Water Authority
of Western Australia

Research to Improve Reforestation Techniques for Saline Groundwater Discharge Control in Water Resource Catchments in the South-west of Western Australia

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ABSTRACT

This report describes a research programme, commenced in 1986, to improve reforestation techniques for saline groundwater discharge control in water resource 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 were high soil salinity, waterlogging, drought, low soil fertility and hardpans. Recognizing 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 characterize 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 only 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 fertilizer 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. One leaf conductance trial and 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.

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 (Fig. 1) over 5000 hectares of cleared land have been planted with a variety of species, mostly eucalypts, since 1976. Planting is continuing at the rate of approximately 6-700 ha yr^{-1}.

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 i.e. greater than 1000 or 5000 mg L^{-1} total soluble salts (Stokes <u>et al</u>. 1980). With clearing, groundwaters increase in salinity as they rise and mobilize 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

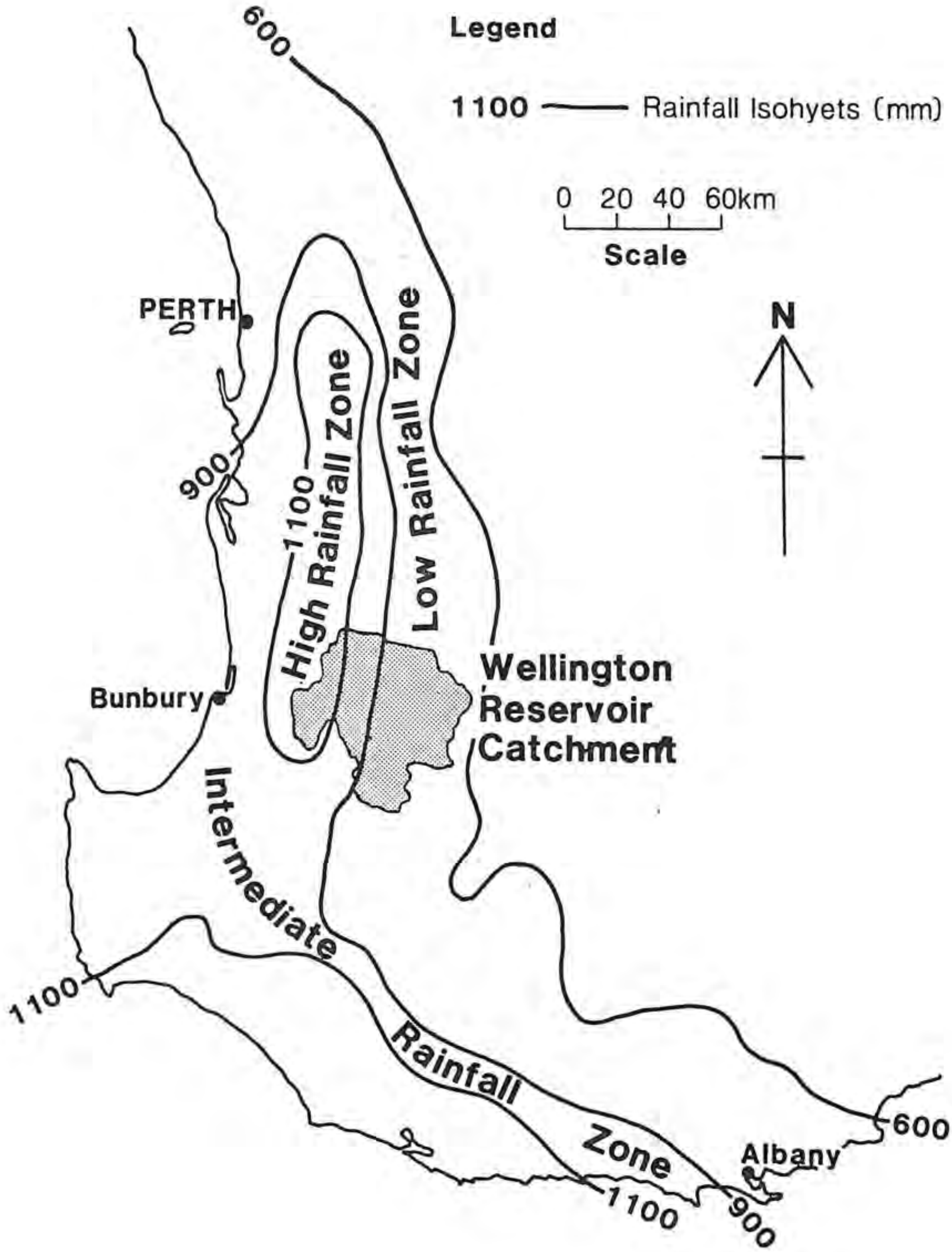


Figure 1 Location of the Wellington Reservoir Catchment and rainfall zones

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 described 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 e.g. 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 e.g. see Morris and Thompson (1983); Schofield et al. (in prep.). 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.

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. All trials commenced or planned for commencement in 1988 are briefly described but results are only presented and discussed for those trials which have progressed such that useful conclusions can be drawn from the results already obtained.

2 DEVELOPING A RESEARCH PROGRAM

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 i.e. often (especially in winter and spring) less than 0.5 m deep. Stresses, relating to oxygen deficiency, will occur below and just above the watertable.

(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, out of the above environmental stresses, 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 e.g. Barrett-Lennard (1986) has pointed out the particularly important interaction between salinity and waterlogging in restricting plant growth.

Recognizing the importance of salinity and waterlogging for plant growth three site types were defined and are referred to in this report. i.e.

(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/waterlogging 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 and, also, 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 directly relevant 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 i.e. :

(1) 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 i.e. 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 randomized block design experiment.

Most establishment trials were commenced in winter 1987. Others were commenced in winter 1986 or are planned for commencement in winter 1988.

The main evaluation of trials will be based on survival and early growth of seedlings and should be possible in two years from trial commencement i.e. most results from the establishment trials should be obtained in the years 1988-90. Notwithstanding this, the trials should be monitored beyond two year's age to check initial conclusions.

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 so formed. 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 enough 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 sites (see Fig. 2 and Table 1). The mounds were formed with a Buckeye pipeline trenching machine.

