown to brown, greyish brown, or dark yellowish brown; usually massive structure; may be friable when moist, soft to hard when dry; usually strongly acid to neutral (pH 5.1-7.3).

* The A horizon varies generally from 2 to 12 in. in thickness, but is mostly about 6 in. thick.

Usually clear, sometimes gradual transition

- A₂ Similarly textured to A₁; colours often lighter ranging from dark brown, greyish brown, dark yellowish brown, strong brown to brown and yellowish brown; dry colours often much lighter, resembling "ashy" greys and ranging from light grey via light brownish grey to

very pale browns; always massive structure; strongly acid to neutral (pH 5.1-7.3).

Abrupt transition

- B₁ Fine-textured subsoils; wide range of colours from very dark grey-brown very dark brown, dark reddish brown, yellowish red to brown, yellow, and grey, often mottled; usually strong grade of subangular blocky or blocky structure, rarely massive; plastic when wet, firm to very firm but rarely friable when moist, and very hard when dry; normally strong acid to neutral (pH 5.1-7.3) but never more than mildly alkaline (pH 7.4-7.8), sometimes very strongly acid (pH 4.5-5.0).

Gradual transition

- B₂ Textures and colours same range as for B₁ horizon; structures often of a weaker grade or massive; plastic when wet, firm when moist, very hard when dry; strongly acid to mildly alkaline (pH 5.1-7.8).
- C Weathering material derived from bed-rock, colluvium, or alluvium.

APPENDIX 2

ANOVA TABLES FOR GLASSHOUSE AND FIELD EXPERIMENTS

In all ANOVA tables (+) denotes significant at 10% level.
 + denotes significant at 5% level.
 ++ denotes significant at 1% level.

(i) Glasshouse Experiment 1. N x P (seed) Exp.

F values (combined species)

Source	dF	Root wt.	Shoot wt.	Total wt.	R/S Ratio	Germ. %	Germ. energy
Species (S)	1	63.5 ++	155.2 ++	138.1 ++	11.1 ++	1.04	3.3
Substrate (O)	2	32.3 ++	39.1 ++	26.3 ++	98.1 ++	26.3 ++	17.1 ++
P	3	8.6 ++	3.9 +	5.9 ++	.2.5 (+)	4.9 +	7.4 ++
N	3	6.2 ++	13.2 ++	12.0 ++	6.3 ++	0.4	1.7
S*O	2	2.4	28.4 ++	12.8 ++	32.2 ++	0.7	1.1
S*P	3	1.6	0.9	1.2	2.9 (+)	5.2 ++	15.7 ++
S*N	3	3.9 +	4.8 +	4.8 +	1.7	0.3	0.3
O*P	6	2.7 +	1.1	1.3	4.7 ++	1.6	3.4 +
O*N	6	3.0 +	1.5	1.9	1.2	1.3	1.8
P*N	9	2.7 +	2.6 +	2.7 +	2.1 (+)	1.3	2.1
S*O*P	6	0.9	2.1	1.6	1.1	0.3	2.8 +
S*O*N	6	1.9	0.9	1.2	2.7 +	3.0 +	2.0
S*P*N	9	1.7	2.2 (+)	2.0	2.1 (+)	0.8	1.0
O*P*N	18	1.2	1.5	1.4	0.9	1.6	2.0

(ii) Glasshouse Experiment 2. Soil Condition Exp.

F values (combined species)

Source	dF	Root wt.	Shoot wt.	Total wt.	R/S Ratio	Germ. %	Germ. energy
Species (S)	1	46.1 ++	66.0 ++	69.9 ++	0.1	13.0 ++	3.1 (+)
Substrate (O)	2	28.0 ++	55.6 ++	52.9 ++	4.7 +	21.5 ++	12.4 ++
Soil condit. (C)	4	8.5 ++	7.7 ++	9.3 ++	0.7	0.2	3.8 +
S*O	2	5.9 ++	13.0 ++	12.2 ++	0.6	11.5 ++	6.7 ++
S*C	4	0.9	0.9	1.1	0.5	1.1	0.5
O*C	8	0.4	2.2 (+)	1.5	0.9	1.1	0.7
S*O*C	8	0.7	0.5	0.5	0.9	0.5	1.3

(iii) Glasshouse Experiment 3. Effect of different watering regime Exp.

F values.

