Research into Reforestation Techniques for Saline Groundwater Control

by N E Pettit and R H Froend

Report No. WS 97
June 1992

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PREFACE

This report is an update of a previous Water Authority report (WS 25 - 'Research to Improve Reforestation Techniques for Saline Groundwater Discharge Control in Water Resources Catchments in the South-West of Western Australia' by P. Ritson and N. Pettit) printed in August 1988. Most of the research trials discussed in this earlier report have now produced some interesting results. As WS 25 is now out of print and copies of this report are still being requested we have taken the opportunity to include a summary of some of the results in this report. Full descriptions of some of the trials have been printed elsewhere and references are given for these in the text.

ABSTRACT

This report describes a research programme, commenced in 1986, to improve reforestation techniques for saline groundwater discharge control in water resources catchments in the south-west of Western Australia. The programme was developed in the Wellington Reservoir Catchment. However, results should also have application to other water resource catchments in the south-west of Western Australia with similar salinity problems.

Environmental stresses likely to be problems for reforestation were identified. These are high soil salinity, waterlogging, drought, low soil fertility and hardpans. Recognising the major importance of waterlogging and salinity, site types of combined salt/waterlogging stress, as indicated by pasture cover, were defined. These site types were used to characterise trial sites.

Research trials to test possible ways of overcoming or alleviating environmental stresses are discussed. These sections include reviews of relevant literature and the rationale for each trial. Results are presented and discussed for those trials which have progressed sufficiently to draw useful conclusions from the results already obtained.

The trials fall into two groups according to alternative strategies for improving reforestation of difficult sites.

The first group are establishment trials. The objective of these is to find ways of reducing environmental stresses by modifying the environment or changing planting practices. Establishment trials described include experiments with ridge mounding, drainage, mulching, ripping, planting time, seedling containers and fertiliser regimes.

The second group of trials are plant selection trials. The objective of these is to find suitable plants which are most tolerant of the environmental stresses. Four adaptation trials with various tree and shrub species are described.

The best solutions to improving reforestation techniques for saline groundwater discharge control is likely to come from combinations of improvements in tree establishment techniques and improved plant selection.

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1. INTRODUCTION

A programme of research to improve reforestation techniques for salinity control in water resource catchments in the south-west of WA commenced in 1986.

Of immediate concern in setting up the research programme was the reforestation project in the Wellington Reservoir Catchment (WRC). In the low rainfall zone of that catchment (Figure 1) over 6500 hectares of cleared land have been planted (up to and including winter 1991) with a variety of species, mostly eucalypts, since 1976.

The objective of the reforestation is to reverse the chain of events commonly brought about by clearing for agriculture in the low rainfall zone. This is briefly outlined below.

Conversion from tall forests to low annual pastures and crops results in reduced annual evapotranspiration. This allows more recharge, causing groundwater tables to rise. In the low rainfall zone the groundwaters of forested areas are usually brackish or saline ie. greater than 1500 mg L-1 total soluble salts (Stokes et al. 1980). With clearing, groundwaters increase in salinity as they rise and mobilise salts accumulated in the soils above. Once these groundwater tables reach a critical depth below the land surface saline seeps form leading to increased salt discharge into streams.

The term critical depth is used for the minimum depth to a saline groundwater table which will result in significant accumulation of salts in or on surface soils. Salts are brought to the surface by upward capillary flow from shallow groundwater tables. They accumulate with evaporation from the soil and may be washed into streams by runoff. As discussed by Williamson (1986) there is no single value for critical depth for all soils as it depends on soil texture and other factors, but it is generally in the range 1 m to 2 m. The rate of salt discharge will increase as saline groundwater tables rise above the critical depth. If saline groundwater tables intersect the land surface saline groundwater may flow directly into streams.

The term saline seep (or salt seep) is used to describe areas where surface salinity recently increased significantly and a seasonal or permanent watertable occurs within 2 or 3 m of the land surface (Peck, 1978). Generally saline seeps develop in valley bottoms but occasionally they develop on slopes eg. above dykes or bedrock highs (Nulsen, 1985). The first sign of a developing saline seep in cleared land in south-west Australia is usually the appearance of the salt and waterlogging tolerant sea barley grass (*Hordeum marinum*) in the pasture. Core areas of well developed saline seeps, where watertables are often (especially in winter and spring) less than 0.5 m deep, are mostly bare of even salt and waterlogging tolerant vegetation.

For reforestation to give effective salinity control in water supply catchments the groundwater tables beneath saline seeps must be lowered below the critical depth.

Where best to place the trees and at what density to plant for salinity control have been subjects of much debate eg. see Morris and Thompson (1983); Schofield et al. (1989). Detailed discussion of the arguments for and against the various strategies proposed is beyond the scope of this report.

The reforestation strategy applied in the WRC has been to plant the lower 25-40% of cleared land with approximately 800 trees per hectare. Thus groundwater discharge zones (saline seeps) and adjoining lower slope recharge areas are planted. One problem with application of this strategy is that saline seeps, especially the core areas, are difficult sites for reforestation. In the WRC the saline seeps are typically up to half (sometimes more) of the lower 25-40% of cleared land targeted for reforestation. It was recognition of this problem which led to the commencement of the research programme outlined in this report.

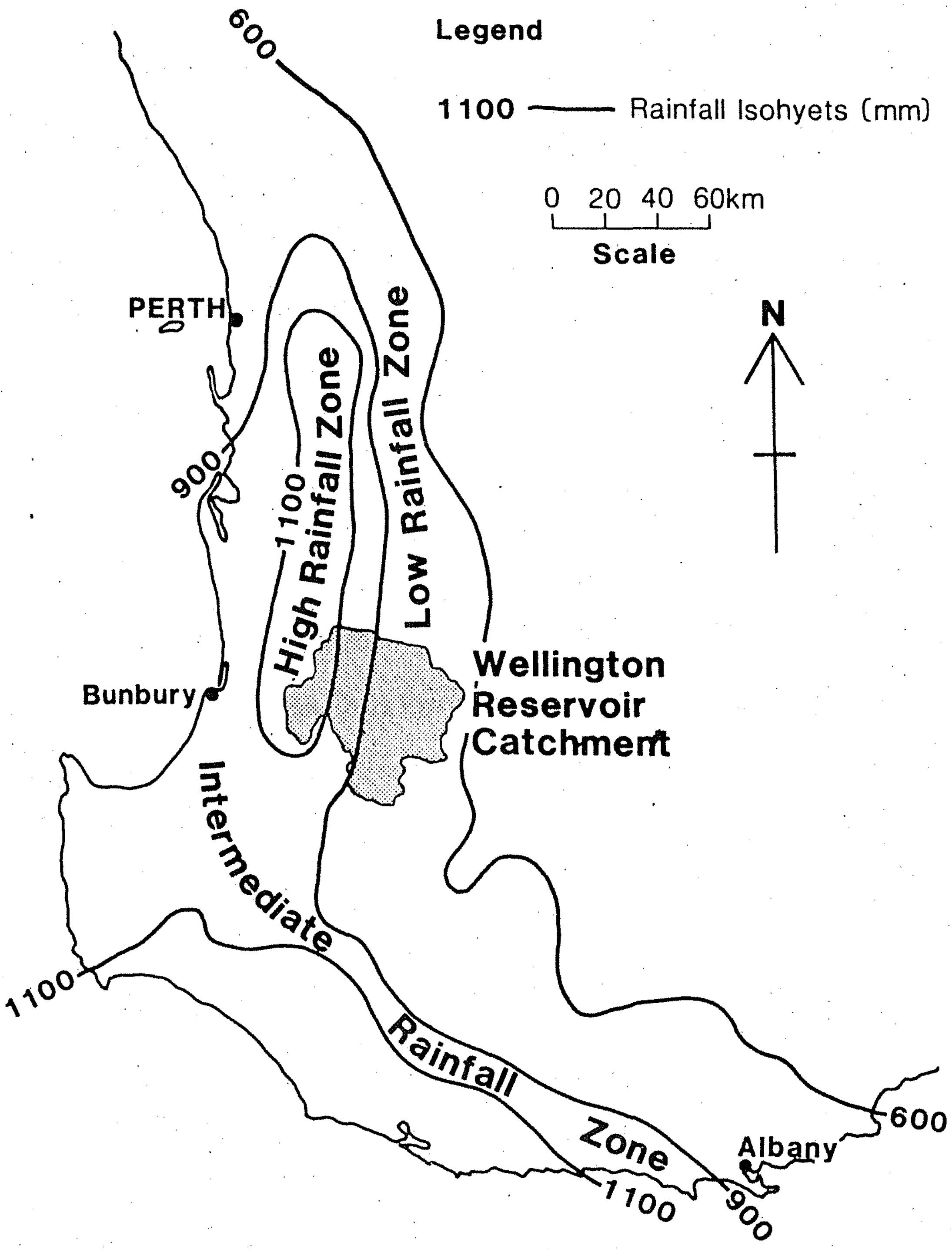


Figure 1 Location of the Wellington Reservoir Catchment and rainfall zones

The focus of the research programme is on improving reforestation techniques for saline seeps. However, as land immediately above saline seeps is also being reforested in the WRC some trials relate to improving reforestation techniques for those sites as well.

Although all field trials have been located in the WRC, other water resource catchments in Western Australia have similar sites and a similar salinity problem. Thus the results obtained should have application for assessing the potential for reforestation in those catchments and implementing any reforestation projects.

The purpose of this report is to describe the research programme undertaken and to present some initial results.

2 DEVELOPING A RESEARCH PROGRAMME

2.1 Identifying Environmental Stresses

An essential first step in developing a research programme was to identify environmental stresses in and around salt seeps likely to make reforestation difficult. This was necessary to focus research efforts onto ways of overcoming the stresses.

In core areas of saline seeps in the WRC five stresses may be identified.

(i) High soil salinity - Total soluble salts in the surface 20 cm of soil are typically in excess of 0.1 % by weight and sometimes in excess of 1.0 % by weight.

(ii) Waterlogging - due to high watertables ie. often (especially in winter and spring) less than 0.5 m from the surface.

(iii) Drought - Although waterlogging may be important in winter and spring the Mediterranean type climate means that drought may be a factor in summer and autumn. Only 18% of rainfall in the eastern WRC falls in the 6 months from November to April.

(iv) Low soil fertility - The importance of this is not known. Eucalypts appear to be well adapted to low nutrient soils (Florence 1981).

(v) Hardpans - In some sites hardpans apparently prevent root growth below approximately 0.5 metres depth.

In the outer areas of salt seeps all the above environmental stresses may apply although salinity and waterlogging stresses will be less severe.
Upslope of saline seeps, but within the lower 30-40% of cleared land targeted for reforestation in the WRC, only drought and low soil fertility are likely to be a problem. Usually these sites have ample depth of soil above any saline groundwater table which is well drained and does not contain sufficient salts to restrict plant growth.

Interactions occur between environmental stresses eg. Barrett-Lennard (1986) has pointed out the particularly important interaction between salinity and waterlogging in restricting plant growth.

Recognising the importance of salinity and waterlogging for plant growth, three site types were defined and are referred to in this report. ie.

(i) Severe S/W - a severe salt/waterlogging stress site. Mostly core areas of well developed saline seeps. Have less than 20% cover of sea barley grass or other salt tolerant species.
(ii) Mild S/W - a mild salt/waterlogging stress site. May be an entire saline seep area or the peripheral area of a well developed saline seep. Have more than 80% pasture cover, mostly sea barley grass.
(iii) Non S/W - a site with no (or minimal) salt/waterlogging stress. Outside of saline seeps. Have complete pasture cover of non salt/waterlogging tolerant species.

Areas in between the above site types were regarded as transitional sites.

The use of plant cover as an indicator of salt/waterlogging stress was preferred to measurement of physical parameters such as soil salinity and waterlogging. Soil salinity is very variable spatially and temporally. It is therefore difficult to quantify and measurements of soil salinity alone do not relate well to plant cover (Nulsen 1981). An indication of waterlogging can be obtained by the position of the watertable. However, watertable depth will vary in response to rainfall and is also difficult to quantity. Nevertheless some measurements of soil salinity and watertable depth and salinity are being made at most experimental sites. This is for comparison with plant cover assessments, so that results can be compared with those obtained by other researchers who have measured soil salinity and watertable characteristics.

2.2 Research Strategy

A check of published literature showed that little work had been done that is of direct relevance to improving the reforestation of sites with conditions (environmental stresses) such as those in the eastern WRC. The main exception was some work (discussed in Section 4.1) aimed at selecting species, or provenances of species, for particular stresses such as salinity and waterlogging. Therefore field trials were initiated. They fall into two groups representing alternative strategies for research to improve reforestation of difficult sites ie. :

(i) Establishment trials : To find ways of reducing environmental stresses by modifying the environment or changing planting practices.

(ii) Plant selection trials - to find suitable plants which are most tolerant of the environmental stresses.

The best solution is likely to come from a combination of both research strategies ie. by improving plant selection as well as site preparation techniques and planting practices.

The trials initiated so far are discussed in Section 3 (Establishment trials) and Section 4 (Plant selection trials).

3 ESTABLISHMENT TRIALS

3.1 Experimental Design and Evaluation of Trials

All establishment trials were designed with the following features.

(i) Adequate replication and control to facilitate statistical analysis of results.

(ii) Two, or three, species in each trial.

(iii) Row plots, usually with 12 or 15 seedlings.

(iv) All trials were laid out as a randomised block design experiment.

The main evaluation of trials was based on survival and early growth of seedlings and should be possible in 2-3 years from trial commencement. Notwithstanding this, the trials will be monitored beyond 3 years to check initial conclusions.

Monthly rainfall for the research areas covering the period of results is recorded in Figure 2.

3.2 Mound Design

One technique used in plantation forestry is ridge mounding (bedding). This is usually done with special mound ploughs which have offset discs designed to heap soil into a ridge mound between the discs. Furrows are formed in this operation either side of the mounds. Seedlings are planted in the tops or sides of the ridge mounds. The technique is used in low fertility soils to concentrate nutrients and organic matter in the mounds (Attiwill et al. 1985; Frederick *et al.* 1984). It is also used effectively in waterlogged soils to improve tree survival and growth (Langdon 1962; Geary *et al.* 1983; Yadav 1980) through improved drainage and hence soil aeration.

Ridge mounding is used for site preparation in S/W sites in WRC reforestation. Salt/waterlogging tolerant eucalypt species such as *E. sargentii*, *E. cornuta*, *E. rudis* and *E. camaldulensis* have been established in mild S/W sites by this method. It seems this is due to reductions in waterlogging but not, as discussed later, reductions in soil salinity through salts leaching from the mounds. Unfortunately in severe S/W sites the standard ridge mounds (15-20 cm high) have not been sufficient for tree establishment even with salt/waterlogging tolerant species.

Two trials, commenced in 1985 and 1986, with metre high mounds formed in a severe S/W site indicate that, with this drastic site preparation, it is possible to establish trees in these conditions (see Table 1 and Figure 3). The mounds were formed with a Buckeye pipeline trenching machine.