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

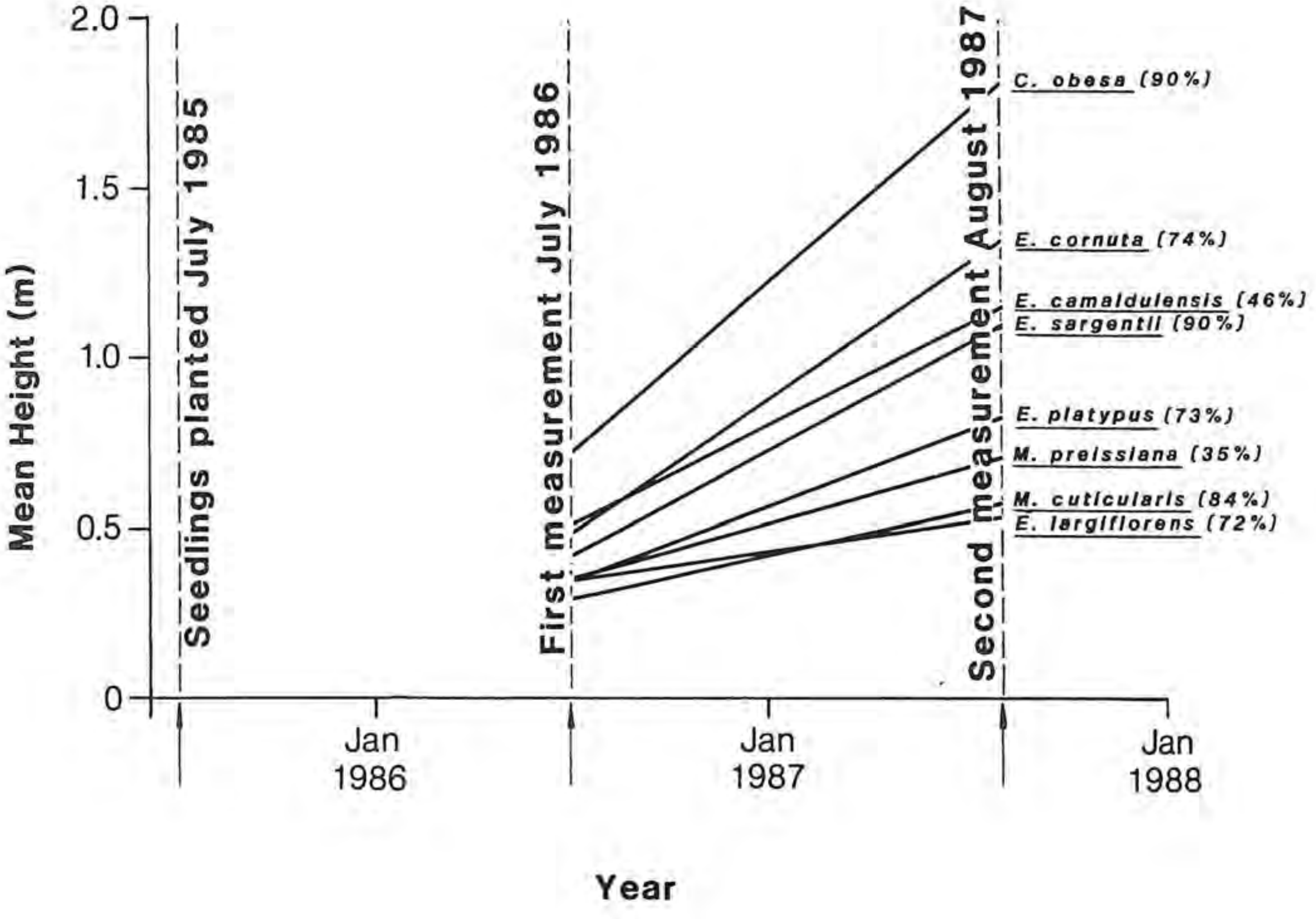


Figure 2 Height and survival (in August '87) of *Eucalyptus*, *Casuarina* and *Melaleuca* species planted in high mounds in a severe S/W site in the ex-Ricetti farm

Table 1. Height and survival at age 12 months of species planted in high mounds in a severe S/W site in the ex-Ricetti farm.

Species	Mean height (m)	Survival (percentage)	Rank survival (percentage)
Melaleuca rhaphiophylla	0.45	97	1
Eucaplyptus cornuta	0.59	95	2
Melaleuca cuticularis	0.41	94	3
Eucalyptus sargentii	0.44	92	4
Casuarina obesa	0.61	83	5
Eucalyptus accedens	0.31	82	6
" *occidentalis*	0.65	77	7
" *microcarpa*	0.25	73	8
" *melliodora*	0.33	67	9
" *camaldulensis*	0.31	62	10
" *kondininensis*	0.32	62	11
" *wandoo*	0.23	51	12
" *globulus*	0.76	48	13
" *sideroxylon*	0.33	46	14
" *largiflorens*	0.33	40	15
Melaleuca quinquenervia	0.32	37	16
Eucalyptus viminalis	0.39	31	17
" *polyanthemos*	0.26	31	18
" *saligna*	0.42	28	19
" *resinifera*	0.91	24	20
" *rubida*	0.23	22	21

Notes: (i) Trial planted in August 1986.

(ii) Mounds were approximately 1.05 m high at time of formation and 0.80 m high after one year.

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 (Fig. 3). 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.

As shown in Fig. 4 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, not waterlogging, 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 seedling root zones would benefit the seedlings.

