Performance of Selected Tree and Shrub Species Grown for Stream Salinity Control in the Wellington Reservoir Catchment

by N. E. Pettit and P. Ritson

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SUMMARY

Selection of plant species (genotypes) which are appropriate for particular site conditions is essential for revegetation to be successful in reducing stream salinity.

Trials were set up in the Wellington Catchment to test a range of tree and shrub species. Establishment and growth on saline and non saline sites, in well-drained and poorly drained areas on different soil types have so far been assessed for up to 4 years. In artificially drained (mounded) saline soils the best performing species were, *Eucalyptus occidentalis, E. sargentii, E. cornuta* and *C. obesa. E. globulus* had the fastest early growth but poor survival. On salt and waterlogging affected sites *C. obesa* was the outstanding performer. A clone of *E. camaldulensis* also performed well. The use of a hay mulch improved seedling survival on these sites. On non saline well drained sites *E. globulus* was consistently the best performer. Other species to perform well were *E. botryoides, E. saligna, E. camaldulensis* and *E. cornuta.*

We put forward these results as indications of appropriate species to establish in the various soil environments on farmland in the eastern Wellington Catchment, or other similar environments. However further monitoring is required to confirm long term survival and growth prospects of any promising species. The value of refining the selection process from species (these studies) to provenance and finally individual tree (clone) level is discussed. Also discussed is the importance of capitalising on sound genotype selection with appropriate nursery, site amelioration and planting practices.

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INTRODUCTION

In Western Australia there has been a history since European settlement of land clearing in drier(<900mm/yr rainfall) regions causing large increases in salt levels in water courses. Wood (1924) suggested that as far back as 1897 there was evidence that the destruction of the native vegetation had turned the water in creeks in the Northam-Toodyay district salty. By 1905 a number of railway water supplies had become too salty for economical use in boilers (Wood 1924).

In the south-west of Western Australia 36% of divertible surface water resources are saline or brackish i.e. have salinities in excess of 1 500 mg/L total soluble salts (TSS). A further 16% are of marginal quality (500-1,500 mg/L TSS) and only 48% remain fresh (<500 mg/L TSS) (Western Australian Water Resources Council 1986).

Clearing bans were introduced in the Wellington Reservoir Catchment in 1976 in an effort to minimise further deterioration in reservoir salinity levels. Despite bans, the effects of past clearing would still have resulted in reservoir salinity reaching unacceptable levels, particularly in dry years (Loh and Anson 1987). For this reason a reforestation program was commenced in 1979, with over 6 000 ha planted so far (Schofield *et al.* 1989). Planting has been concentrated in the eastern portions of the catchment where annual rainfall is less than 750 mm/yr (Figure 1). The strategy has been to plant trees on the lower slopes and valley bottoms to cover some 25-40% of the cleared land, at a stem density of about 800 trees/ha.

For reforestation to give effective control in water supply catchments the groundwater table beneath saline seeps must be lowered below a critical depth (Williamson 1986; Ritson and Pettit 1988). This depth can vary depending on the soil type but is generally around 1 to 2 metres. Where a saline watertable is less than this depth there will be significant movement of salts to the soil surface in capillary flow.