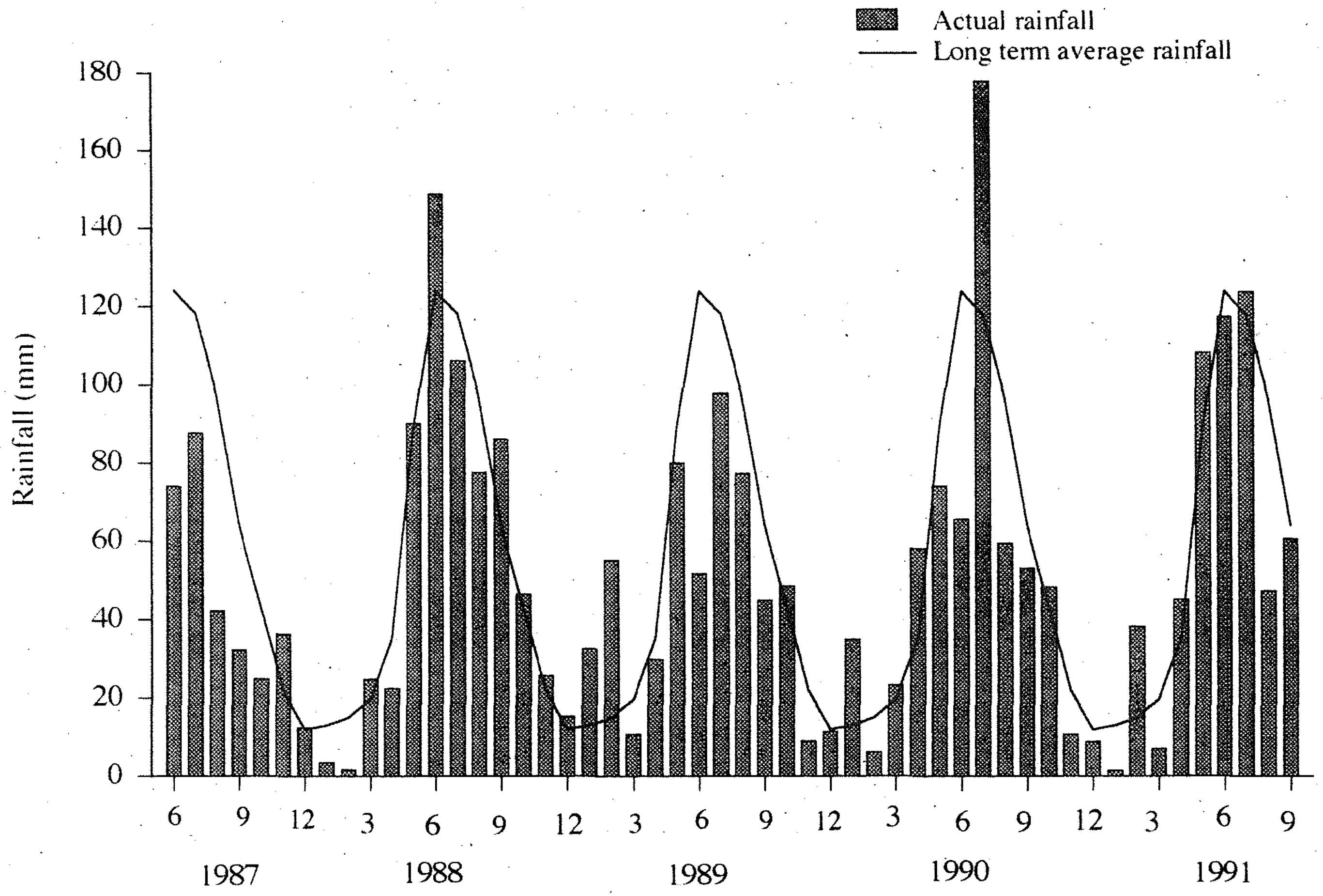


Figure 2 : Monthly rainfall from June 1987 to September 1991 and average monthly rainfall on the study sites. Data are the means of rainfall stations in the vicinity of the study sites.

Table 1: Survival, Height, Crown Volume Index and Basal Area 4 years after planting[a] on high mounds[b] in a severe saline waterlogged site.

Species	Survival (%)	Mean Height (m)	Crown Volume Index[c] (m^3)	Basal Area (cm^2)	Biomass Index[d]
E. sargentii	91	3.31	25.56	10.1	2326
E. occidentalis	73	4.12	30.28	22.0	2210
C. obesa	79	4.37	27.22	12.8	2150
E. cornuta	84	3.49	21.3	12.2	1789
E. kondininensis	57	3.60	24.3	13.8	1385
E. globulus	31	5.45	43.0	31.7	1333
E. accedens	75	2.53	15.1	14.2	1065
E. microcarpa	73	2.20	13.39	13.3	977
E. viminalis	20	3.98	41.22	15.13	824
E. sideroxylon	35	3.14	21.37	21.82	748
E. saligna	23	3.30	31.72	13.19	734
E. melliodora	50	2.38	14.58	12.70	729
E. camaldulensis	44	2.47	16.40	17.47	722
E. resinifera	28	3.30	20.91	25.10	585
E. wandoo	38	2.31	13.65	10.20	519
M. cuticularis	86	1.23	4.61	5.99	396
M. rhaphiophylla	97	1.34	2.57	4.30	249
E. rubida	10	2.84	13.91	8.40	139
M. quinquenervia	18	1.57	7.55	7.50	136

a) Trial planted in August 1987 measured July 1991.
b) Mounds approximately 1.0 metre high at time of formation.
c) Crown volume index = height x crown diameter^2.
d) Biomass index = survival x crown volume index.

However other research indicates it may not be necessary to make the mounds quite so high if the design is changed. Malcolm and Allen (1981) and Malcolm (1983) describe an alternative mound design for seeding salt bushes (*Atriplex* spp) in saline soils subject to occasional waterlogging. Instead of the standard single ridge mound used for tree establishment they used a double ridge mound and established salt bushes in the trough (niche) between the ridges.

A trial was commenced in July, 1987 to test the double ridge mound design for tree establishment. Treatments included single and double ridge mounds of four heights formed with a road grader (mound heights 0.25, 0.5, 0.75 and 1.0 m) as well as standard mounds formed with a mound plough. Seedlings were planted in the tops of standard mounds, in the sides of single ridge mounds (at 0.75 of mound height) and in the trough bottoms of double ridge mounds (Figure 4). Heights of trough bottoms in the double ridge mounds, in order of increasing mound height, were approximately 0.1, 0.3, 0.5 and 0.75 m.

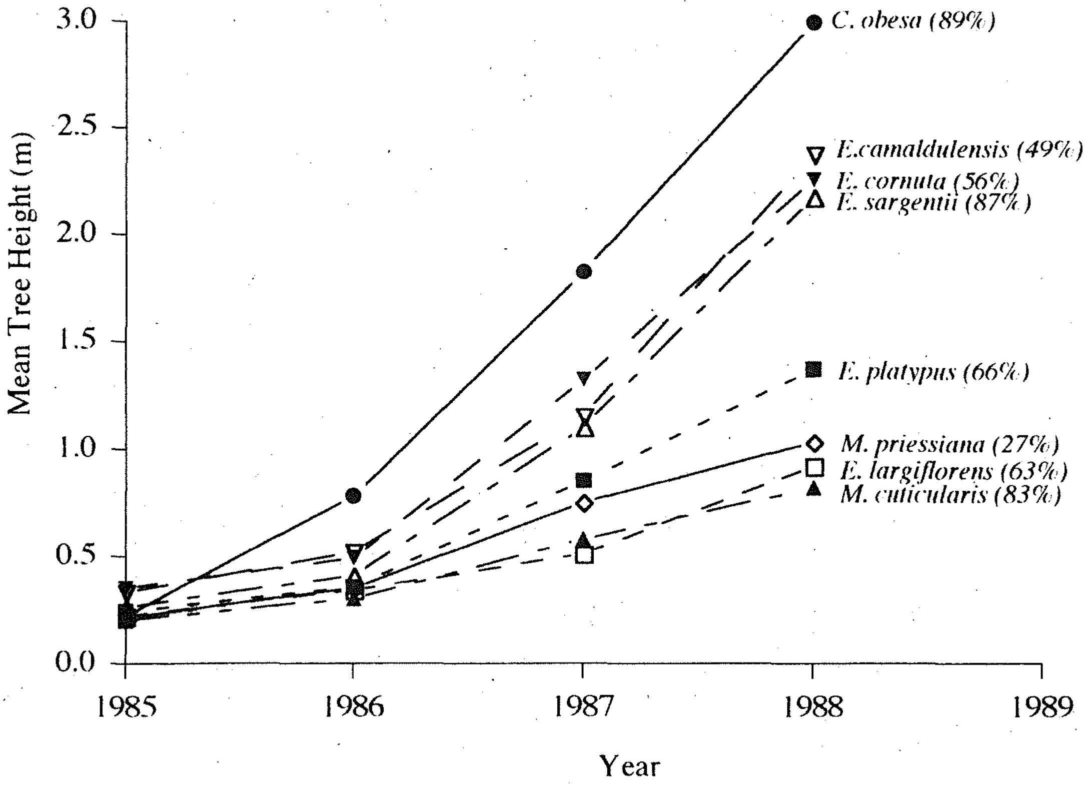


Figure 3 : **Height and survival of Eucalyptus, Casuarina and Melaleuca species planted in 1 metre high mounds in a severe saline waterlogged site. Seedlings planted in July 1985 and measured annually.**

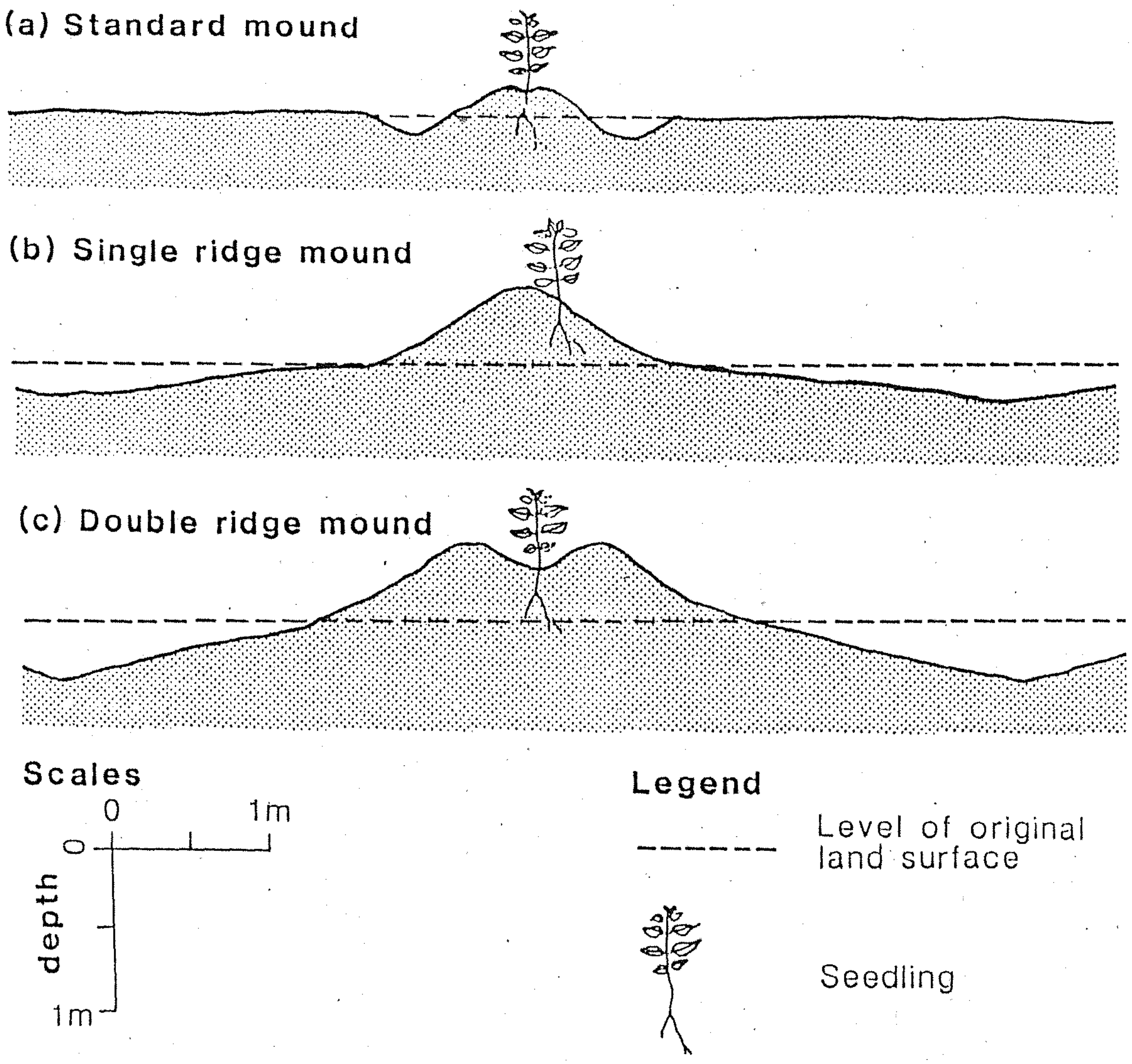


Figure 4 Cross sections of a standard mound and 0.5 m high single and double ridge mounds showing positioning of seedlings

As shown in Figure 5 the results have been very encouraging. Trends were the same for both species. Clearly the double ridge mounds gave better establishment (survival rates) than the single ridge mounds. Establishment in standard mounds was better than in the single ridge mounds up to 0.5 m high. This may have been due to the small trough in the standard mounds which is formed by the roller packer pulled behind the mound plough. Only comparatively small improvements in establishment were obtained with increasing mound height.

One essential difference between the single ridge and double ridge mounds appears to be the effect on soil salinity in the seedling root zones. Single ridge mounds would tend to shed rainfall and wet up either from the water table below or from water collected in the furrows formed to make the mounds. This would cause salts to accumulate in single ridge mounds. Such an effect has been demonstrated in laboratory studies (Bernstein and Fireman 1957) and reported from field studies (Bernstein et al. 1955; Fanning and Carter 1963). In contrast to the single ridge mound, the double ridge mound would tend to collect, not shed, rainwater because of the trough. This would facilitate rainfall percolation and therefore salt leaching from soil in the seedling root zone. Some waterlogging may occur, especially in winter. However this is likely to be temporary due to the free draining nature of the mounds. Also, reducing salinity would reduce the impact of the salinity/waterlogging interaction. In summer when drought is likely to be the problem the effect of the trough in double ridge mounds in catching water from occasional rainfall events and channelling it to the root zone would benefit the seedlings.

The actual patterns of salt and water movement in the single and double ridge mounds in the trial in the WRC has been monitored by soil sampling and analysis. Results indicate that salt leaching occurs below the troughs of double ridge mounds in winter but re-accumulates by the following Autumn. Moisture levels were also higher below the trough of double ridge mounds in late summer indicating an advantage of double ridge mounds in channelling moisture to the seedling root zone (Ritson and Pettit 1989).

There were large effects on survival of both mound height and mound type (Figure 5). For both single and double ridge mounds survival tended to increase with increasing mound height. However, double ridge mounds gave much better survival than single ridge mounds with the lowest height of double ridge mounds (0.25 m) giving better survival than any height of single ridge mound. Although initially (after 1 year) there were significant differences in growth of seedlings in single and double ridge mounds this difference had disappeared after 2 years. This may be due to the roots of the older seedlings growing beyond the improved soil conditions of the mounds and therefore losing this advantage. Full details of this experiment are reported in Ritson and Pettit (1992).