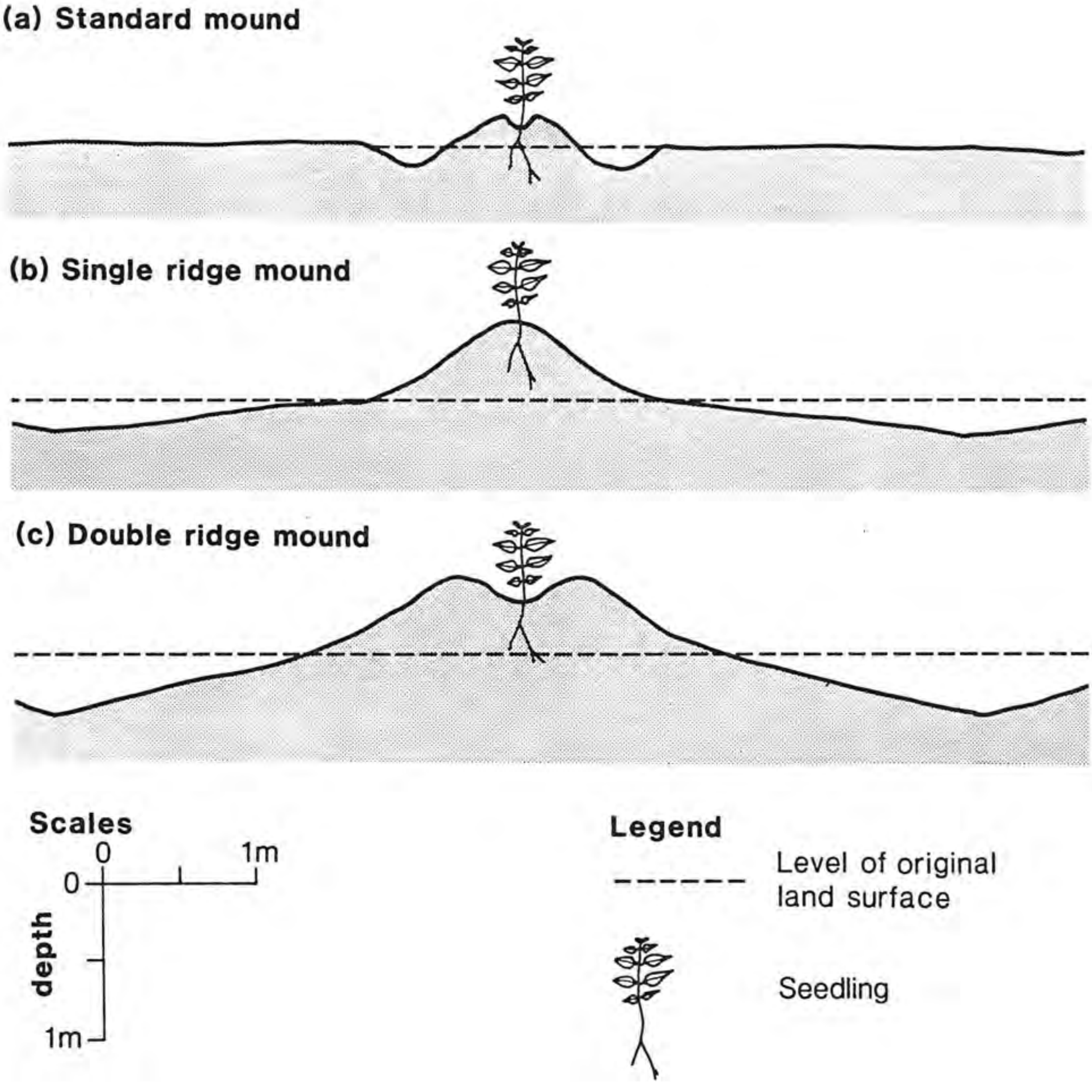