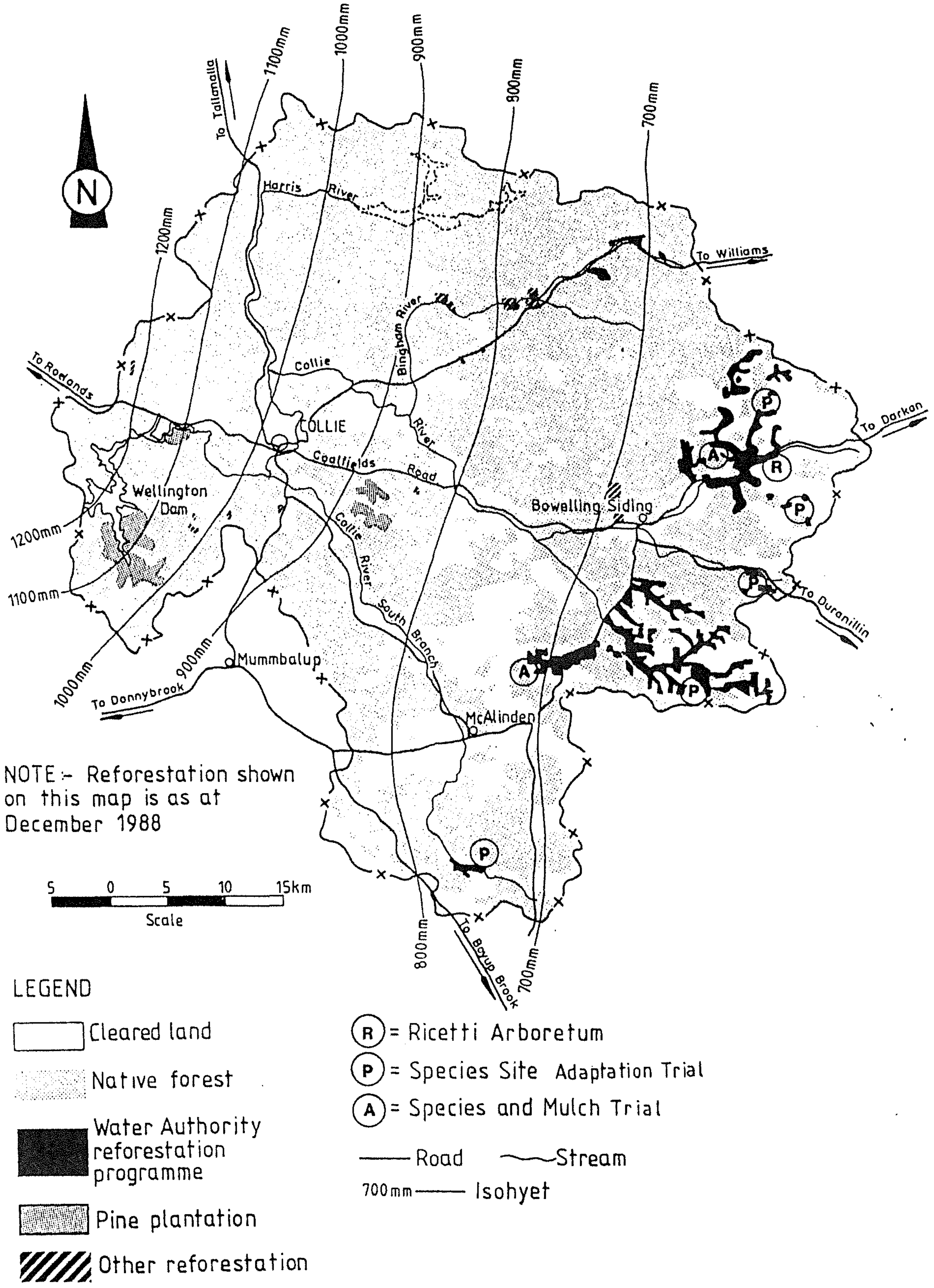


Figure 1: The Wellington Catchment, showing areas of cleared land, reforestation and the trial sites.(Adapted from Schofield *et al.* 1989)

On a local (sub-catchment) scale the area planted usually includes a saline groundwater discharge zone (saline seep) and the adjoining lower slope portion of the groundwater recharge zone. The proportions of each vary but the discharge zones are often estimated to be around half the area. Tree selection will be different for the two zones.

Discharge Zones

Trees selected for the reforestation of saline discharge zones must have some tolerance to high concentrations of salts in the root zone. The degree of waterlogging of a site is also an important factor to consider when choosing plant species. This is because the combination of salinity and waterlogging is usually more detrimental to plant growth than salinity alone (Barrett-Lennard 1986). Seasonal waterlogging can exclude some species from a site even where there is no evidence of salinity. There is evidence that some species can tolerate high levels of salinity in well-drained soils but they are killed when salinity is combined with waterlogging (van der Moezel *et al.* in press). For successful reforestation of saline discharge sites trees must be tolerant of the combined effects of high soil salinity and waterlogging.