The results indicate that for reforestation of saline seeps, there is considerable scope for increasing survival compared with that achieved with standard mounds. This may be done by forming higher mounds, and in particular, double ridge mounds.

More research is needed to determine the best design for double ridge mounds. In particular trough width may be important. A wider trough would catch and channel more water to the seedling root zone. However an excessively wide trough may catch too much water, causing excessive waterlogging, and would be expensive to construct. A trial specifically to investigate the effect of varying trough width on tree establishment was commenced in July 1988.

In this trial mounds were constructed using an excavator and the trial was divided into 6 blocks over 2 sites. Severity of waterlogging and salinity conditions varied between blocks and sites. Two mound heights (10 cm and 30 cm) were tested and four trough widths (O, 30, 70 and 120 cm). Seedlings were planted in winter 1988 and two tree species were planted *E. camaldulensis* (clone) and *Casuarina obesa*).

Survival of *C. obesa* was very good over all sites and there was no separation in survival of this species on the different mound designs. For *E. camaldulensis* on the 2 most severe blocks survival was significantly better on 30 cm high mounds (55%) than on 10 cm high mounds (19%). Survival also improved as trough width increased from 0 cm (28%) to 120 cm (47%). Results given in Figure 6(a) show that for any trough width, 30 cm high mounds had better survival than 10 cm high mounds. This would indicate the importance of mound height at these sites. The interaction between mound height and trough width for

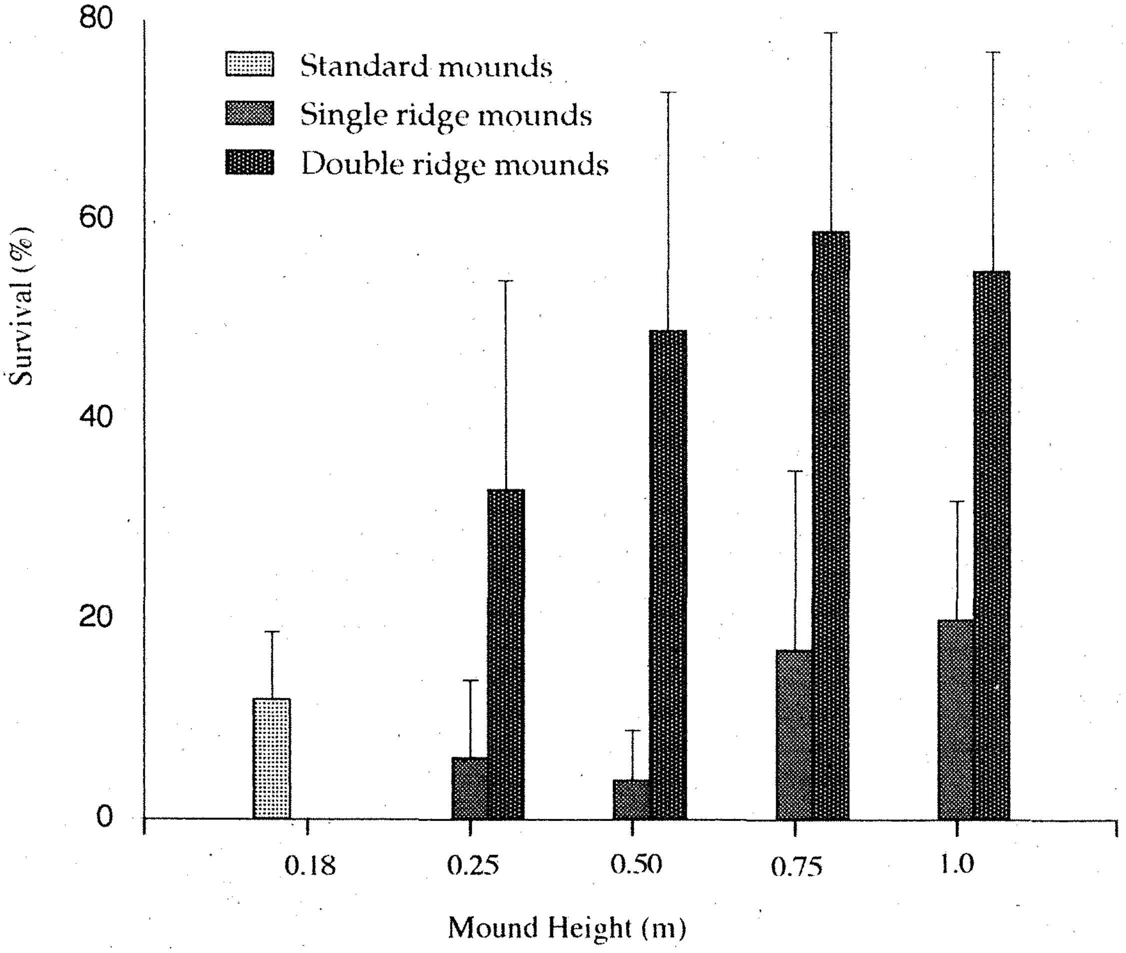


Figure 5 : Survival 3 years after planting of seedlings planted in single and double ridge mounds. Data are averaged for both species *(E. camaldulensis* and *E. largiflorens)* and the 5 saline seep sites.

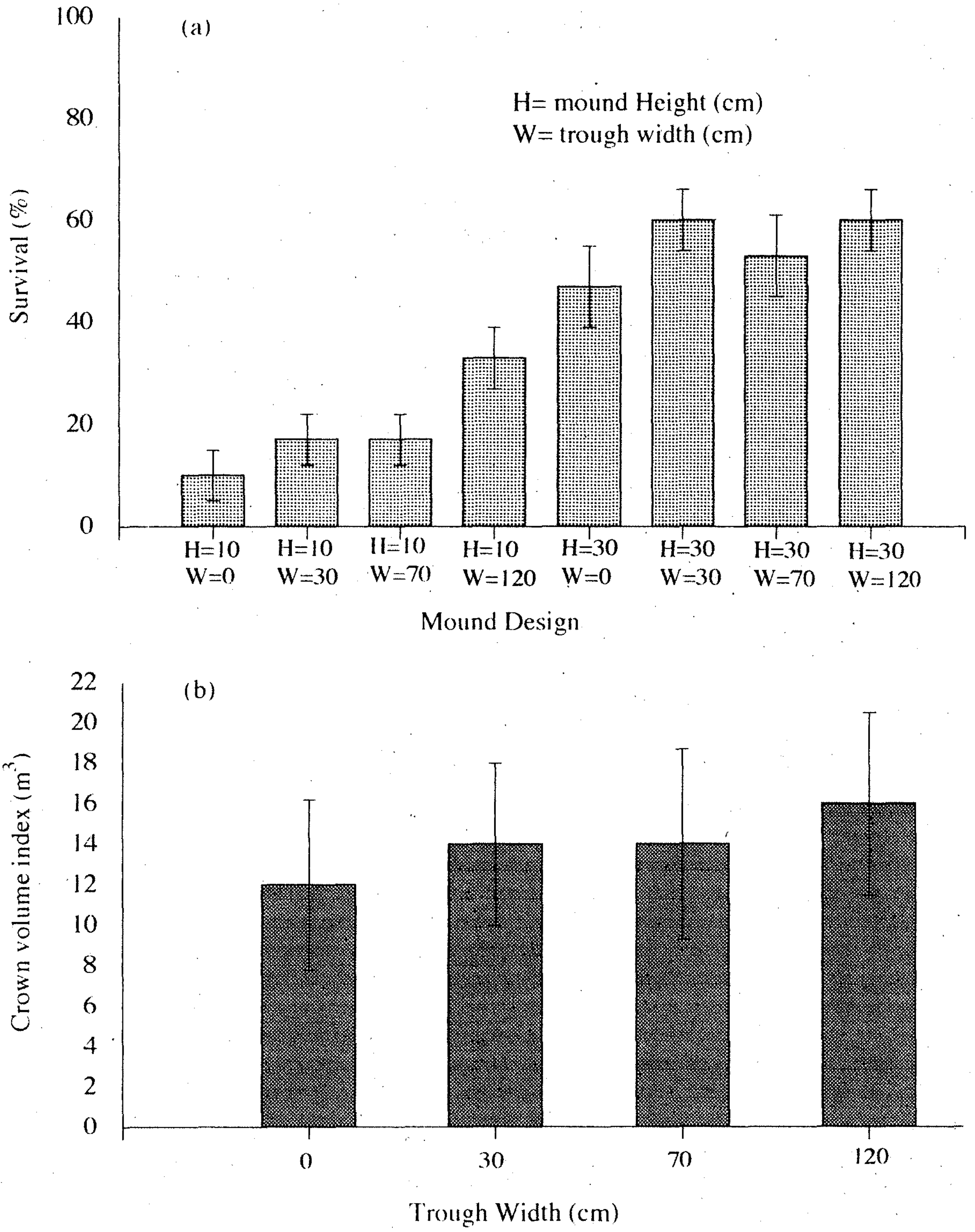


Figure 6 : **(a) Survival of *E. camaldulensis* clones 3 years after planting on the most severe saline waterlogged sites with different combinations of mound height and trough width. (b) crown volume index of seedlings with increasing trough width. Data are averaged for 2 species (*E. camaldulensis* and *C. obesa*) and 6 replications over 2 sites.**

survival showed that for the smaller mound height, survival was improved by large trough widths where as for large mound heights trough width only slightly improved survival.

For all sites planted in 1988, *C. obesa* had better height (3.2 m) and CVI (16.24 m^3) than *E. camaldulensis* clones (2 m and 11.3 m^3) 3 years after planting. There was also a significant effect of trough width for CVI with CVI increasing with increasing trough width (Figure 6b). For sites planted in winter 1989 survival rate of *E. camaldulensis* (Lake Albacutya provenance) seedlings (77%) was significantly less than *E. camaldulensis* clones (89%) and *C. obesa* seedlings (88%). There was also a significant effect of trough width on mean tree height and CVI with growth being better with increasing trough width. On the milder saline waterlogged sites trough width appears to be more important for seedling growth than mound height. This is possibly due to the effect of the trough channelling rainwater to the seedling root zone, increasing water availability over summer.

3.3 Mound Age

In Western Australia there is a widespread belief that ridge mounds in S/W sites should be formed a year in advance of planting to allow salt leaching from the mounds before planting eg. Hart (1972). This is despite the evidence that salts will accumulate rather than leach from single ridge mounds.

A trial was established in a transitional mild to severe S/W site to compare fresh and year old mounds. The area was mounded and planted in 1986 but required replanting due to high seedling mortality. In 1987 fresh mounds were formed between the year old mounds and both planted ie. seedlings were planted in, alternatively, 0 and 1 year old mounds. Standard single ridge mounds were used.

Survival was significantly better for all species planted in freshly formed mounds than in one year old mounds (Figure 7). However only *C. obesa* showed good establishment on this site. This illustrates the better adaptation of *C. obesa* to severe salt/waterlogging conditions. **From these results there is no evidence to suggest that forming mounds a year in advance of planting improved seedling establishment or growth, in fact there is evidence here that freshly formed mounds are better for survival and possibly growth of seedlings** (Pettit and Ritson 1990). For practical reasons mounds are usually formed in late summer/early autumn in the year of planting to give mounds time to stabilise.

3.4 Drainage

Improving drainage of S/W sites seems an obvious way of improving tree establishment. Active pumping to lower saline groundwater tables poses effluent disposal problems in water supply catchments. However, dewatering with surface drains may be useful. One way of doing this may be to use the furrows formed in the ridge mounding process as open ditch drains. Ways of improving the effectiveness of the furrows as drains would be to align them for maximum grade (recommended by FAO 1979) and to make the furrows deeper.

A trial to investigate the effectiveness of deeper furrows was established alongside the mound age trial ie. in the area mounded and planted unsuccessfully in 1986. A road grader was used to treat sections of the area by making every second mound higher, forming deeper furrows in the process. The deeper furrows should improve drainage of the standard mounds in between. This left treatment sections with alternatively (i) standard mounds with improved drainage and (ii) higher mounds, also with improved drainage (Figure 8). Between the 'treatment sections' untreated sections were left as a control ie. standard mounds without better drainage.

Standard mounds with improved drainage gave better survival of *C. obesa* than standard mounds without improved drainage (Figure 9a). Survival of *E. camaldulensis* was very low. Height and CVI growth of *C. obesa* was significantly better in standard mounds improved by drainage. For both species the higher mounds gave better survival as well as height and CVI growth (Figure 9 b,c). **The results clearly demonstrate the benefits of providing effective drainage through mounding for tree establishment in saline seeps. Both increasing furrow depth and increasing mound height were of benefit** (Ritson and Pettit, 1991).

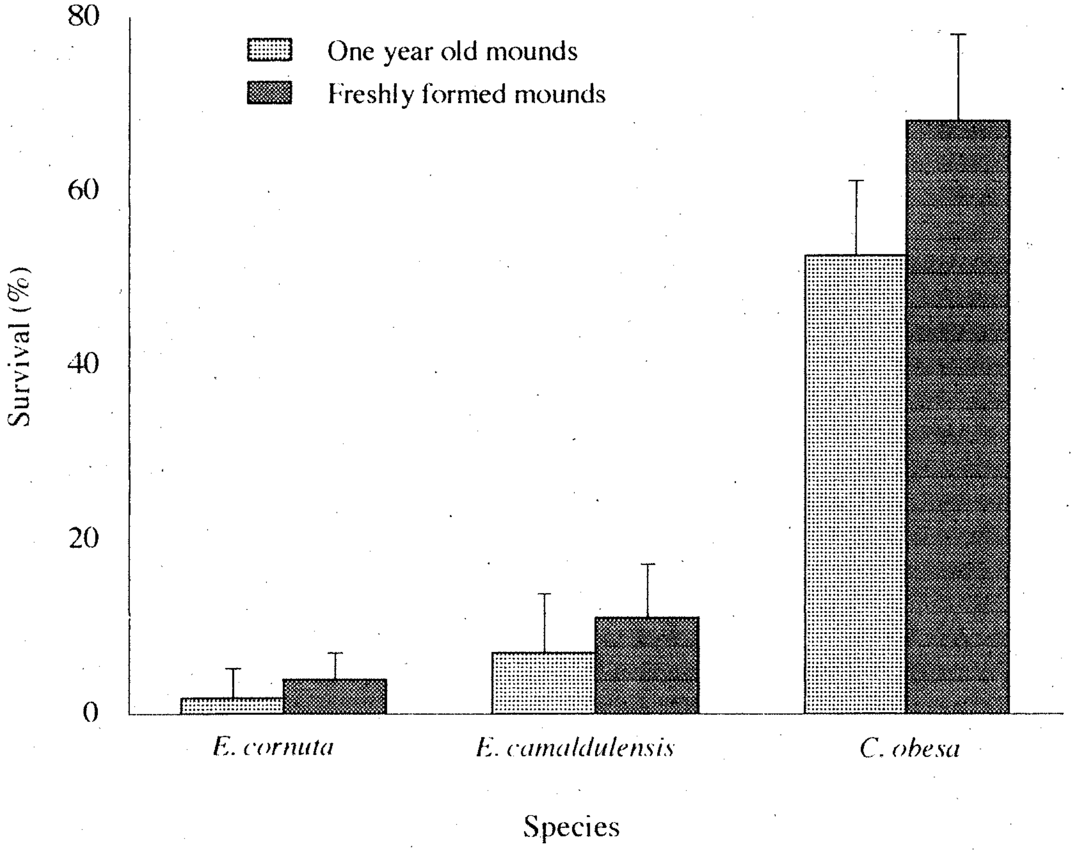
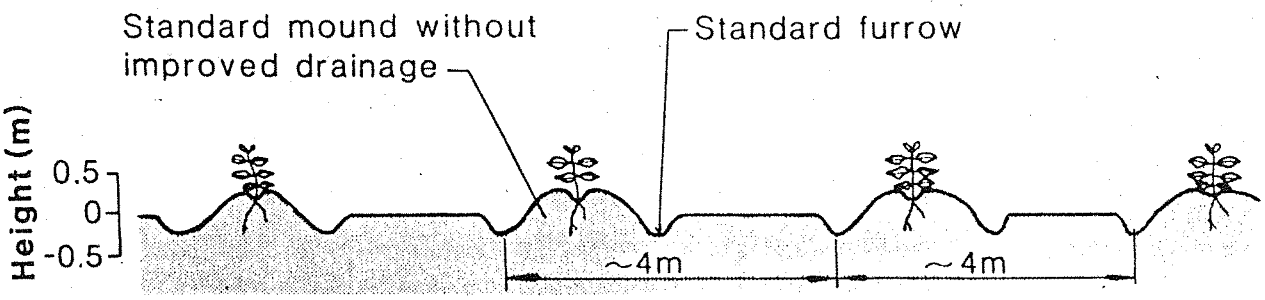