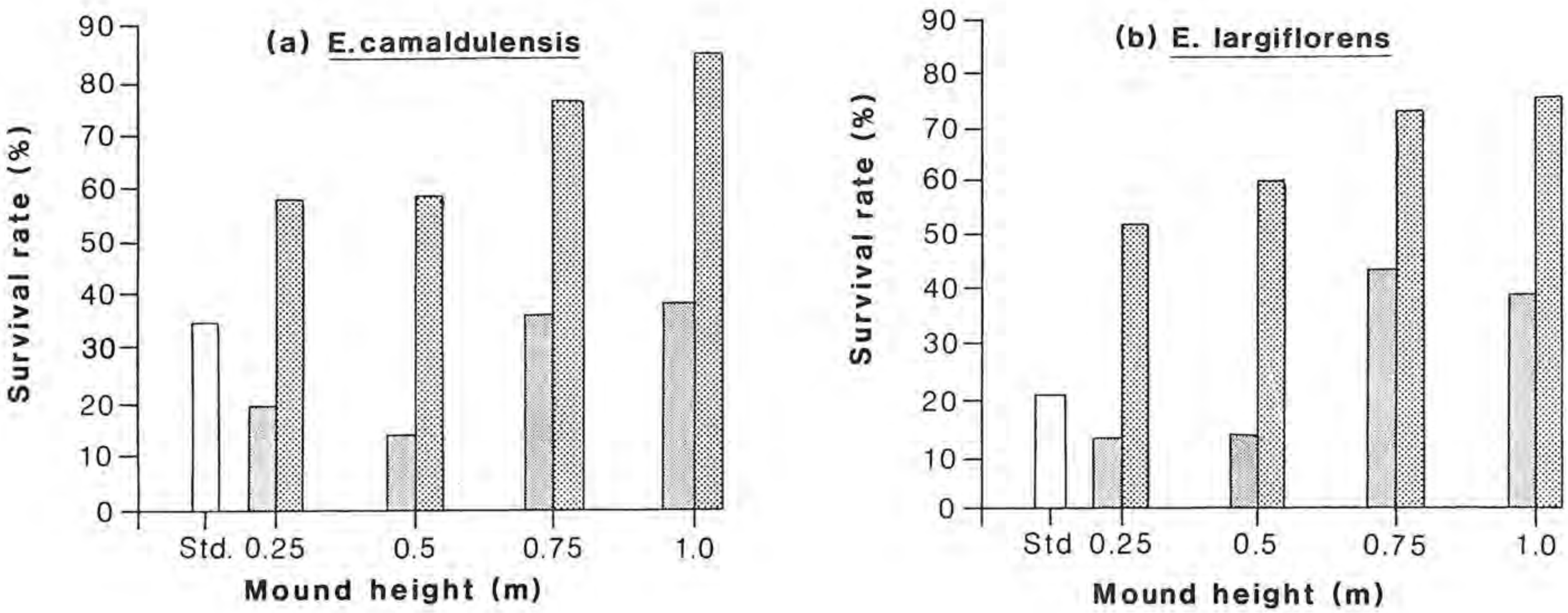