Morris and Thompson (1983) suggest that as trees use water in a saline seep and the water table is lowered due to evapotranspiration, salts will be concentrated in the root zone. Increasing salt concentrations to toxic levels could affect the long term viability of revegetation on discharge areas. The actual consequences of this theoretical effect are not yet known, however it should be considered when selecting species. Some balance may be achieved by the trees lowering watertables, thereby reducing waterlogging and thus making them able to withstand comparatively much higher soil salt concentrations.

Recharge Zones

The lower slope portions of recharge zones that are also reforested (in the Wellington Catchment reforestation program) along with the discharge zones are not affected by salinity or seasonal waterlogging. These recharge areas impose fewer constraints upon species selection than saline seeps due to less adverse conditions. Plant selection can be based on establishing commercially useful trees, making reforestation more cost effective, or even a commercially attractive option competitive with agriculture.

Criteria for Selection

Selection criteria have been provided for reforestation for control of saline groundwater discharge by Morris and Thompson (1983). They considered three criteria to be important when making plant selection.

1. Trees must be able to achieve good growth on the site to be planted.

2. Trees should transpire large quantities of water.

3. Trees should provide other products or benefits as far as possible.

A plants ability to survive and grow on a particular site is an essential criterion for selection. Any species considered should be adapted to the soil type, topography and climatic conditions that prevail in the area to be replanted. These may be either native species or species whose natural range has similar climatic and soil conditions to those in the area to be reforested.

Morris and Thompson (1983) suggest that those species that can maximise water use on different site types and predominantly use groundwater in supplying their moisture requirements would be the most useful for salinity control. However comparative water use of trees has been difficult to quantify in the field (Borg and Giles 1988).

The reforestation of previously cleared agricultural land is an expensive operation. It would therefore be useful to plant species that can provide some economic return in the future. The management of fast-growing species on a short rotation system for pulpwood or the planting of fodder trees could make reforestation for salinity control more cost effective.

Plant selection criteria and the secondary benefits of reforestation for salinity control are discussed at length by Schofield *et al.* (1989).

Intra-Specific Variation

There is evidence of variability in salt tolerance both between and within species. This is illustrated by the often conflicting reports of a particular species tolerance, especially species of *Eucalyptus*. Many eucalypts have a very wide natural distribution. Karshon and Zohar (1975) found that salt tolerance of *E. camaldulensis* varied significantly with seed source, indicating the importance of provenance consideration in the search for salt-tolerant trees. Intra specific selection is not only important for salt/waterlogging environments, it can also be valuable in improving the commercial potential of trees, such as *E. globulus*, on recharge sites.

With the use of tissue culture techniques for tree propagation, plant selection could be further narrowed to clones of individual trees that display a high degree of salt tolerance.

Field Trials

This report presents early results of three trials commenced in the eastern Wellington Catchment to test a wide variety of species for their suitability for reforestation for salinity control.

(a) Ricetti High Mounds - Arboretum

This trial was located on a severely waterlogged and salt affected broad river flat. An arboretum was established in the winter of 1986 with trees planted on 1.0 m high mounds to test twenty tree and shrub species for their adaptation to saline/waterlogged conditions.

(b) Species Site Adaptation Trial

This trial was commenced in the winter of 1987. It was designed to test the range of species operationally planted in the Wellington Catchment. Species were planted on the main soil types that occur in the eastern Wellington Catchment under well drained and saline/seasonally waterlogged conditions. Species were selected on the basis of known growth in salt and waterlogging affected conditions, high summer transpiration or high growth rates. In addition, one local species, *E. wandoo*, was included.

(c) Species and Mulch Trial

This trial commenced in the winter of 1988 to test three tree and three shrub species on severely saline/waterlogged sites. The selection of species was based on those having good performance in previous trials on severe sites. A hay mulch treatment was included to assess whether this would improve the establishment of these species.

MATERIALS AND METHODS

Only features common to all trials are given in this section, otherwise details are given in the sections for each particular trial.

All the trials where in the eastern Wellington catchment. The mean annual rainfall is between 650 and 700 mm/yr (Fig. 1) though actual rainfall for a site central to the study sites was 431 mm (1987), 649 mm (1988) and 549 mm (1989). Actual and recorded monthly rainfall is shown in Fig. 2 which also illustrates the distinct winter maximum to summer drought pattern. From one to twenty frosts occur each winter.