Figure 7 : **Survival 2 years after planting, with 95% confidence limits, of seedlings in mounds formed one year prior to planting and in freshly formed mounds.**

(a) Control section



(b) Treatment section

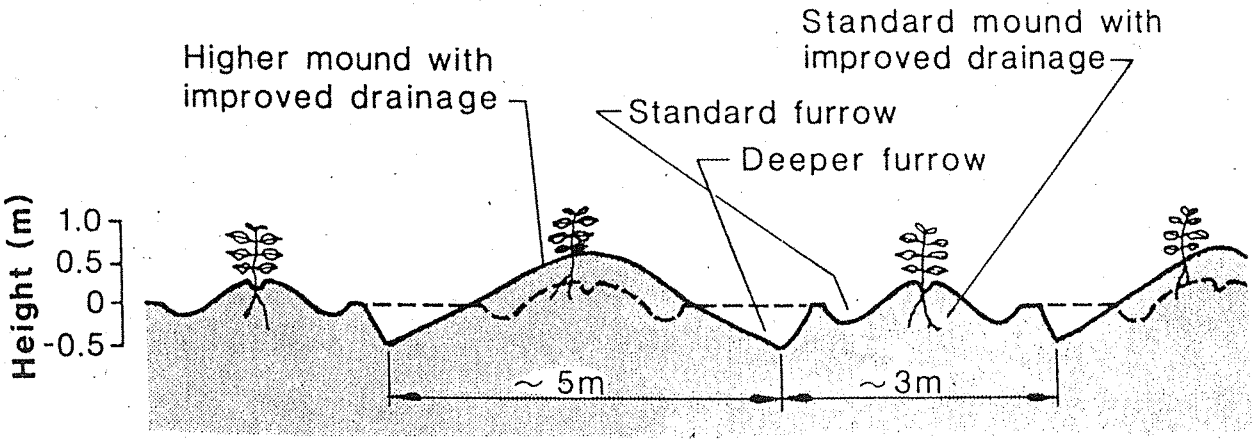


Figure 8 Mounds and furrows in the control and treatment sections of the drainage trial in 'Maringee' farm. The dotted line in the treatment section indicates the landform prior to a road grader forming deeper furrows (providing improved drainage) and higher mounds. The planting positions of seedlings are also shown

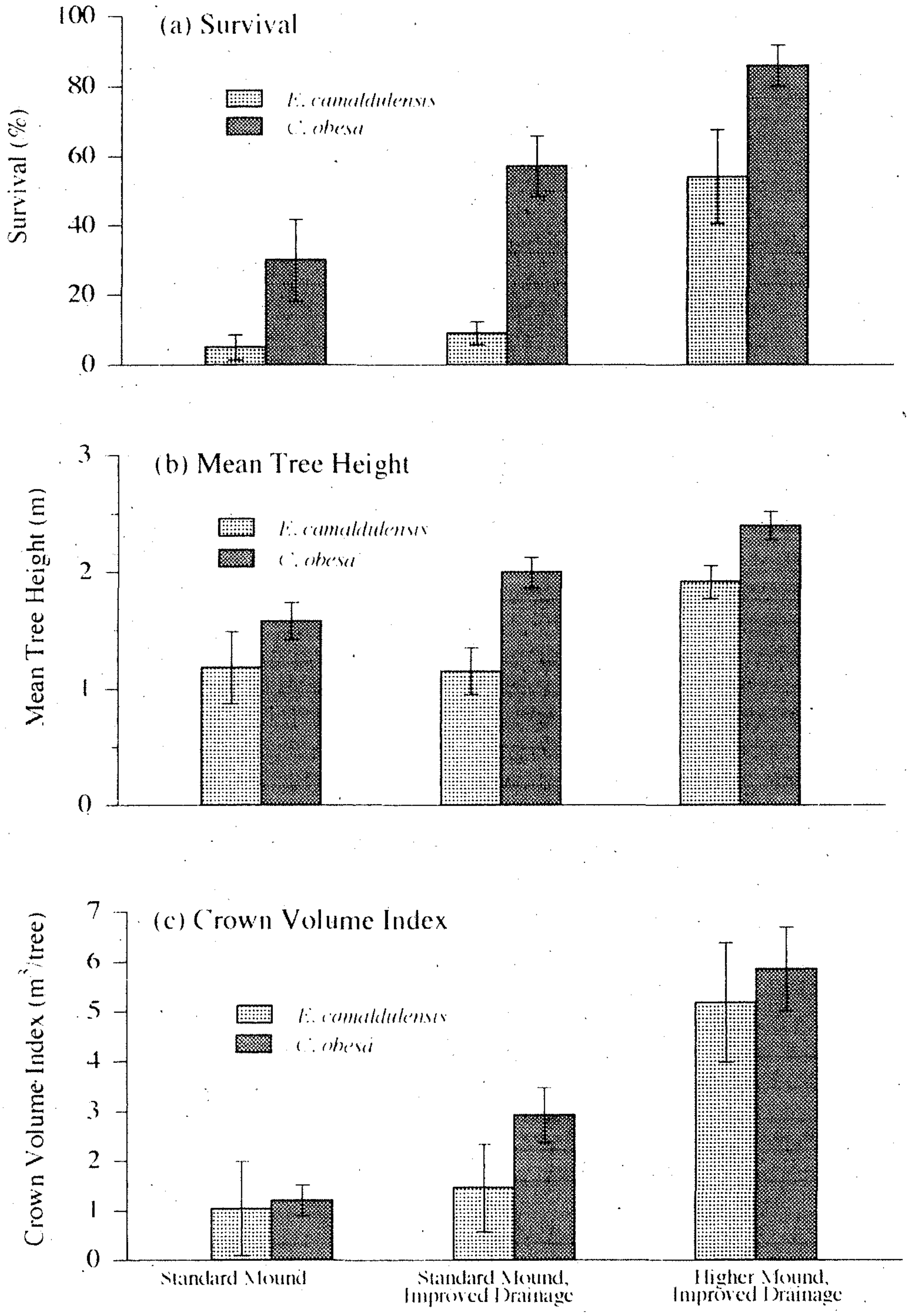


Figure 9 : (a) Survival, (b) Mean tree height and (c) Crown volume index, with 95% confidence limits, of *E. camaldulensis* and C. obesa 3 years after planting in the 3 drainage treatments.

3.5 Mulching

Covering soil with mulches such as hay, coarse sand or commercial preparations has been used to reduce salt concentration in the surface (20 or 30 centimetres) layer of soil and so aid revegetation with grasses or shrubs (Hamilton 1972; Malcolm and Swaan 1985; Smith and Stoneman 1970). Hamilton (1972) also reported that revegetation dramatically reduced salt content in the surface soil.

The effect of mulches is to conserve soil moisture by reducing evaporation. This increases downward water movement (hence salt leaching) with rainfall and reduces upward water movement (hence salt accumulation) with evaporation.

A trial commenced in 1987 in a mild S/W site to investigate whether hay or sawdust applied as mulches to ridge mounds can improve tree establishment.

Results have shown that a hay mulch spread 8-10 cm deep over standard mounds significantly improved seedling survival compared with survival with no mulch or a mulch of jarrah sawdust (Figure 10). Growth of seedlings was not affected by the use of a mulch. Another trial established in 1988 indicated that a hay mulch was effective in improving seedling establishment in the most severe saline waterlogged sites (Pettit and Ritson 1991). **Although this trial has indicated that tree survival in saline seeps can be improved by hay mulching there remains the problem of developing suitable techniques for mulch application on an operational scale.**

3.6 Hardpan Ripping

Hardpans have been found in the eastern WRC in some broad flat valleys subject to waterlogging and salinity. They have been noticed in areas where reforestation attempts have failed. The hardpans are generally encountered at around 0.5 metres depth. Four holes drilled through hardpans in the WRC indicated they were 20-80 cm thick.

The hardpans in the WRC appear similar to hardpans occurring elsewhere in Western Australia which have formed with aluminosilicates as the cementing agent (C.R.M. Butt and M.R. Thornber personal communication 1988; Butt 1983 and Thornber *et al.* 1987).

Where reforestation has failed in hardpan sites in the WRC it is most likely due to the increased waterlogging, caused by the hardpan, in combination with high salinity. It seems likely that the hardpans would also make tree establishment difficult by restricting root growth to the top 0.5 metres of soil.

A trial commenced in 1988 to determine if deep ripping (to 1.6 metres depth) improves tree establishment and rooting depth of 3 species (*C. obesa, E. sargentii* and *E. camaldulensis* clones) in hardpan sites. The trial has blocks in a mild S/W and a medium S/W site. A Komatsu 355 bulldozer was used for the ripping. Seedlings were planted in July '88.

Three years after planting tree height and CVI of seedlings were significantly better where planted after deep ripping treatment than under shallow ripping. The benefits of deep ripping in terms of tree growth have continued to improve over time with the difference increasing especially for CVI (Figure 11). Of the species planted *E. camaldulensis* clones had the best survival (82%) followed by *C. obesa* (63%) and *E. sargentii* (41%). In terms of survival there was a significant interaction between ripping treatment and site for survival with the shallow ripping showing better survival on the wetter site and the deep ripping showing better survival on the drier site. This may be due to the lack of mounding for the deep ripped treatment which reduced survival on the more waterlogged sites. Soil excavation beneath selected 18 month old trees at both sites showed that the maximum rooting depth for the shallow ripping treatment was 0.5 metres and 1.1 metres for deep ripping. **Although breaking up of hardpan by deep ripping has definite benefits for tree growth it requires the power of a large bulldozer which is very expensive. Work is continuing on improving the efficiency of deep ripping techniques** (Tsykin and Pettit, unpublished report).

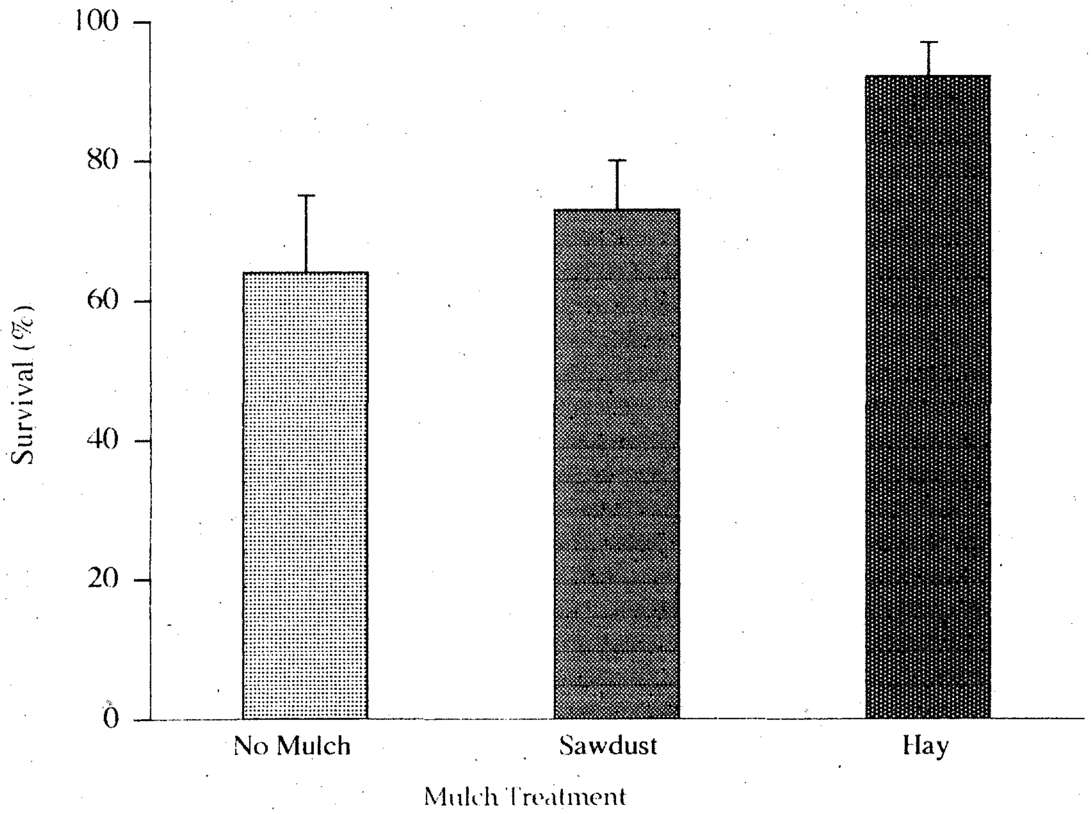


Figure 10 : Mean survival one year after planting, with 95% confidence limits, of seedlings planted in mounds with no mulch, sawdust mulch and hay mulch treatments. Data are averaged for 2 species (*E. camaldulensis and E. botryoides)* and 6 replications of treatment combinations.