Figure 3 Cross sections of a standard mound and 0.5m high single and double ridge mounds showing the positions seeding were planted in



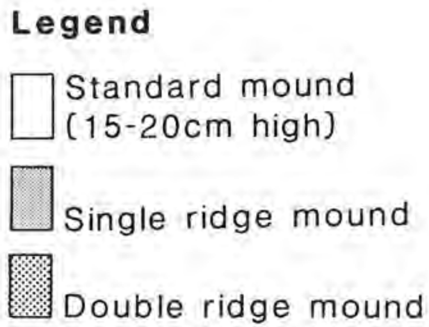


Figure 4 **Survival of *E. camaldulensis* and *E. largiflorens* at age 4 months in the mounding Trial. Seedlings were planted in the first week of August '87 in row plots of 15 seedlings. Each bar represents a mean of 5 replicates (plots) covering four farms**

The actual patterns of salt and water movement in the single and double ridge mounds in the trial in the WRC are being monitored by soil sampling and analysis. Initial results indicate that salt leaching below the troughs of double ridge mounds extends to below the original land surface.

The use of double ridge mounds appears to be a promising technique to improve tree establishment in S/W sites. However 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 is planned for commencement in July 1988.

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 e.g. 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 heavy seedling mortality. In 1987 fresh mounds were formed between the year old mounds and both planted i.e. seedlings were planted in, alternately, 0 and 1 year old mounds. Standard single ridge mounds were used.

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 i.e. 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 (a) standard mounds with improved drainage and (b) higher mounds, also with improved drainage (Fig. 5). Between the 'treatment sections' untreated sections were left as a control i.e. standard mounds without better drainage.

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 further 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.