Species Selection

A total of twenty six different trees and shrub species have been used in these trials (Table 1). Eucalypts where the main species used. They have a wide distribution throughout Australia including many species which are adapted to conditions similar to those in the eastern Wellington Catchment. They have the added benefits of ready availability of seed ; adaptability to fire and visual compatibility with the remaining native vegetation (Bartle and Shea 1978). Eucalypts have long been known as good performers in reforestation/afforestation programs in Australia and overseas (Food and Agriculture Organization (FAO) 1979). All the eucalypts listed in Table 1 are in the informal sub-genus Symphyomyrtus which is considered to contain most of the salt tolerant species (Florence 1981). Within this sub-genus the series Bisectaria contains known salt tolerant species such as *Eucalyptus sargentii, E. kondininensis* and *E. occidentalis* (Hart 1972; Gardner 1979).

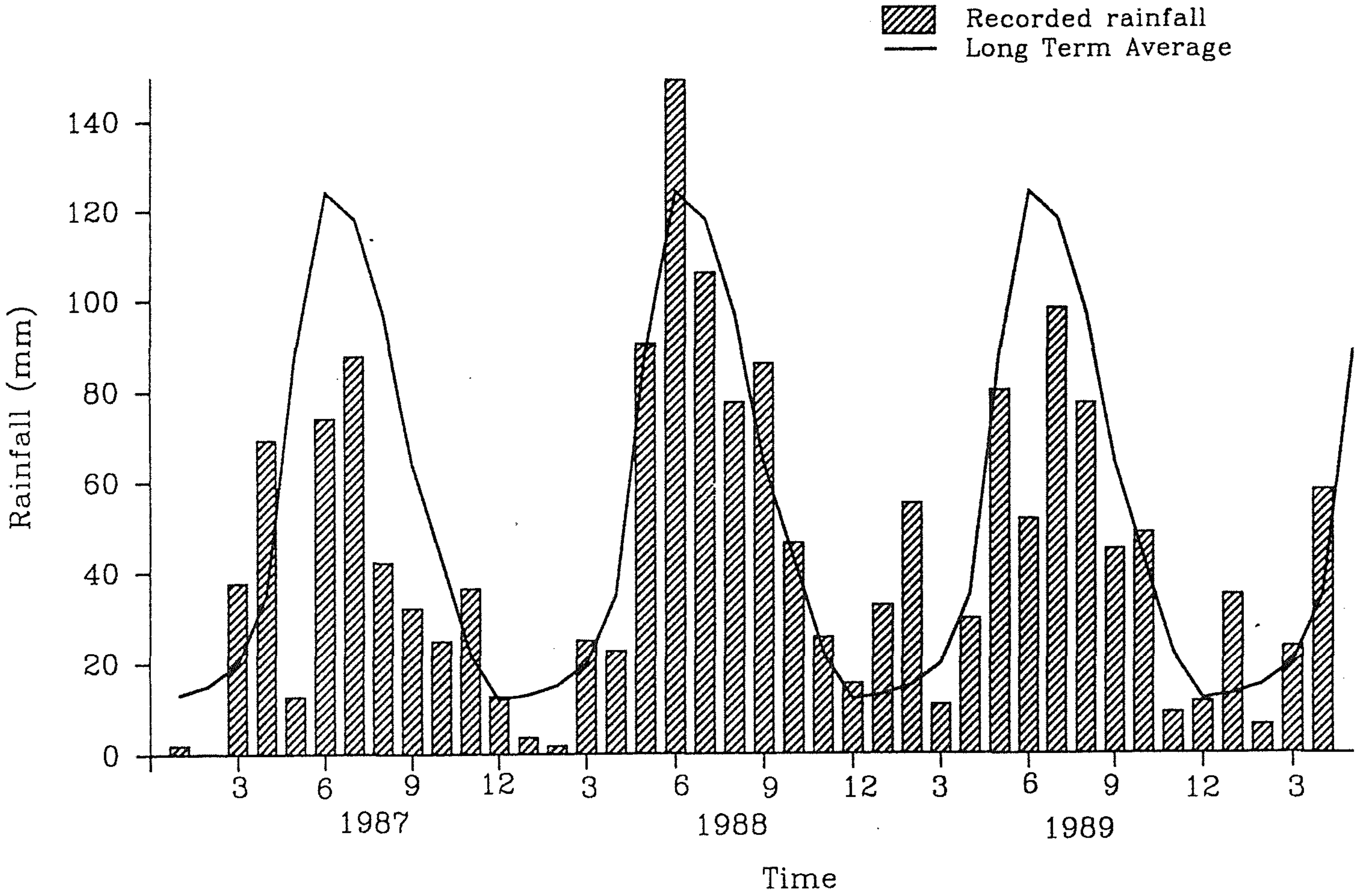


Figure 2: Monthly rainfall from January 1987 to April 1990 and average monthly rainfall on the study sites. Data are means of rainfall at two rainfall stations in the vicinity of the study sites.

TABLE 1
Details of all species included in the trials.

SPECIES	NATURAL DISTRIBUTION	RAINFALL (a) mm/yr	No. FROSTS	SOIL (b) TYPE	REASON (c) INCLUDED	SECONDARY (d) USES
C. obesa	S.W. West Aust.	250-850 W	1-12	C,S	S,W,	Fu,Fo
E. accedens	N.E. to S.E.of Perth	450-1000 W	0-20	C,L,G	C	Fu,Fe
E. botryoides	Central N.S.W.,N.E. Vic	700-1300 U	5-20	L,S	C	P
E. camaldulensis	Mainland Aust(not S.W)	250-600	0-20	S,A	C,W	S,Fu,P,Fe