Source	dF	Grav.H ₂ O	Mean Pen.	Source	dF	pH	EC
Treatment (T)	1	1099.2 ++	669.2 ++	Treat (T)	1	44.6 ++	13.2 ++
Substrate (O)	2	163.0 ++	46.4 ++	Substrate (O)	2	401.5 ++	4.9 +
T*O	2	0.1	38.9 ++	Days (D)	5	22.9 ++	7.7 ++
Rep (T*O)	12	2.9 **	1.9 *	T*O	2	3.4 (+)	3.6 (+)
Days (D)	5	393.2 ++	303.6 ++	T*D	5	7.0 ++	3.7 +
T*D	5	134.7 ++	121.9 ++	O*D	10	3.6 +	1.5
D*O	10	3.0 ++	8.3 ++				
T*D*S	10	1.9 (+)	7.8 ++				

(iv) Glasshouse Experiment 4. Nutrient omission Exp. (H.V. No. 1).

F values (combined species)

Source	dF	Root wt.	Shoot wt.	Total wt.	R/S Ratio	Av. wt.	Surv. %
Species (S)	1	48.9 ++	46.8 ++	61.6 ++	9.0 +	193.2 ++	20.6 ++
Substrate (O)	1	21.4 ++	66.7 ++	62.1 ++	15.3 ++	185.5 ++	6.9 +
Fertilizer (F)	8	3.3 (+)	4.3 +	4.7 +	2.1	4.9 +	4.7 +
S*O	1	17.1 ++	19.2 ++	24.0 ++	0.1	88.9 ++	6.9 +
S*F	8	2.5	3.2 (+)	3.5 +	0.6	4.7 +	
F*O	8	0.9	0.9	0.7	2.3	1.5	1.0

(v) Glasshouse Experiment 5. Nutrient omission Exp. (H.V. No. 1).

F values

Source	dF	Root wt.	Shoot wt.	Total wt.	R/S Ratio	Av. wt.	Surv. %
Substrate (O)	2	92.0 ++	797.6 ++	458.5 ++	5.0 +	72.5 ++	13.2 ++
Treatment (T)	8	1.3	7.9 ++	4.7 ++	4.7 ++	4.6 ++	1.5
T*O	16	0.5	1.8 (+)	0.9	1.9 (+)	3.4 ++	1.0

(vi) Glasshouse Experiment 6. N x P (seedlings) Exp.

F values (combined species)

Source	dF	Root wt.	Shoot wt.	Total wt.	R/S Ratio	Av. wt.	Surv. %
Species (S)	1	71.5 ++	349.0 ++	292.1 ++	50.5 ++	196.0 ++	15.4 ++
Substrate (O)	2	303.4 ++	486.6 ++	520.4 ++	16.7 ++	411.6 ++	1.3
P	3	23.0 ++	72.7 ++	66.0 ++	24.3 ++	54.8 ++	0.2
N	3	1.4	10.8 ++	8.2 ++	6.8 ++	8.0 ++	0.4
S*O	2	47.7 ++	198.7 ++	170.6 ++	6.5 ++	133.2 ++	0.3
S*P	3	5.5 ++	6.1 ++	5.8 ++	2.8 (+)	4.3 +	0.3
S*N	3	0.4	5.2 ++	3.6 +	3.8 +	3.2 +	0.2
O*P	6	4.2 ++	5.3 ++	5.8 ++	4.8 ++	4.6 ++	0.5
O*N	6	1.4	4.7 ++	3.3 +	6.5 ++	2.1	1.9
P*N	9	0.9	2.4 (+)	2.0 (+)	2.8 +	1.6	0.7
S*O*P	6	2.4	4.6 ++	4.2 ++	0.9	3.9 +	0.3
S*O*N	6	3.0 +	4.7 ++	4.8 ++	1.7	3.5 +	1.0
S*P*N	9	0.9	0.8	0.6	1.2	0.9	1.1
O*P*N	18	0.8	2.5 +	2.1 (+)	1.6	1.8	0.4

(vii) Glasshouse Experiment 7. Pre-emergent herbicide Exp.

F values (combined species)

Source	dF	Root wt.	Shoot wt.	Total wt.	Germ. %	Germ. energy	Surv. %
Species	2	63.5 ++	113.6 ++	105.7 ++	68.8 ++	50.3 ++	3.1 (+)
Herbicide	4	32.3 ++	63.3 ++	56.8 ++	11.4 ++	5.8 ++	138.6 ++
Species * herbicide	8	8.4 ++	17.4 ++	15.5 ++	6.6 ++	4.2 ++	2.6 +

(viii) Field Experiment 1. Site prep./mulch exp.