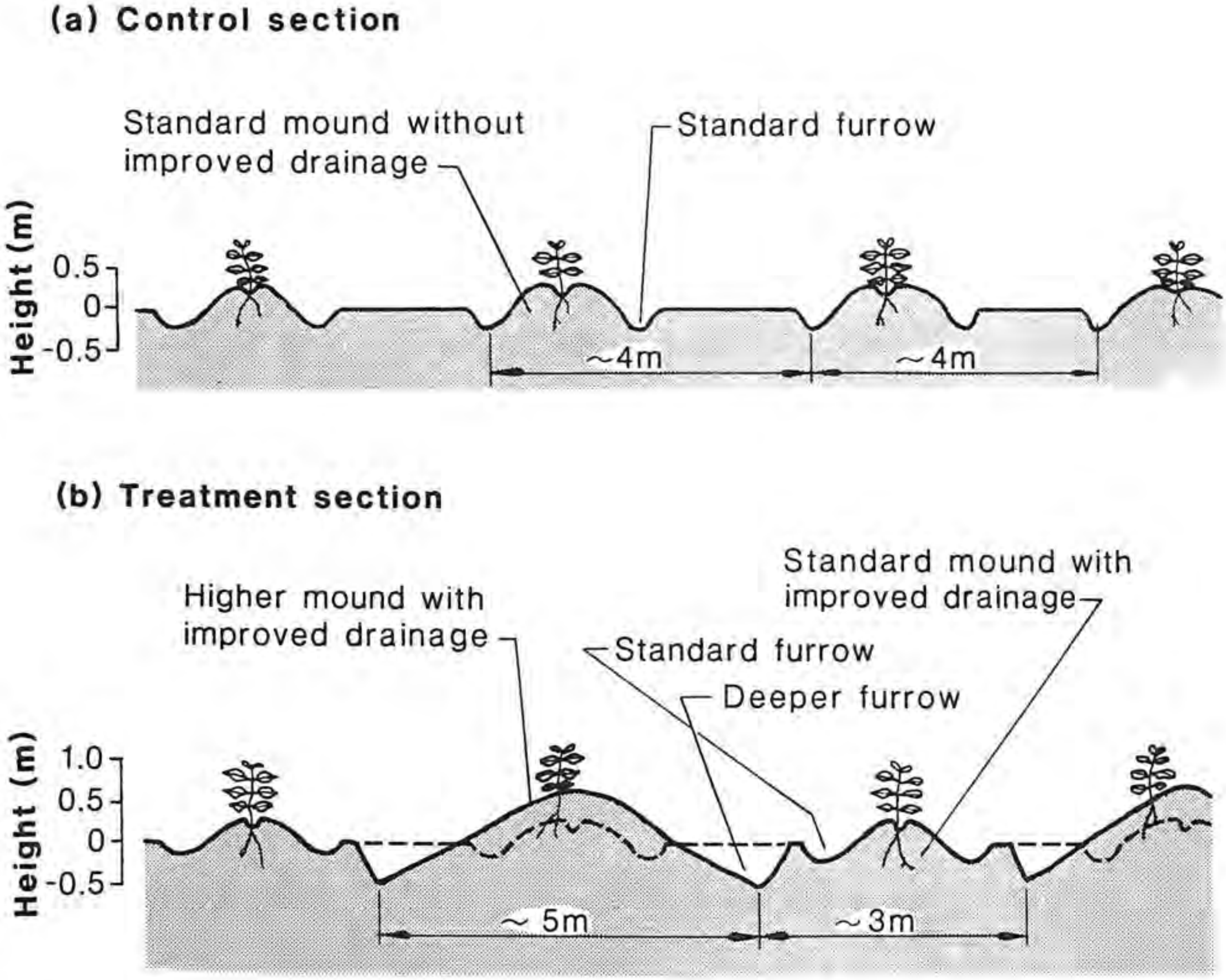


Figure 5 Mounds and furrows in the control and treatment sections of the drainage trial in 'Maringee' farm. The dotted line in the treatment section indicates the landform prior to a road grader forming deeper furrows (providing improved drainage) and higher mounds. The planting positions of seedlings are also shown

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

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 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 not known whether the hardpans or other environmental stresses such as waterlogging and salinity are the main cause of the failure. It seems likely that the hardpans would 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 in hardpan sites. The trial has blocks in a mild S/W and a severe S/W site. A Komatsu 355 bulldozer was used for the ripping. Seedlings are to be planted in July '88.

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 then 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.

Three trials were 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 are 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 mounds and unmounded soil are also being made as part of the trials.