E. cornuta	Southern W.A.	700-1200 W	0-3	L,S,G	W	Fe,H
E. globulus	S.E. Tasmania	600-1200 W	5-40	L,S	C	P
E. kondininensis	S.E. West Australia	300-500 W	0-10	C	S	Fe
E. largiflorens	Western N.S.W.	200-380 W	1-15	C,L	T	Fu
E. melliodora	Western Vic.,N.S.W.,Qld.	500-900 U	5-60	L,S,A	T	Fu,H
E. microcarpa (e)	Western Vic.,N.S.W.,Qld.	400-700 U	5-30	C,L,A	T	Fu
E. occidentalis	S.W. West Australia	300-800 W	0-20	C,A	S,W	Fu,Fe
E. polyanthemos	Central Vic.,N.S.W.	500-800 U	5-60	C,G	T	Fu
E. resinifera	North Qld.to Nth.N.S.W.	800-2500 S	0-15	L,S	C	S,P
E. rubida	Central Tas.,Vic.,N.S.W.	600-1600 U	15-100	C,L	C	S,Fu,Fe
E. saligna	Coastal N.S.W.	900-1800 S	0-60	L,S,A	C	S,P
E. sargentii	W.A. central Wheatbelt	330-480 W	0-10	C,L,S	S	Fu
E. sideroxylon	Northern Vic.,to Sth Qld.	450-1000 U	0-40	C,S,G	T	Fu,Fe
E. viminalis	S.E. Australia	500-2000 U	0-100	L,G	C	S,P
E. wandoo	S.W. West Australia	400-700 W	1-20	C,L,S	L,C	S,Fu,Fe,H
A. cinerea	Coastal Southern Aust	450-800 W	0-20	C,A	S	Fo
A. lentiformis	California, U.S.A.	200-450 U	0-20	C,A	S	Fo
M. cuticularis	S.W. West Australia	400-850 W	0-20	C,S	L,S,W	
M. quinquenervia	North Qld. to N.S.W.	800-2500 S	0-5	A	W	
M. rhaphiophylla	S.W. West Australia	700-1000 W	0-10	S	W	
M. thyoides	S.E. West Australia	250-500 W	0-20	C,A	S,W	

Notes : (a) W=winter maximum; U=uniform; S=summer maximum.

(b) C=clay; L=loam; S=sand; A=alluvial; G=gravelly.

(c) L=local species; C=some commercial potential; S=salinity tolerant; W=waterlogging tolerant; T=indicated as having high transpiration rates.

(d) S=sawn timber; Fu=fuelwood; P=pulpwood; Fe=fencing; Fo=fodder; H=honey.

(e) Includes E. woollsiana.