F values
(combined species)

Source	dF	Germ. %	Surv. %	Av. germ energy	Av. ht.	Av. b.a.	Log. b.a.	Arc sin surv. %
Substrate (O)	2	4.5 +	2.3	7.7 ++	0.8	1.4	0.6	3.8 +
Rep	6	1.5	0.3	0.2	0.5	0.8	0.8	0.4
Site Prep. (S.P.)	2	8.0 +	2.8	0.1	2.3	0.9	1.7	2.0
O*S.P.	4	1.6	0.1	1.5 +	1.1	1.7	0.8	0.1
Rep*S.P.	12	1.6	0.8	0.4	0.8	1.1	0.8	0.8
Mulch (M)	2	6.5 ++	1.4	2.0	0.4	0.3	1.2	0.6
S.P.*M	4	1.0	0.8	1.2	0.6	0.7	0.3	1.1
O*M	4	1.5	0.3	2.1	0.7	0.5	0.8	0.6
O*S.P.*M	8	0.7	0.8	1.3	0.9	1.0	1.0	0.9

(viii) Field Experiment 1 (cont.)

F values
(Individual Species Analysis)

Rep*S.P.*M	29	0.5	1.2	1.4	1.8	1.6	1.5	1.0
Species (Spp.)	4	33.1 ++	3.4 +	4.5 ++	24.7 ++	27.2 ++	28.3 ++	3.1 +
O* Spp.	8	0.6	2.5	0.1	1.6	1.8	2.0	2.2 +
S.P.* Spp.	7	0.3	0.8	0.9	1.8	2.4 +	1.4	0.6
M.* Spp.	7	1.0	2.0	0.6	1.7	1.2	1.2	1.6
O*S.P.* Spp.	8	0.7	1.6	0.9	1.0	2.2 +	0.9	1.9
O*M* Spp.	6	0.1	0.6	0.8	0.9	0.8	0.6	0.4
S.P.*M* Spp.	6	1.4	2.4	1.4	0.2	1.1	0.3	2.6 +
O*S.P.*M* Spp.	6	0.1	1.1	1.5	1.0	1.8	0.5	1.0

Note: Subsequent test of hypotheses for Av. Germ. Energy O*S.P. interaction significant at 5% level.

(ix) Field Experiment 2. Soil Amendment Exp.

F values
(combined species)

Source	dF	Germ. %	Surv. %	Av. germ energy	Av. ht.	Av. b.a.	Log. av. b.a.	Arc sin surv. %
Substrate (O)	2	3.2 ++	4.4 +	5.1	4.3	4.1	5.5 ++	3.7 +
Rep	6	0.2	0.5	0.8	0.1	0.5	0.1	0.7
Soil Con. (C)	3	0.2	0.1	0.7	1.0	1.4	0.7	0.1
O*C	6	1.4	0.4	1.2	0.6	0.5	0.5	0.4

(x) Field Experiment 3. Fertilizer rate/Pellet Exp.

F values (combined species)

Source	dF	Germ. %	Surv. %	Av. germ energy	Av. ht.	Av. b.a.	Log. av. b.a.	Arc sin surv. %
Substrate (O)	2	0.8	2.8	3.1	4.7	5.5	6.8	3.4 +
Rep	6	1.8	0.6	1.3	0.9	1.9	2.1	0.6
PN	2	2.8	1.6	1.3	0.9	0.5	1.7	1.9
Pellet	1	15.5 ++	0.9	3.2	1.2	0.4	1.0	0.0
PN*pellet	2	2.7	4.4	1.4	2.3	2.5	4.2	3.4
O*PN	4	1.1	6.3	2.1	1.0	0.5	0.7	6.2
O*pellet	2	0.2	3.1	2.0	0.3	0.1	0.6	3.6
O*PN*pellet	4	1.2	1.3	2.4	0.7	0.1	0.7	1.6

(xi) Field Experiment 4. Grass compet./herbicide Exp.

Insufficient germination to allow statistical analysis.

(xii) Field Experiment 5. Sowing time Exp.

F values (combined species)

Source	dF	Germ. %	Surv. %	Av. germ energy	Av. ht.	Av. b.a.	Arc sin surv. %
Substrate (O)	2	2.6	0.4	1.2	1.8	2.8	0.4
Rep	6	2.1	1.7	0.8	0.5	0.6	1.6
Month	5	0.6	0.9	1.2	0.4	0.5	1.0
O*Month	10	1.2	2.1	0.3	1.1	1.1	2.2

(xiii) Field Experiment 7. Japanese millet Compet. Exp.

F values (combined species)

Source	dF	Germ. %	Surv. %	Av. germ energy	Av. ht.	Av. b.a.	Arc sin surv. %
Substrate (O)	1	5.7	5.3 ++	4.4 +	5.4	0.6	6.8 +
Rep	4	2.9	0.2	0.2	1.4	1.9	0.3
Rate of Japanese millet (R)	4	2.5	0.6	0.3	5.1 ++	3.9	1.5
O*R	4	1.5	1.9	0.6	0.8	0.6	2.5