3.8 <u>Seedling Containers</u>

Healthy, more robust, seedlings will have a better chance of survival after planting out than weak ones. In particular seedlings planted out 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 trails were commenced in 1987, one in a mild S/W site and the other in a non S/W site. Two aspects of seedling container design are being investigated.

i) <u>Container size</u>

With a bigger seedling container it is possible to raise a seedling with a bigger root system and hence higher root/shoot ratio. In these trials we have planted seedlings raised in three sizes of container i.e. small jiffy pots, large jiffy pots and large plastic pots which are approximately 2.5, 5 and 10 centimetres across the top respectively.

ii) Root pruning

Seedlings will have a more healthy root system if root binding can be avoided. This often occurs, either in the nursery due to excessive root growth so that roots encircle the inside of the container or it may occur in the field e.g. if jiffy pots dry out in the field they can become too hard for root penetration.

One container designed to prevent root binding is the Adrian's Trays pot. This is a plastic pot being investigated at the Department of Conservation and Land Management nursery at West Manjimup. Chemical root pruning is achieved by spraying the inside of the pots with root inhibitor prior to filling in the nursery. Seedlings, complete with soil are easily lifted from the containers prior to planting out. They are, unlike jiffy pot stock, planted free of any container. Thus there is no container to cause root binding in the field. (L. Bunn, personal communication 1987).

Seedlings raised in Adrian's Trays pots were also included in the seedling container trial. The pots are intermediate in size between small and large jiffy pots.

3.9 Fertilizer Trials

Three fertilizer trials were commenced in 1987 to determine nitrogen and phosphorous requirements (if any) 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 with reforestation in that catchment i.e.:

(a) <u>mild S/W sites</u>

(i) comparatively infertile sand over clay soils

(ii) comparatively fertile gravelly sandy loam soils

(b) <u>Non S/W site</u>

(i) moderately fertile gravelly sandy loam soils.

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

Other trials (one in a mild S/W site and the other in a non S/W site) were commenced in 1987 to compare the effectiveness of combinations of the following:

(a) <u>Fertilizer form</u>

(i) Fertilizer applied in granular form.

(ii) Fertlizer applied as one compressed pellet for each seedling.

(b) <u>Application time</u>

(i) Fertilizer applied at time of planting.

(ii) Fertilizer applied one month after planting.

The application rate in each treatment was 100 grams of Agras No. 1 fertilizer. (18% N, 8% P).

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 for saline groundwater discharge control the following criteria, in order of consideration, should apply. The criteria are similar to those developed by Morris and Thompson (1983).

(i) Adapted to the environment to be planted in i.e. 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 i.e. 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.

Native species may not always be the best. As examples, 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 water logging 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 indications for 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 water table) 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 Eucalyptus 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 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. So far the studies have mostly been in greenhouse conditions. Results confirm that there is a wide variation of tolerance between provenances of most species. This emphasizes 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 plant's tolerance to combined waterlogging and salinity stresses. This emphasizes 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 is also being undertaken, but this work is at an early stage. (Kabay et al. 1986; van der Moezel and Bell 1987; van der Moezel et al. in press; D T Bell personal communication 1988).

Despite the progress made in plant selection for salt/waterlogging tolerance more is needed. This applies particularly to selection for severe S/W sites. Some progress in improving site preparation is expected. However, this should be complemented by improved plant selection.

(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. Selection from these species based on relative ability to depress saline groundwater tables is desirable. However, this is difficult to quantify directly.

Studies showing that reforestation at various sites 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. They were the best performers in terms of survival and growth of 70 species of Eucalyptus (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 (e.g. 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 of a hillside saline seep. The plantations were seven years old and located near Bannister (annual rainfall of 800 mm yr^{-1}) 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 are being tried. 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 did not support a forest community prior to clearing anyway. They would have supported shrub communities e.g. predominantly Melaleuca communities. There may be some environmental factor, such as a hardpan, which makes tree growth impossible.

Two trials have commenced, and one is planned, 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 has a randomized 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 12 months are shown in Table 2. Casuarina obesa and the two Melaleuca species, M. lanceolata and M. cuticularis show some promise.