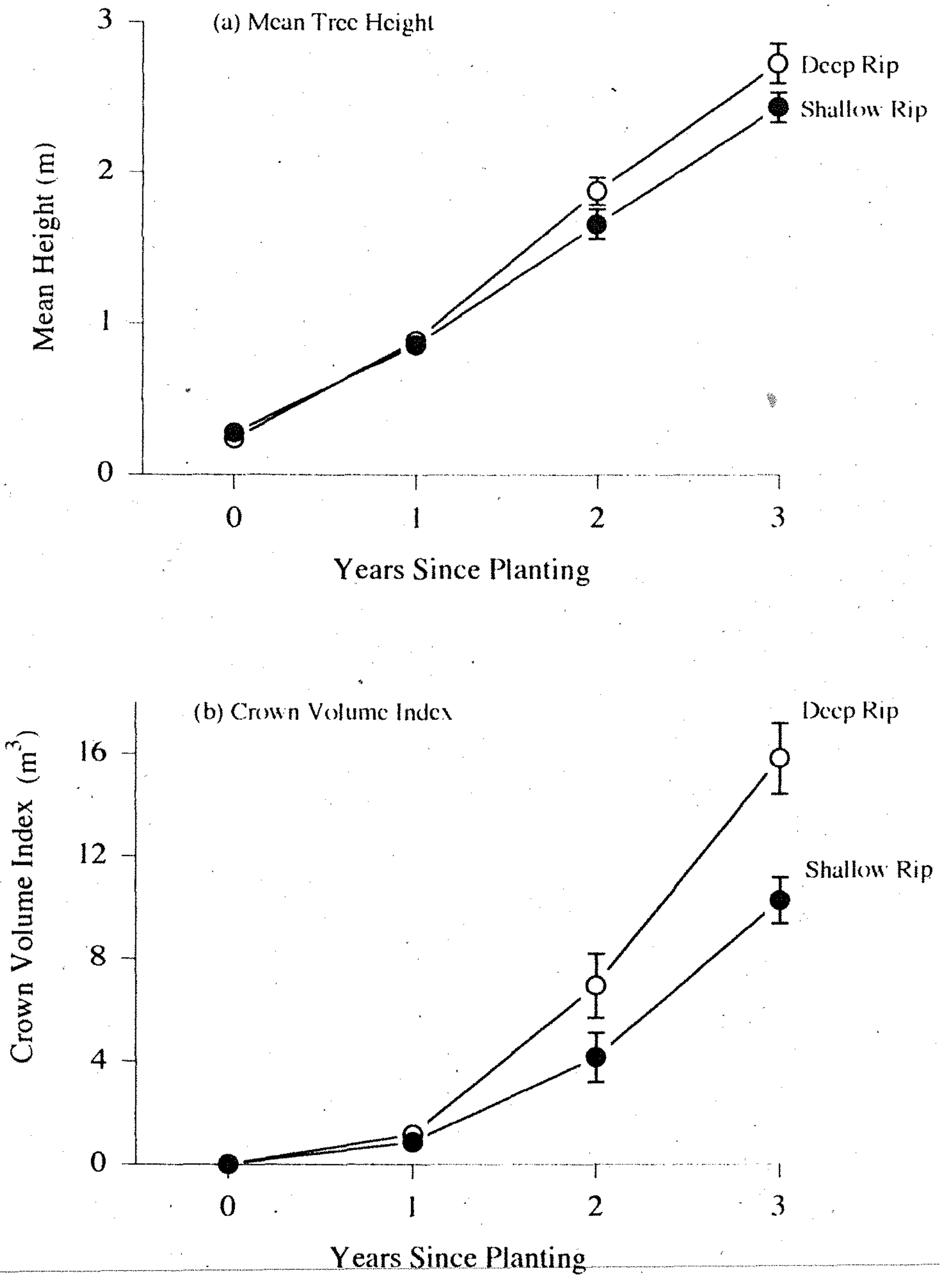


Figure 11 : **Mean tree height and crown volume index (with standard error)over time, of seedlings planted above shallow ripping (0.6 m) and deep ripping (1.5 m). Data are averaged for all species (E. camaldulensis, E. sargentii and C. obesa) and the two sites.**

3.7 Planting Time

It may be possible to improve tree establishment by adjusting planting times to take advantage of seasonal variations in waterlogging and soil salinity. For example S/W sites in the WRC are often planted early, rather than late in winter, as access is easier then. Early planting may put extra stress on seedlings compared with mid or late winter planting in two ways:

i) The seedlings must survive a whole winter of waterlogging before the main growing season commences in spring.

ii) Soil salinity may be at a seasonal high at the end of summer/beginning of winter, but at a seasonal low at the end of winter due to salt leaching by winter rains.

A trial was commenced in 1987 with seedlings planted each month from April to September. Two mild S/W and a non S/W site were included in the trials. Objectives were to find the best time to plant the seedlings and the range of months suitable for planting. Monthly measurements of soil moisture content and soil salinity in mounded and unmounded soil were also taken.

Survival rates approximately 2 years after planting for seedlings planted at the 3 sites are shown in Figure 12. Although rainfall for the year of planting (1987) was well below average (454 mm cf. annual average 640 mm) some useful indications as to when to plant are apparent from the results. Results indicate that late planting (post August) of any site should be avoided. This is due to the lack of reliable rainfall in late spring or early summer when seedlings have not developed a good root system and are at their most vulnerable. **Planting can commence in well drained sites once pre-winter or winter rainfall provides sufficient soil moisture for good seedling establishment. On poorly drained sites pre-winter planting is not recommended. If sites are also salt affected planting should not commence until sometime after rains have leached salts from surface soils** (Ritson and Pettit 1990).

3.8 Seedling Containers

Healthy, more robust seedlings will have a better chance of survival after planting than weak ones. In particular, seedlings planted in a harsh environment should benefit from a healthy root system. To test ways of raising more robust seedlings with healthy root systems, seedling container trials were commenced in 1987 and 1990. The 1987 trial was planted on a S/W site and a non S/W site. The 1990 trial was planted on 3 saline waterlogged sites varying in degree of severity.

With a bigger seedling container it is possible to raise a seedling with a bigger root system and hence higher root/shoot ratio. In the 1987 trial seedlings were raised in three sizes of container ie. small jiffy pots, large jiffy pots and large plastic pots which were approximately 2.5, 5 and 10 centimetres across the top respectively, with volumes of 24, 80 and 320 cm^3. Seedlings were planted on a harsh saline waterlogged site and a well drained non saline site. **On the harsh saline waterlogged site survival 2 years after planting improved with increasing container size** (Figure 13a). However survival was <20% for the biggest container, so on this site increasing container size alone was not sufficient to obtain good survival. **On the well drained non saline site survival was significantly improved with each increase in container size** (Figure 13b). **This indicates that large soil volumes can also prove to be an advantage in having a better root system at time of planting aiding survival over the dry summer period.**

A further seedling container trial was established in winter 1990 to test the effect on seedling establishment of 7 different container types and sizes. Preliminary results indicate there was uniformly good survival of C. *obesa* in all the container types. For *E. camaldulensis* the large soil volume root trainer pots improved survival significantly (Table 2). However the very large soil volume in the large root trainer pots make them difficult to handle and plant and they are also expensive. Therefore in this case it maybe better to improve survival by other means such as better species selection or site amelioration.

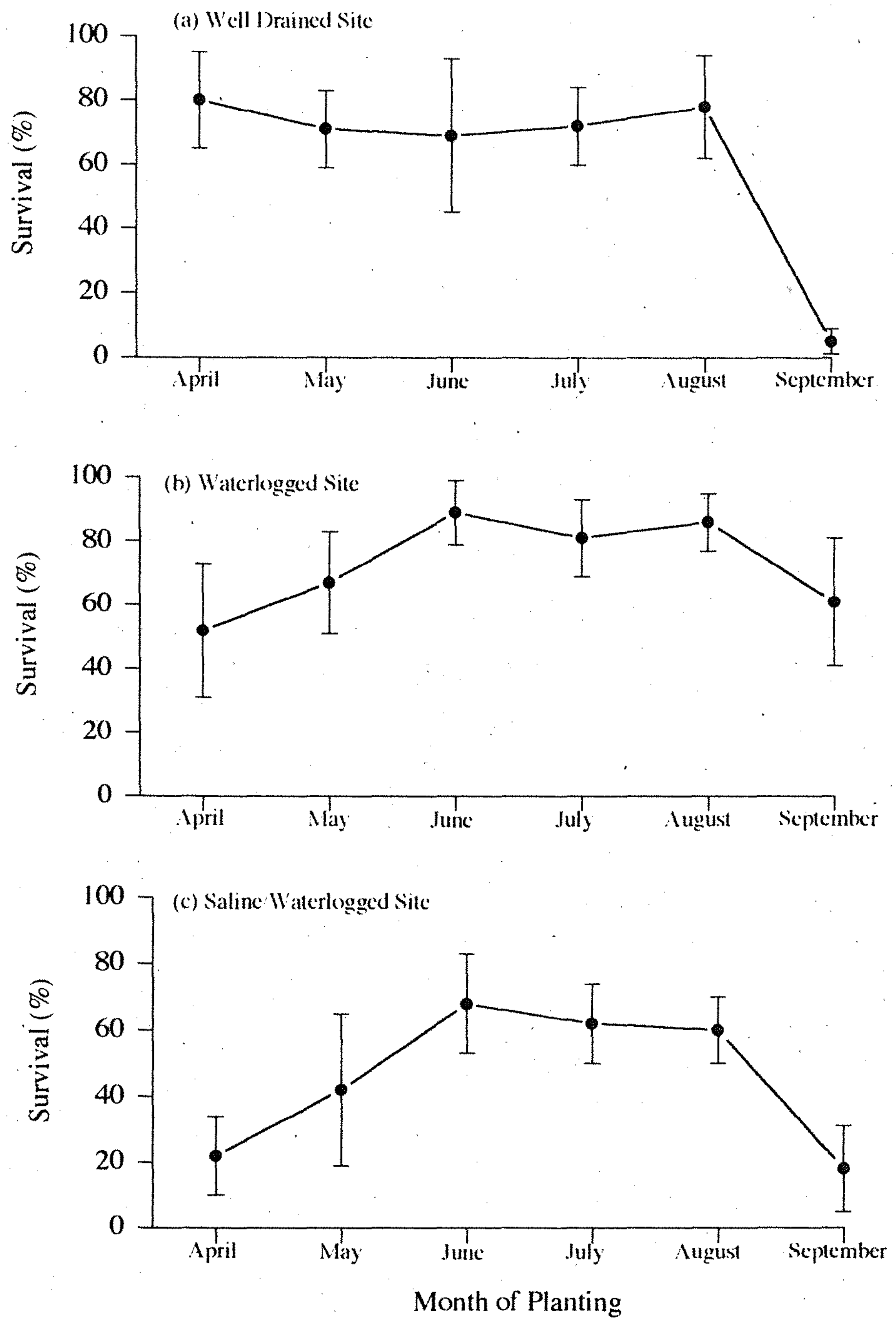


Figure 12 : Mean survival in July 1989 (approximately 2 years after planting) with 95% confidence limits, of seedlings planted in : (a) well drained site, (b) waterlogging affected site, (c) saline waterlogging affected site.

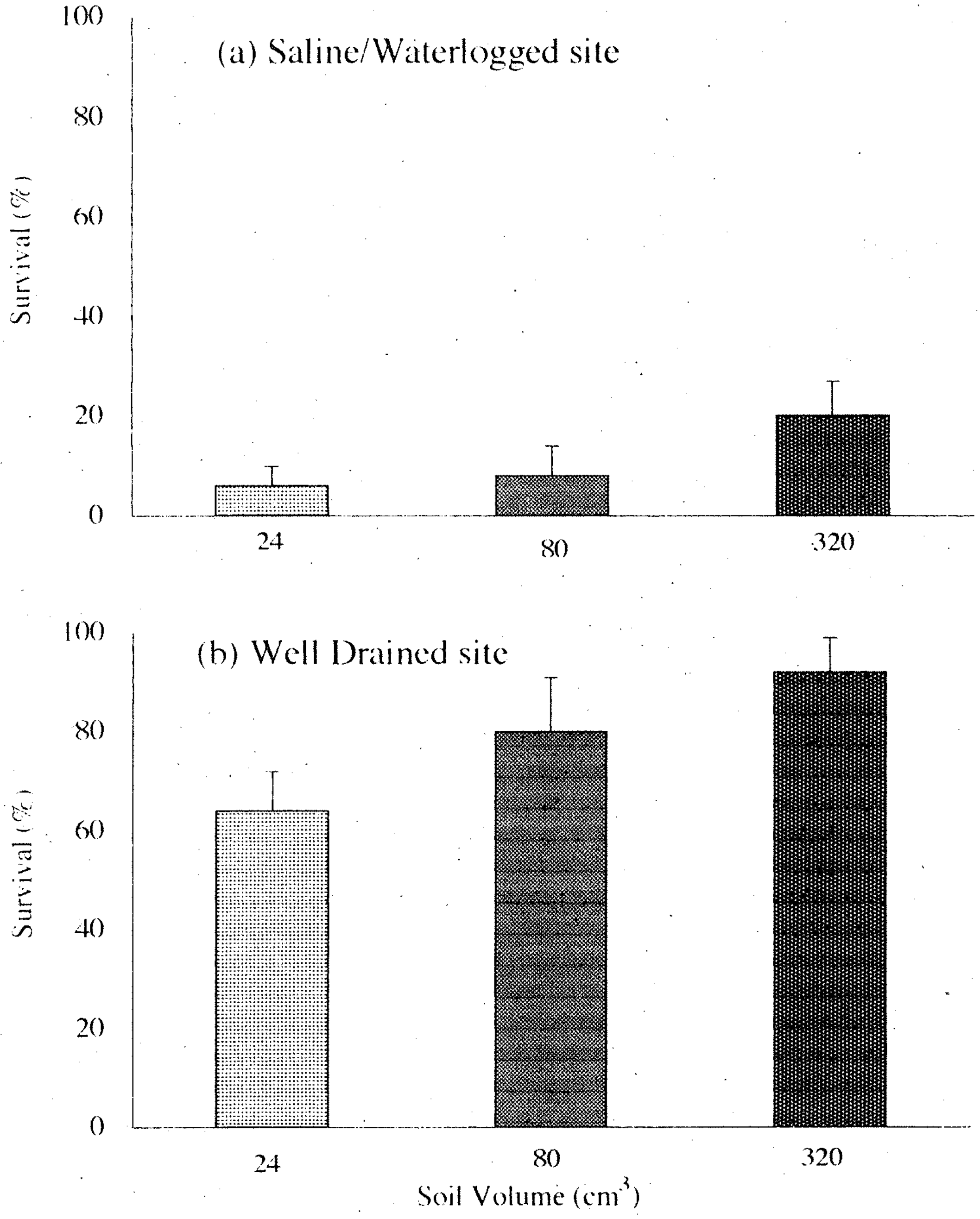


Figure 13 : **Mean survival one year after planting, with 95% confidence limits, of seedlings raised in peat based pots (soil volumes 24 and 80 cm^3) and plastic pots (320 cm^3 soil volume) . Data are averaged for the 3 tree species (*E. camaldulensis, E. woollsiana and E. cornuta*) and the 4 replications of treatment combinations.**

Table 2 : Survival rate of seedlings raised in different container types, one year after planting out in the field[a]. Survival rates are averaged for 5 replications over 3 sites.

Container Type	Soil Volume (cm^3)	*E. camaldulensis* [b] Survival (%) ± S.E.	*C. obesa* [c] Survival (%) ± S.E.
Small Jiffy Pot[d]	15.6	58 ±20	76 ± 8
Large Jiffy Pot	216	61 ±22	92 ± 4.5
Large Jiffy Pot [g]	292	64 ±19	89 ± 4.5
Small Kwik Pot[e]	15.6	60 ±20	83 ± 6
Large Kwik Pot	216	70 ±20	86 ± 6
Small Root Trainer[f]	315	61 ± 15	89 ±9
Large Root Trainer	864	84 ±11	82 ± 5

[a] Seedlings planted out in August 1990 and survival measurements taken in July 1991.
[b] Chi Square Test for survival of *E. camaldulensis* (p=0.013).
[c] Chi Square Test for survival of *C. obesa* (p=0.123).
[d] peat based containers.
[e] Moulded plastic trays treated with root inhibitor to prevent root binding and ease of removal.
[f] Long split moulded plastic containers with ribbed sides.
[g] Large Jiffy Pot with a greater depth of container.