(ii) Saltbush (Atriplex) species trial

This trial is a replicate of trials commenced 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. Results of measurements at age 11 months are shown in Table 3. The best three performers i.e. A. cinerea (945 and 524 accessions) and A. lentiformis showed little, or no, reduction in survival percentage from ages 1 to 11 months. This indicates they are well adapted to the site.

Table 2. Height and survival at age 12 months of species planted in a mild S/W site in South's Flat in the ex-South's farm.

Species	Mean height (m)	Survival (%)	Rank Survival
Casuarina obesa	0.82	53	1
Melaleuca lanceolata	0.29	52	2
Melaleuca cuticularis	0.29	50	3
Eucalyptus occidentalis	0.50	39	4
Tamarix aphylla	0.36	20	5
Eucalyptus cornuta	-	0	6

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 out of three blocks (replicates) in the trial. In the other block all seedlings died.

Table 3. Performance at age 11 months of Atriplex species/ecotypes planted in a transitional mild to severe S/W site in South's Flat in the ex-South's farm.

Species	S=survival percentage	H=mean height (m)	D=mean diam. (m)	$S.H.D.^2$ = performance index	Rank performance index
A.cinerea (524)	55	0.33	1.06	20	1
A.cinerea (945)	65	0.28	0.935	16	2
A.lentiformis	65	0.61	0.59	14	3
A.amnicola (Gutha)	30	0.38	0.40	1.8	4
A.undulata	40	0.29	0.245	0.7	5
A.amnicola (577)	30	0.37	0.25	0.7	6
Atriplex spp	20	0.50	0.155	0.2	7
A.numularia	30	0.45	0.125	0.2	8
A.amnicola (949)	15	0.42	0.135	0.1	9

Notes:

(i) Trial planted in September 1986.

(ii) Small (5-10 cm high) circular mounds formed with a spade for each seedling.

(iii) Numbers in brackets in the "Species" column are Department of Agriculture seed accession numbers.

(iii) 1988 trial

A third trial planned for commencement in 1988 is to include 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.

4.3 Plant Selection Trials for Mild S/W and Non S/W sites

Two projects are underway.

(i) Leaf conductance

Leaf conductance of four eucalypts found to be most tolerant of S/W conditions in the WRC project plantings were measured in the summer months of 1986/87. The method used is described by Hookey *et al*. (1987). Species and sites included in the study are shown in Table 4. So far data have not been processed sufficiently to present results here.

(ii) Species performance trial

A species performance trial was commenced in 1987 in which the species of most interest for planting in the WRC were planted in a variety of sites. The 13 species selected for the trial, with reasons for their selection, are shown in Table 5. Species performance is to be evaluated by survival and initial growth. A randomized block design was used for the trial with two blocks in each of six sites. The sites, three each in S/W and non S/W conditions, were chosen to represent the range of soil conditions in the catchment.

Table 4. Species/sites included in the leaf conductance study.

South's Flat [a]	Bingham River Arboretum [b]
E.camaldulensis (Lake Albacutya provenance).	E.camaldulensis (Lake Albacutya provenance)
E.camaldulensis (Silverton provenance).	E.woollsiana
E.cornuta	E.largiflorens
E.sargentii	

(a) In ex-South's farm. A mild S/W site planted in 1982.

(b) In ex-Stene's farm. Transitional between a mild S/W and a non S/W site planted in 1979.

Table 5. Species selected for the species performance trial.

Species	Reason for selection			
	1. Desirable water use[a]	2. Known to grow in S/W sites	3. Dual use[b]	4. Native species[c]
Eucalyptus sideroxylon	X			
" microcarpa	X			
" woollsiana	X			
" melliodora	X			
" polyanthemos	X			
" largiflorens	X	X		
" camaldulensis		X		
" cornuta		X		X
" globulus			X	
" saligna			X	
" botryoides			X	
" wandoo				X
Casuarina obesa		X		X

(a) Suggested from Bingham River Arboretum leaf conductance study reported by Hookey, Loh and Bartle (1987).

(b) Fast growing species with potential to provide commercial pulpwood crop as well as depressing groundwater tables.

(c) Occurs naturally in south-west of Western Australia.

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