3.9 Stress Conditioning

A trial was established in 1990 to test whether conditioning of seedlings in the nursery before planting on harsh saline waterlogged sites could improve survival. Three species were used *E. camaldulensis* (clone), *C. obesa* and *Melaleuca halmaturorum*. Seedlings for each species were divided into 3 groups and each group was subjected to one of 3 treatments.

i) control - standard nursery watering.
ii) waterlogging - seedlings subjected to waterlogging conditions in the nursery for 8 weeksbeforeplanting
iii) waterlogging and salinity - seedlings subjected to waterlogging and gradually increasing salinity (up to 300 mmol for *E. camaldulensis* and 600 mmol for the other species) 8 weeks before planting .

After nursery treatment seedlings were planted out into 3 saline waterlogged sites in the field. For analysis of results after one year *E. camaldulensis* was omitted as the seedlings for the saline/waterlogging pre-treatment were overstressed in the nursery and poor survival resulted. For the other 2 species both treatments gave significantly better survival than the control seedlings (Figure 14). The fact that the waterlogging pre-treatment gave as good or better survival as the salinity and waterlogging pre-treatment at all of the sites indicates the importance of this as a useful stress conditioning treatment. The waterlogging treatment would be much easier to set up in the nursery than trying to gradually increase salinity levels. Another interesting result from this trial is the better survival overall of *M. halmaturorum* (89%) than *C. obesa* (62%) which is usually regarded as the most salt tolerant species grown in the eastern Wellington Catchment. It is too early to tell if the pre-treatments will have any effect on seedling growth. **These preliminary results are promising and indicate that stress conditioning may be useful in improving seedling establishment when planted in saline waterlogged conditions.** Further trials in collaboration with the University of W.A. have been planned for 1992 looking at a range of species and several salinity and waterlogging pre-conditioning treatments.

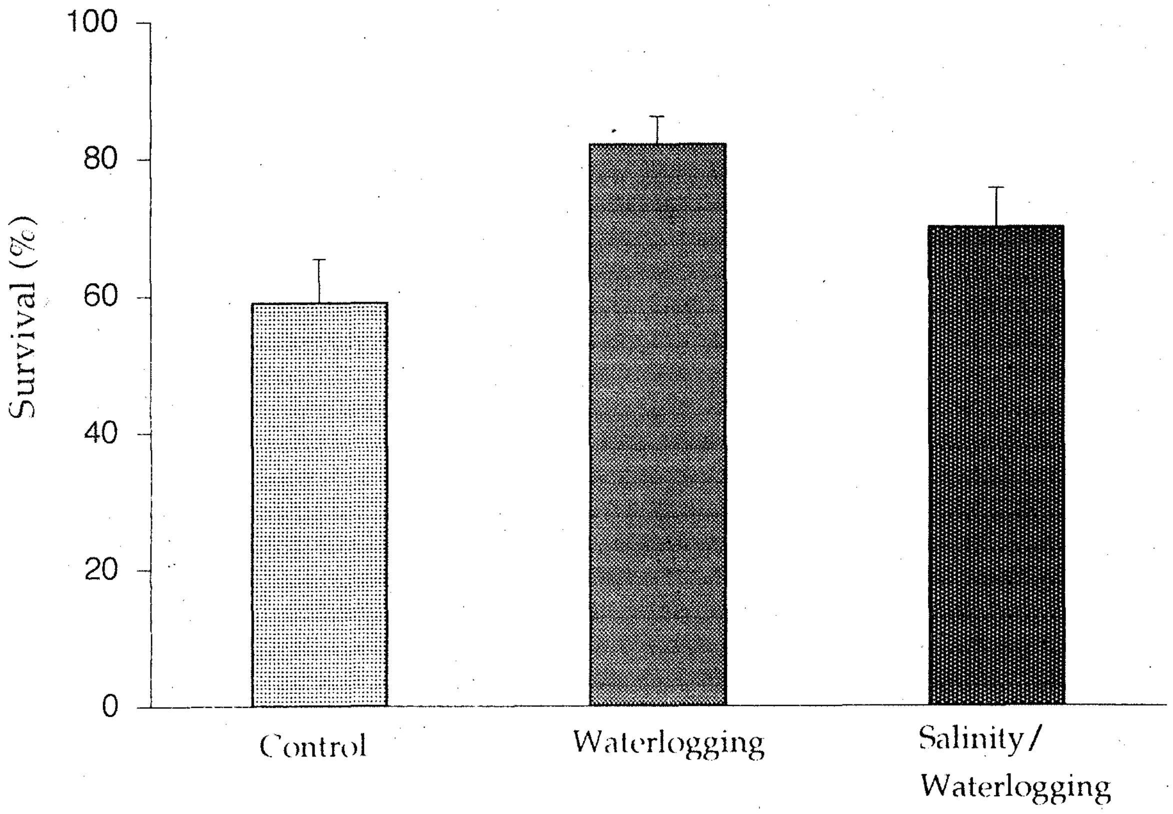


Figure 14 : Survival of seedlings 1 year after planting with stress conditioning treatment. Data is averaged from 3 sites and 2 species (*C. obesa* and *M. halmaturorum*).

3.10 Fertiliser Trials

Three fertiliser trials were commenced in 1987 to determine nitrogen and phosphorous requirements of seedlings planted on farms in the WRC. These were the two elements judged most likely to restrict plant growth. Sites were selected to be representative of the range of conditions encountered in the reforestation areas within the catchment ie.

(a) seasonally waterlogged.
    (i) comparatively infertile sand over clay soils.
    (ii) comparatively fertile gravelly sandy loam soils.

(b) well drained
    (i) moderately fertile gravelly sandy loam soils.

The same sixteen fertiliser treatments were applied in each trial. They were combinations of nitrogen and phosphorous rates ie. four rates of nitrogen (0, 6, 17 and 34 grams per seedling in Agran 34 fertiliser) times four rates of phosphorous (0, 5, 12 and 24 grams per seedling in Superphosphate fertiliser). Fertiliser was applied in the first two weeks after planting.

On the seasonally waterlogged sites, results over 3 years of measurement showed no response to any level of N, P or N+P fertiliser. There was in fact a decline in survival with increasing rates of N. An experiment was commenced in 1991 to test the effect of using slow release fertilisers or delaying fertilising of seedlings on waterlogged sites. This is to test whether this lack of response is due to the loss of the applied fertiliser before seedlings were able to use it. On the well drained site there was a growth response to fertiliser. This differed for each species. *E. microcarpa* showed no response to any level of N or P fertiliser. **There was a significant response of *E. globulus* to addition of P fertiliser. This was from 0 up to 5g P with little further increase at higher levels of P (Figure 15). There was also an initial significant response of *E. globulus* to N. After 2 years, tree height and CVI improved with increasing levels of N. However after 3 years this response was not apparent.** For *E. sideroxylon* there were significant NxP interactions on tree growth. These included a significant increase in growth with increasing levels of P at 34 g N and a significant growth increase with increasing levels of N at 24 g of P. Unless there is a commercial benefit to be obtained from the trees there may be no advantage in fertilising except maybe to bring forward the time at which maximum crown cover is achieved. The experiment is described in full in (Ritson *et al.* in press).

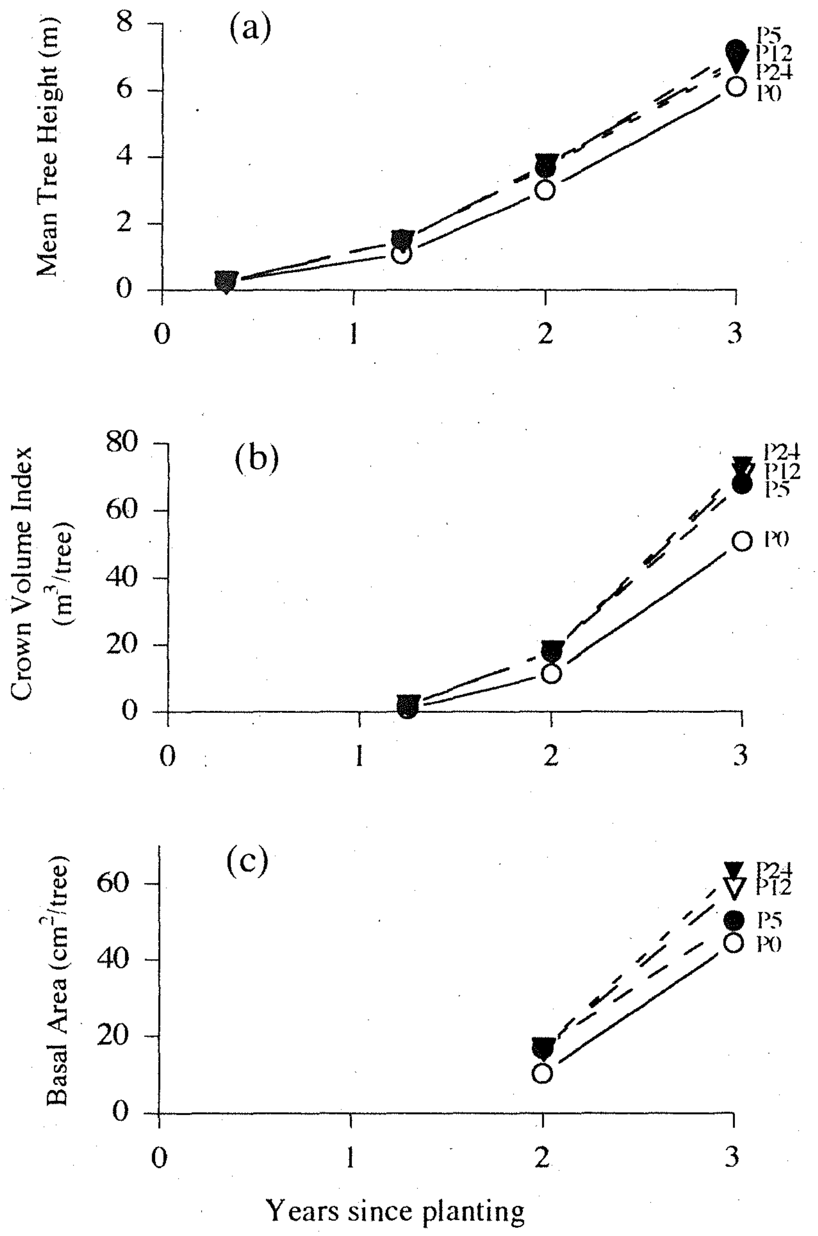


Figure 15 : Response over time of E. globulus **(a) mean tree height, (b) crown volume index and (c) basal area to selected P levels i.e. 0 g P (P0), 5 g P (P5) 12 g P (P12) and 24 g P (P24). Data are averaged for all replications and levels of N fertilisation.**

4. PLANT SELECTION TRIALS

4.1 Introduction

(a) Level

Initial selection of plants is usually done at species level. Once promising species have been identified the selection process may be refined by selection at provenance level or individual superior plants ('plus trees') may be selected for cloning.

(b) Criteria

In selecting trees and shrubs for reforestation to control saline groundwater discharge, the following criteria should apply. The criteria are similar to those developed by Morris and Thompson (1983).

(i) Adapted to the environment to be planted in. ie. tolerant of environmental stresses and capable of long term survival and growth.

(ii) Give most rapid depression of saline groundwater tables.

(iii) Multiple use trees or shrubs ie. in addition to salinity control provide secondary benefits such as wood products (pulpwood, timber or fuelwood), honey production or stock feed.

Thus, once plants adapted to the environment are identified, selection should be based on ability to depress saline groundwater tables. Amongst plants which give comparable rates of groundwater depression, selection should be based on secondary uses of those species.

Species indigenous to the area may not always be the best. Many of the areas in the WRC which are now saline seeps would have supported forests or woodlands dominated by the eucalypts *E. wandoo* or *E. rudis*. It is usually impossible to re-establish E. wandoo in saline seep areas. This is because *E. wandoo* cannot tolerate the increased soil salinity and waterlogging conditions consequent of saline seep development. *E. rudis* can be re-established in saline seep areas, but frequently suffers extensive leaf loss due to leaf miner (*Perthida* sp) attack.

(c) Other studies

Other studies provide useful information on plant selection. Those studies relate to salt/waterlogging tolerance and groundwater depression and are discussed below.

(i) Salt/waterlogging tolerance

Results of field studies in salinity and waterlogging (high watertable) stress conditions have been reported from Western Australia (Pepper and Craig 1986; Hart 1972; Biddiscombe *et al.* 1981,85), from Victoria (Morris 1984) and from overseas (Donaldson *et al.* 1983; Zohar 1982; Mathur and Sharma 1984). Although Eucalypts species were the most common (or only) species planted in each of the above studies the range of tree and shrub species covered by all trials also included species of *Casuarina, Acacia, Melaleuca, Tamarix, Leptospermum* and *Pinus*. There are apparent inconsistencies between studies in reported salt tolerances of species. This may be due largely to provenance variation within species. Also, differences between sites, not only in soil salinity, but in waterlogging and other site conditions, may have contributed to the apparent inconsistencies. Amongst the eucalypts, the species most consistently reported as salt tolerant were *E. occidentalis, E. sargentii, E. platypus , E. camaldulensis* and *E. spathulata.*

Recommendations of species for planting in sites subject to salinity and waterlogging have also been produced by Negus (1986) and the Woods and Forests Department (undated). Besides the *Eucalyptus* species consistently reported as being salt tolerant, tree and shrub species recommended include *Casuarina obesa* and species of *Melaleuca*, *Tamarix* and *Acacia*.

Further progress in plant selection is being made from studies in Western Australia supported by the National Biotechnology Program. Screening of an extensive range of species and provenances of *Eucalyptus*, *Casuarina*, *Melaleuca* and *Acacia* for tolerance to salinity and waterlogging stresses, both individually and in combination, is being undertaken. Most of the studies have been under greenhouse conditions. Results confirm that there is a wide variation in tolerance between provenances of most species. This emphasises the importance of selecting at provenance, rather than species, level. Results from the greenhouse studies also show that selection of plants for tolerance to the single stress of salinity is a poor indication of a plant's tolerance to the combined stresses of waterlogging and salinity. Interestingly tolerance to the single stress of waterlogging was found to be a much better indication of a plants tolerance to combined waterlogging and salinity stresses. This emphasises the importance of selecting for waterlogging tolerance, as well as salinity tolerance, when identifying plants for establishment in saline seeps. The identification, cloning and testing of superior individual plants has also been undertaken, but this work is at an early stage. (Kabay *et al.* 1986; van der Moezel and Bell 1987; van der Moezel et al. 1988; D T Bell personal communication. 1988).

Despite the progress made in plant selection for salt/waterlogging tolerance more information is needed. This applies particularly to selection for severe S/W sites, that will compliment progress made in improving site preparation.

(ii) Groundwater Levels

In contrast to severe S/W sites a large range of species have been identified in the WRC project and elsewhere which can be established in non S/W sites. Species selection based on relative ability to depress saline groundwater tables is desirable, however this is difficult to quantify directly.

Studies showing that reforestation in south-west Australia has lowered saline groundwater tables have been reported by Engel 1987 (one site) and Bell *et al.* (1988) (eight sites). All sites included a variety of species, but differences in groundwater depression rates between species were not commented on. Only indirect measurements of the relative ability of different species to lower groundwater tables have been reported. Hookey *et al.* (1987) reported a study of 23 provenances (from 19 species) of *Eucalyptus*.. The species selected for the study were the best performers in terms of survival and growth of 70 species (average of two different provenances per species) planted in the Bingham River Arboretum. That arboretum covers non S/W and mild S/W sites in the low rainfall zone of the WRC. Trees in the arboretum were seven years old at the beginning of the two year study period. There were difficulties in interpreting the results due to variation between provenance plots (eg. in soil texture and groundwater depth and salinity) and a lack of leaf area measurements.

However based on seasonal leaf conductance trends estimates of transpiration per unit leaf area and leaf water potential/leaf conductance relationships, it was concluded that provenances of four species had desirable water use characteristics for salinity control in the arboretum site. These were *E. microcarpa* (two out of three provenances), *E. woollsiana* (one out of two provenances), and *E. sideroxylon* and *E. botryoides* (one provenance of each studied). It was recommended that such species be actively considered for planting adjacent to saline groundwater discharge areas.

Greenwood *et al.* (1985) measured annual evaporation from grazed pasture and five species of *Eucalyptus* in two farm plantations, one located immediately upslope and the other located further upslope at a hillside saline seep. The plantations were seven years old and located near Bannister (annual rainfall of 800 mm yr) in the Hotham River Catchment. They found that evaporation from the plantations was 4-5 times that from the grazed pasture. The greatest estimated evaporation rate for each site was from the *E. globulus* plantations although the range between species was not great. Estimates of annual evaporation rates ranged from 1620 to 2210 mm and 2330 to 2660 mm for species in the "immediately upslope" and "upslope" plantations respectively.

(d) Field studies in the WRC

While information from other studies provides useful indications for plant selection separate field trials were considered necessary in the WRC for two reasons.

(i) To check that indications from greenhouse and field trials conducted elsewhere apply in the particular conditions (salinity, waterlogging and other stresses) in the WRC sites.

(ii) More information to indicate the relative ability of different plants to lower saline groundwater tables is required.

4.2 Plant Selection Trials for S/W Sites

Both shrub and tree species were studied. This is because it may only be possible to re-establish shrub, if any, species in the worst sites, even with improved site preparation techniques. Many of the sites originally supported only shrub communities eg. predominantly *Melaleuca* communities. The presence of a hardpan at some of these sites may have restricted or prevented tree growth.

Trials have been planted in sites where previous attempts at reforestation were unsuccessful. Presumably the initial reforestation attempt failed because the species planted were not tolerant of the environmental stresses in those sites. Each of the trials consisted of a randomised block design.

(i) South's Flat trial

The trial is located in an area, known locally as South's Flat, where reforestation with *E. cornuta* and *E. occidentalis* was attempted unsuccessfully in 1982. The site was replanted in 1986 with a selection of shrub and small tree species thought to be more salt and waterlogging tolerant. Results of measurements at age 3 years are shown in Table 3.

Table 3: Survival, Height, Crown Volume Index and Biomass Index of species 3 years after planting on mild saline waterlogged site on South's Flat..

Species	Survival (%)	Mean Height (m)	Crown Volume Index [a] (m^3)	Biomass Index[b]
Casuarina obesa	65	2.56	9.29	603
Eucalyptus occidentalis	64	2.40	7.56	484
Tamarix aphylla	24	1.88	4.43	106
Melaleuca lanceolata	59	0.97	1.53	90
Melaleuca cuticularis	45	0.84	1.43	64
Eucalyptus cornuta	0	-	-	0

[a] Crown volume index = height x crown diameter^2.

[b] Biomass Index = Survival x CVI

Notes :
(i) Reforestation of trial site attempted unsuccessfully in 1982 with *E. cornuta* and *E. occidentalis*
(ii) Area replanted in August 1986 with the above six species.
(iii) Seedlings planted in the original mounds formed in 1982. The mounds were approximately 10 cm high in 1986.
(iv) Above data are means from two blocks (replicates) in the trial.

(ii) Saltbush (Atriplex) species trial

This trial is a replicate of trials conducted by the Agriculture Department of W.A. at various sites, mostly salt affected land in the Wheatbelt region of W.A. (B. Ward, personal communication 1986). Nine species, or ecotypes of species, were planted in 1986.

The results of survival and growth of seedlings after 4 years is given in Figure 16. **Considering the harsh conditions of high soil salinity and waterlogging, survival and growth was encouraging. It is clear that the first year is critical for good seedling establishment. Initial survival could be improved with the use of larger more robust seedlings and better mounds** (see previous trials). A full report of this trial is given in Pettit and Ritson (1991).

(iii) 1988 trial

A third trial which commenced in 1988 included two *Atriplex* species *A. cinerea* and *A. lentiformis*. *Melaleuca thyoides*, *E. sargentii* and a salt/waterlogging tolerant clone of *E. camaldulensis* identified in the National Biotechnology Program studies.

The trial was planted at 2 locations on sites affected to varying degrees by salinity and waterlogging. At each location three replications (blocks) were placed on sites showing mild (100% barley grass cover) medium (50% barley grass cover) and severe (10% barley grass cover) salinity and waterlogging. Results show the better performance of the tree species *C. obesa* and *E. camaldulensis* clone (Table 4). Survival of the *Atriplex* species and *M. thyoides* was low due probably to the waterlogged conditions. Growth of survivors of the *Atriplex* species was good but poor for *M. thyoides*. There was also a large amount of variation in growth response between blocks with the eucalypt species and *C. obesa* showing a large decline in growth with increasing severity of the sites. This was not evident for the other species (Figure 17). Results on the benefit of a hay mulch indicate that using a mulch is only of benefit on the most severe sites. On these sites however the increase in survival is quite substantial (Figure 18) (Pettit and Ritson 1991).

Table 4: Survival, Height, Crown Volume Index and Biomass Index of species 2 years after planting , Species and Mulch Trial.

Species	Survival (%)	Mean Height (m)	Crown Volume Index[a] (m^3)	Biomass Index[b]
Casuarina obesa	81	3.0	11.0	891
Eucalyptus camaldulensis	85	1.6	9.8	833
Eucalyptus sargentii	50	1.6	5.0	250
Atriplex lentiformis	29	1.4	8.2	238
Atriplex cinerea	45	0.35	3.3	148
Melaleuca thyoides	29	0.5	0.24	116

[a] Crown volume index = height x crown diameter^2.

[b] Biomass Index = Survival x CVI

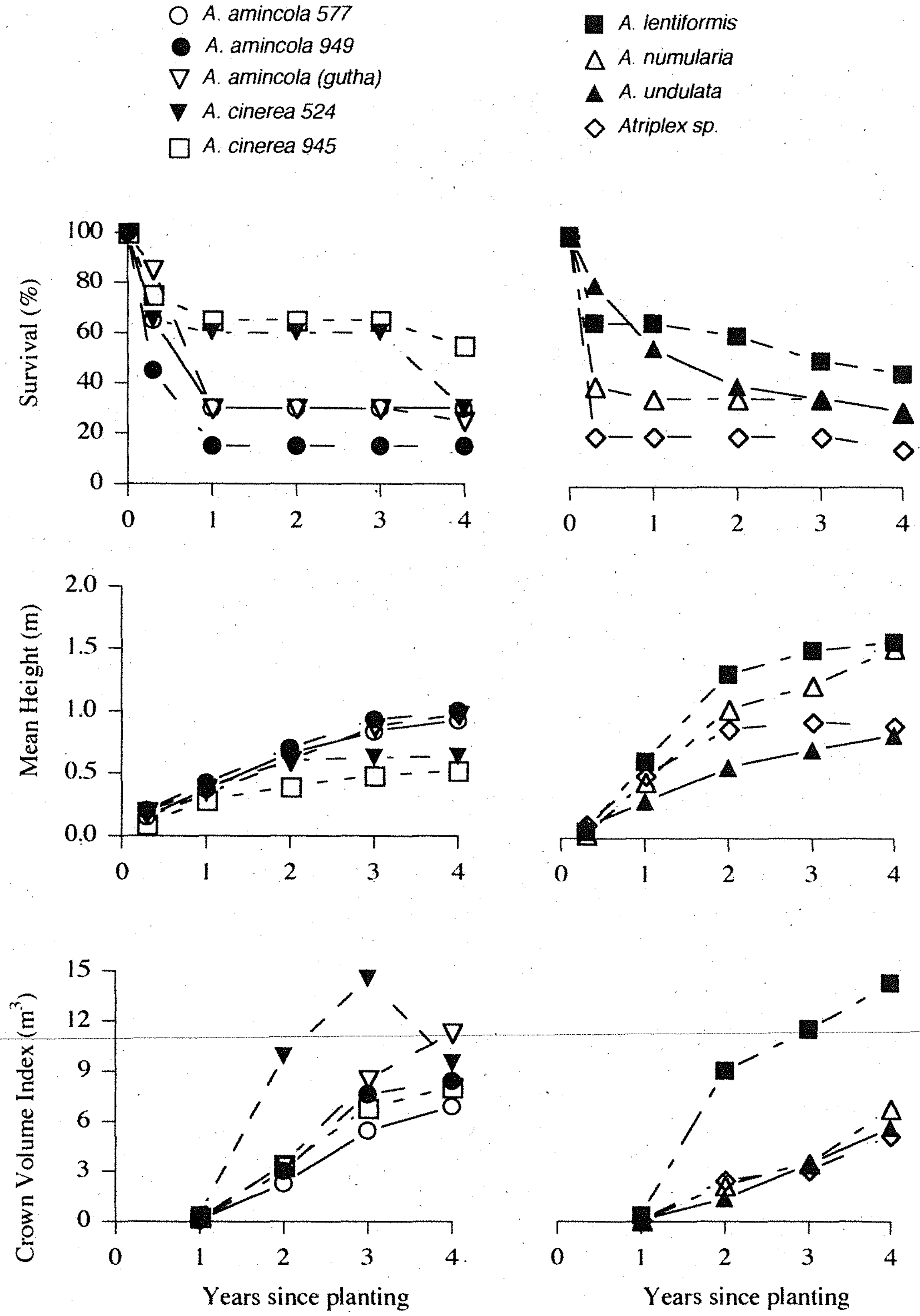
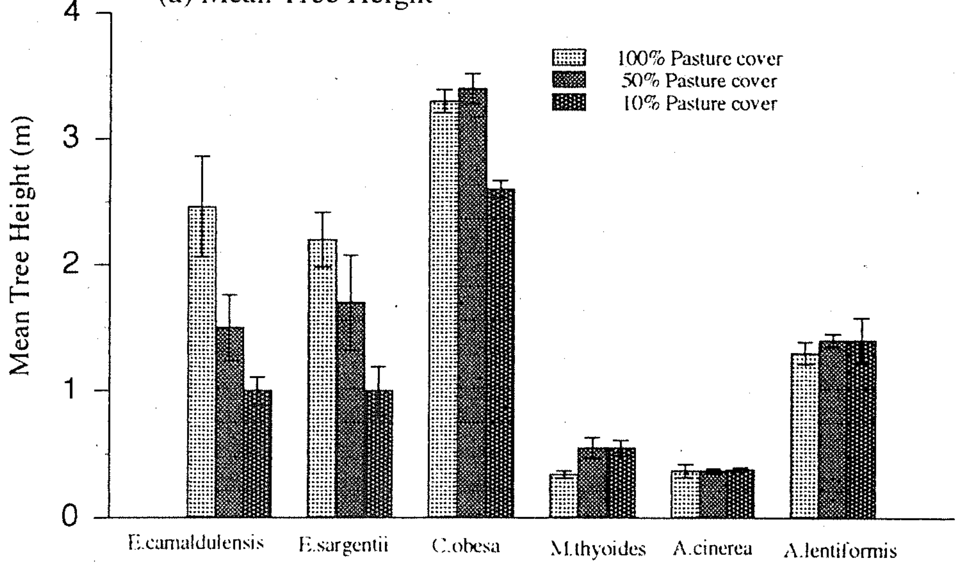


Figure 16: Survival, Mean height and crown volume index over the four years since planting, of nine species and ecotype of Saltbush.

(a) Mean Tree Height



(b) Crown Volume Index

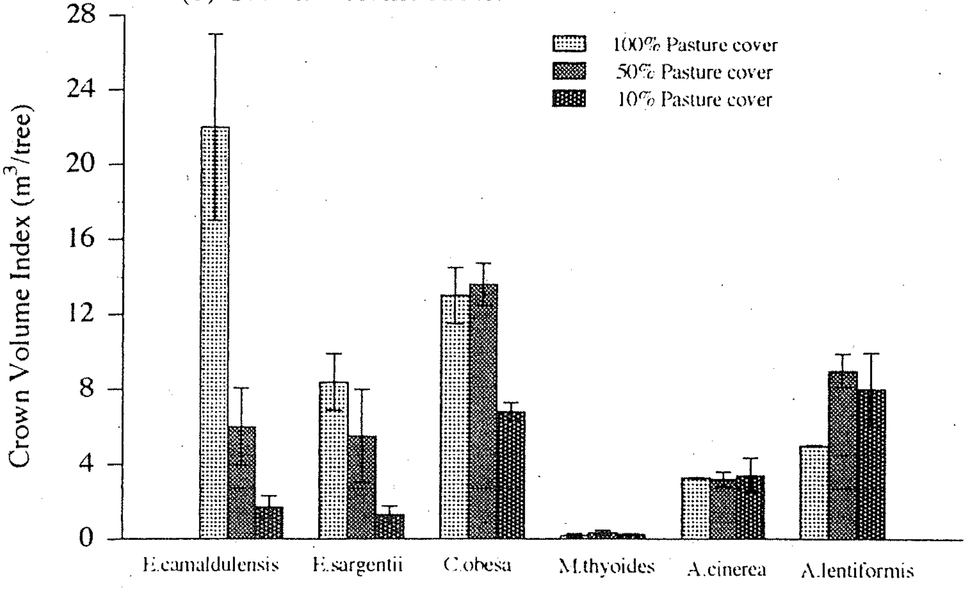


Figure 17: Effect of pasture cover on species, three years affter planting for (a) mean tree height and (b) crown volume index. Data are averaged for both sites in the Species and Mulch Trial.

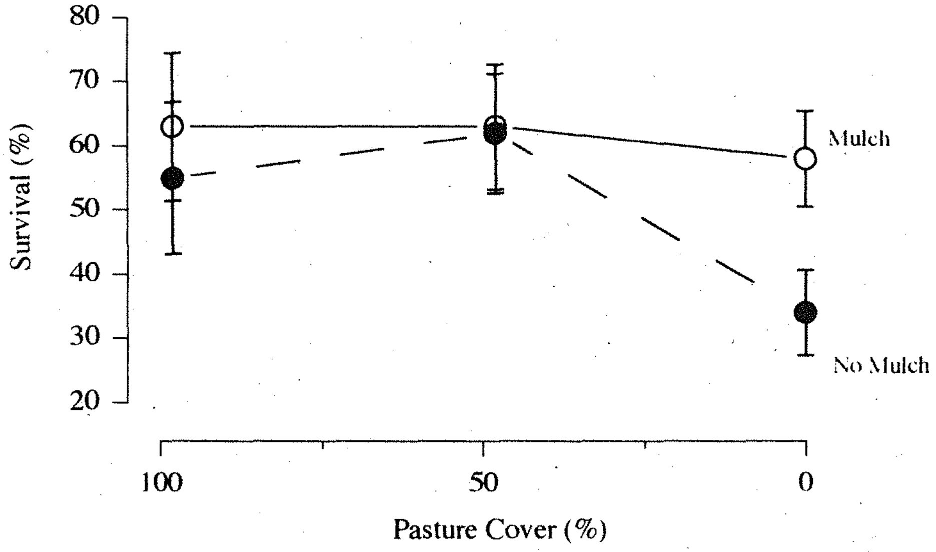


Figure 18: Effect of hay mulch on seedling survival three years after planting at three levels of pasture cover. Most scolded ground (least pasture cover) indicates most severe salt/waterlogging stress. Data are averaged for all species and both sites in the Species and Mulch Trial.

(iv) Species site adaptation trial

A species performance trial was commenced in 1987 in which the species of most interest for planting in the WRC (Table 5) were planted on a variety of sites. The sites, two in S/W , four in non saline well drained and one in non saline waterlogged conditions, were chosen to represent the range of soil conditions in the catchment. Species performance was evaluated by percentage survival and initial growth. A randomised block design was used for the trial with two blocks in each of six sites.

Table 5 : Species selected for the species site adaptation trial.

Species	Reason for selection			
	Desirable water use[a]	Known to grow in salt water-logged sites	Dual Use[b]	Native species[c]
C. obesa		x		x
E. sargentii		x		x
E. camaldulensis		x	x	
E. largiflorens	x			
E. sideroxylon	x			
E. cornuta		x		x
E. wandoo				x
E. polyanthemos	x			
E. botryoides			x	
E. globulus			x	
E. microcarpa	x			
E. woollsiana	x			
E. saligna			x	

[a] Suggested from Bingham River leaf conductance study reported by Hookey *et al* (1987).

[b] Fast growing species with potential to provide commercial pulpwood crop as well as depressing groundwater.

[c] Occurs naturally in south west Western Australia

Results for the 2 S/W affected sites are given in Table 6. This clearly shows the poor tolerance of all species tested in the severe conditions experienced (TSS content averaged 26,200 mg/L for the 2 sites). **The notable exception to this in *C. obesa* .**

Table 6: Survival, Height, Crown Volume Index and Biomass Index of species 4 years after planting on saline sites , Species Site Adaptation trial.

Species	Survival (%)	Mean Height (m)	Crown Volume Index [a] (m^3)	Biomass Index[b]
C. obesa	72	3.1	14.0	1008
E. sargentii	30	2.2	8.8	264
E. camaldulensis	20	1.9	4.0	80
E. largiflorens	13	2.0	9.0	108
E. sideroxylon	6	2.5	12.4	37
E. cornuta	2	2.6	19.0	38
E. wandoo	5	1.4	3.5	17
E. polyanthemos	5	1.0	0.6	2
E. botryoides	0	-	-	0
E. globulus	0	-	-	0
E. microcarpa	0	-	-	0
E. woollsiana	0	-	-	0
E. saligna	0	-	-	0

[a] Crown volume index = height x crown diameter^2.

[b] Biomass Index = Survival x CVI

On the 4 non saline sites survival was generally good for all species, the exception being *C. obesa* at site 6 where seedlings were grazed by sheep (Table 7). **Over all sites, the growth of *E. globulus* was much greater than the other species tested.** However at site 5 (a site with shallow gravelly loamy sand) the biomass index of *E. botryoides* was greater than *E. globulus* this was due to the better survival of E. botryoides on this site (Table 7). The mean height and CVI of the five best performing species are given in Figures 19 and 20. A full report of this trial is given in Pettit and Ritson (1991).

Table 7: Survival, Height, Crown Volume Index and Biomass Index of species 4 years after planting on non saline sites , Species Site Adaptation trial.

(a) Site 3 - gravelly loamy sand, well drained.

Species	Survival (%)	Mean Height (m)	Crown Volume Index[a] (m^3)	Biomass Index[b]
E. globulus	90	9.4	155	13950
E. saligna	73	6.5	109	7957
E. botryoides	73	6.5	104	7592
E. camaldulensis	80	5.4	79	6320
E. cornuta	63	5.3	70	4410
E. polyanthemos	93	4.3	34	3162
E. wandoo	63	2.6	21	1323
C. obesa	90	4.0	14	1260
E. largiflorens	90	2.1	13	1170
E. microcarpa	93	1.7	7	642
E. sideroxylon	77	2.1	7	516
E. woollsiana	83	1.7	5	448
E. sargentii	27	2.5	12	324

(b) Site 4 - deep sand, well drained.

Species	Survival (%)	Mean Height (m)	Crown Volume Index[a] (m^3)	Biomass Index[b]
E. globulus	63	8.5	126	7938
E. saligna	80	5.7	83	6640
E. botryoides	86	5.5	75	6450
E. cornuta	73	5.5	83	6059
E. camaldulensis	87	5.0	50	4350
E. polyanthemos	93	3.3	20	1860
E. wandoo	83	2.0	9	730
E. largiflorens	83	1.9	8	639
C. obesa	93	2.8	5	502
E. sargentii	47	2.6	7	348
E. microcarpa	97	1.3	3	330
E. sideroxylon	77	1.7	4	308
E. woollsiana	80	1.0	1	80

(c) Site 5 - shallow gravelly loamy sand, well drained.

Species	Survival (%)	Mean Height (m)	Crown Volume Index [a] (m^3)	Biomass Index[b]
E. botryoides	84	5.6	92	7728
E. globulus	74	7.6	103	7622
E. saligna	81	4.9	85	6885
E. cornuta	59	5.5	91	5369
E. camaldulensis	80	4.3	53	4240
E. polyanthemos	80	4.0	26	2080
E. sargentii	77	3.8	23	1771
E. wandoo	72	3.2	23	1656
E. largiflorens	81	2.7	16	1296
E. microcarpa	97	2.4	11	1067
C. obesa	81	3.7	10	810
E. sideroxylon	62	2.7	12	732
E. woollsiana	90	1.8	6	540

(d) Site 6 - sandy loam, seasonally waterlogged.

Species	Survival (%)	Mean Height (m)	Crown Volume Index [a] (m^3)	Biomass Index[b]
E. globulus	80	8.0	120	9600
E. saligna	87	5.4	98	8526
E. camaldulensis	97	5.1	86	8342
E. botryoides	77	4.8	63	4851
E. cornuta	50	4.6	62	3100
E. largiflorens	76	2.9	26	1976
E. sargentii	77	3.8	25	1925
E. wandoo	77	3.0	24	1848
E. sideroxylon	47	3.4	33	1551
E. polyanthemos	80	2.7	19	1520
E. microcarpa	76	2.8	17	1292
E. woollsiana	84	2.4	12	1008
C. obesa	35	1.2	1	35

[a] Crown volume index = Tree height x crown diameter^2.

[b] Biomass index = Survival x crown volume index.

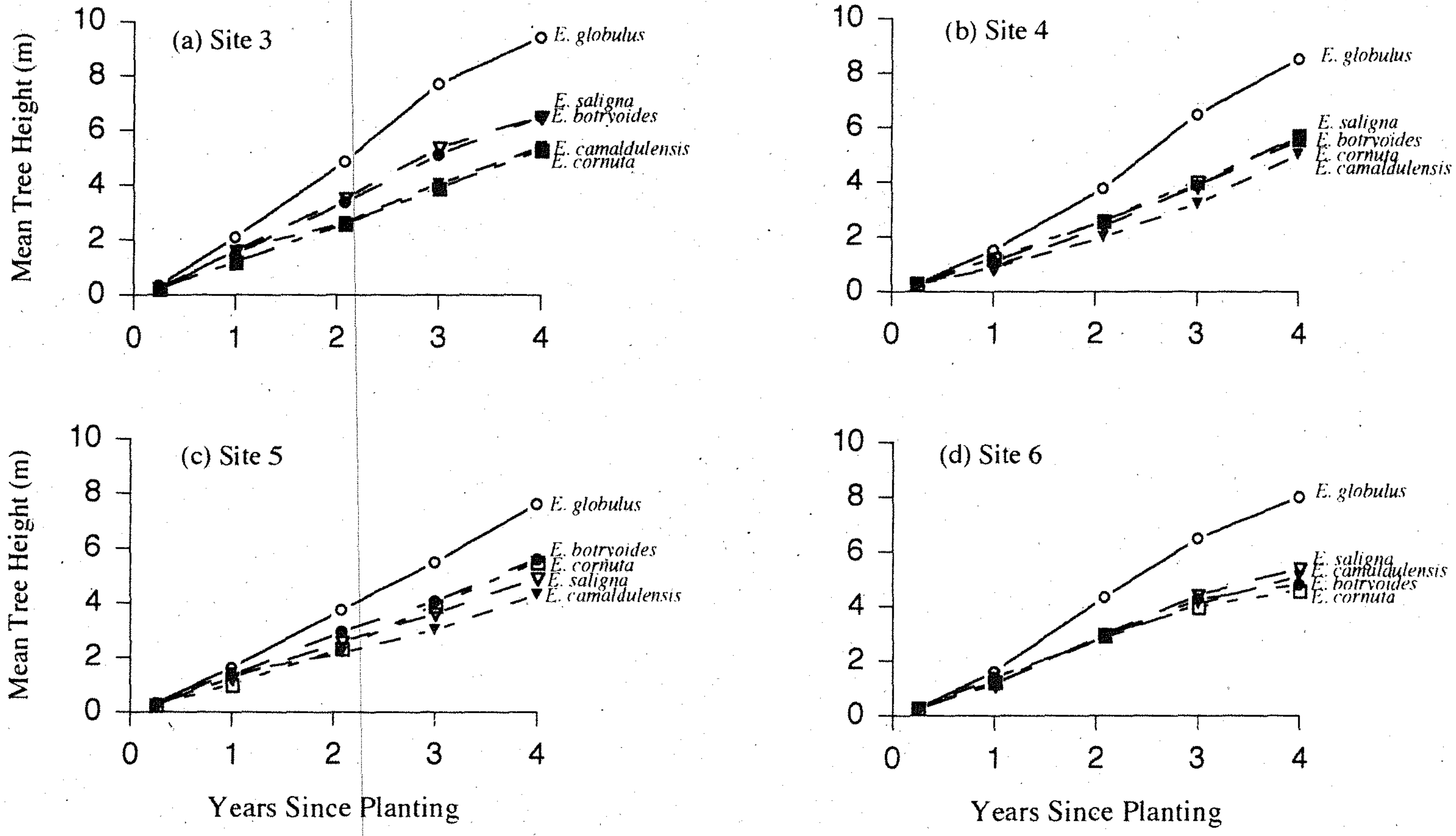


Figure 19 : Mean tree height of the five best performing species on the four non saline sites, Species Site Adaptation trial. (a) Site 3: gravelly sandy loam soil, well drained. (b) Site 4: deep sandy soil, well drained. (c) Site 5: shallow gravelly loamy sand over clay soil, well drained. (d) Site 6: sandy loam soil, poorly drained.

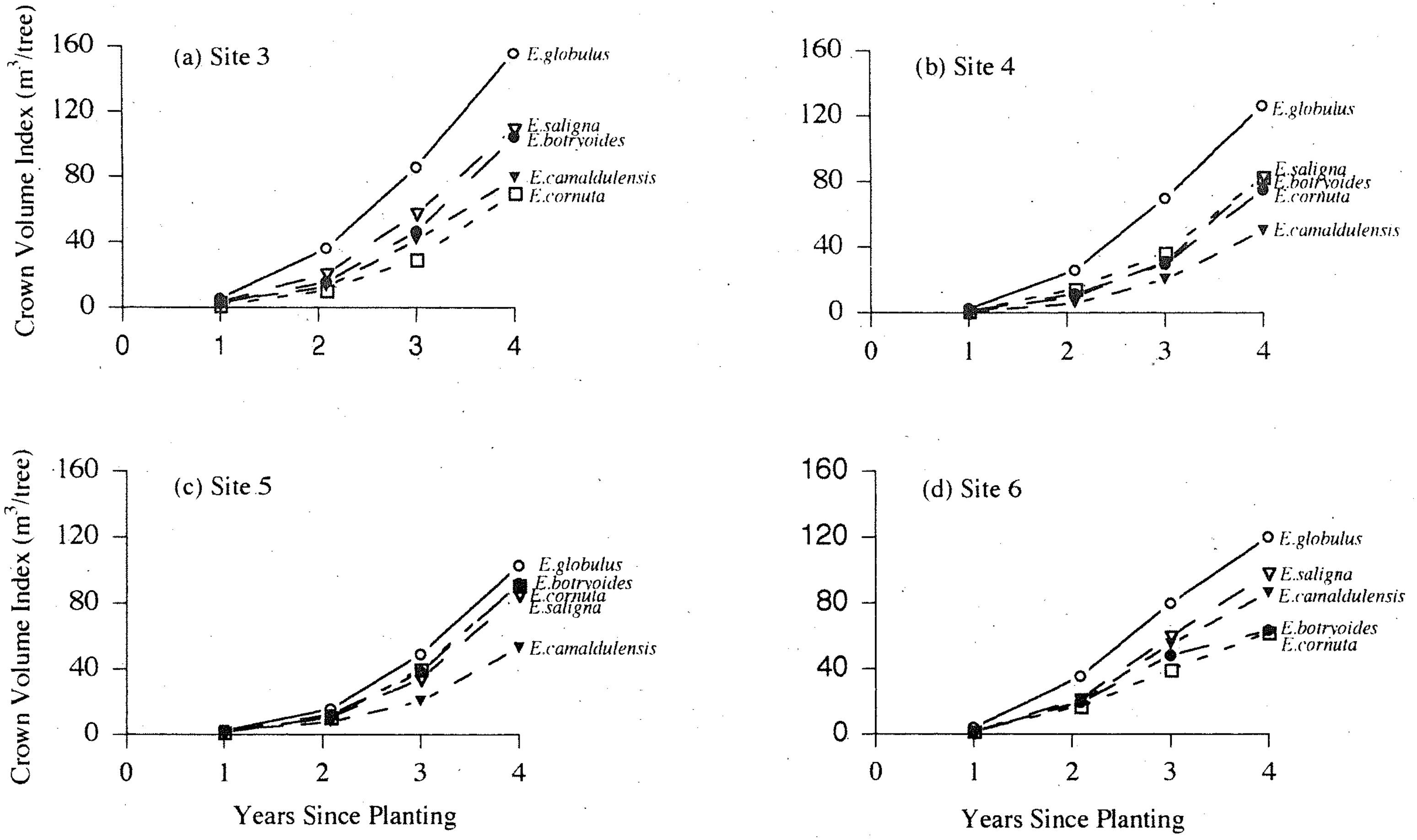


Figure 20 : Crown volume index of the five best performing species on the four non saline sites Species Site Adaptation Trial. (a) Site 3: gravelly sandy loam soil, well drained. (b) Site 4: deep sandy soil, well drained. (c) Site 5: shallow gravelly loamy sand over clay soil, well drained. (d) Site 6: sandy loam soil, poorly drained.

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