Although other sub-genera such as Monocalyptus and Corymbia are represented in the local vegetation (*E. marginata* and *E. calophylla* respectively) their survival and growth where tried in the reforestation program has been poor. The other genera used have been specifically chosen for their adaptation to waterlogging and/or saline conditions.

The literature lists a wide variety of species which have been tested for salt tolerance. Of the species used in the present trials *E. camaldulensis, E. sargentii, E. occidentalis, E. cornuta* and *C. obesa* have been most commonly reported as being salt tolerant (Morris 1980; Blake 1981; Biddiscombe et al., 1981; Luard and El Lakay 1984). For reducing groundwater levels on non saline soils examples have been reported with fast growing species *E. globulus* and *E. camaldulensis* (Merwin 1987). Of the shrub species *Melaleuca thyoides* is reported as being highly salt tolerant (Negus 1984; van der Moezel and Bell 1987). *Atriplex cinerea* and *A. lentiformis* have shown good establishment and growth on saline soils of brown cracking clays (Kok *et al.* 1987) and also in a *Atriplex* species trial in the Eastern Wellington Catchment (Ritson and Pettit 1988).

At this stage only one genotype of each species has generally been tested in our trials. Because of this only tentative conclusions can be drawn from the results. Good performing species obviously have potential and further improvements are likely with intra-specific selection for desirable characterisics. However poor performance by one genotype of a species does not necessarily mean that all genotypes of that species would be unsuitable.

Data Collection

For each of the three trials survival and growth measurements were made annually. In addition measurements were taken quarterly throughout the first year at the Species and Mulch trial. Survival counts were made on each plot and given as a percentage of numbers planted.

To characterize growth, tree height and crown volume index (CVI) were measured. CVI was calculated using the method of Biddiscombe *et al.* (1985) as hd_1d_2 where h is crown depth (the distance between the highest and lowest green leaf) and d is the crown diameter measured at the widest point along (d_1) and across (d_2) the rows. This gives an indication of the evapotranspiration potential of trees. This is an important variable as maximum water use is desirable in trees grown for salinity control. Crown volume can also be used as an indicator of the health and vigour of the surviving trees as trees with a good leaf area would generally be healthy.

Data Analysis

Before applying statistical tests to survival data the data were transformed using the arcsine square root transformation. This was done to normalise the data. An analysis of variance (ANOVA) was applied to survival, height and CVI measurements to determine if there were any statistically significant differences between independent variables. A multiple comparison procedure (Duncan's Multiple Range Test) was performed if any differences were apparent to determine which means differed significantly.

A biomass index was calculated for each species to assist in comparisons between species. This was calculated as the product of survival and CVI. Tree height measurements were not included in the index as the crown depth variable (h) in CVI already gives a measure of tree height and to include it twice would over emphasise the importance of this variable. For these young trees a regression analysis of tree height and crown depth showed a very strong correlation ($r^2 > 0.95$ for all species).

RICETTI HIGH MOUNDS - ARBORETUM

Site Description and Experimental Design

An arboretum was established on farmland in August 1986 on a broad flat at the junction of two tributaries of the Collie River. The original vegetation of the area was most likely a *Melaleuca* shrub community, periodically inundated during winter. The area carried some trees, *Eucalyptus wandoo, E. rudis* and *Allocasuarina heugeliana*. The soils were shallow loamy sand over sandy clay. A detailed soil description for this site is given in Appendix 1. Water table level and salinity was measured from two shallow bores situated on the same flat, adjacent to the trial area. Minimum depth to water table in the two bores occurred in July 1990 and was 0.11 metres. Maximum depth to water table occurred in March 1989 and was 0.7 metres. Salinity of soil samples taken from mounded soil in July, 1986 ranged from 0.65% to 2.0% TSS content by weight.

The area was cleared for pasture in the 1960s and has since become saline, resulting in the death of most of the remaining vegetation. When site preparation began the area was mostly scalded, with small patches of salt-tolerant species such as sea barley grass (*Hordeum marinum*) on the better drained areas. An area of about 20 ha of severely salt and waterlogging affected flat was mounded in 1985 using a Buckeye pipeline trenching machine. This machine produced 1.0 m high mounds of soil in the process of digging trenches. The mounds were formed to provide an elevated planting postion for seedlings to reduce the effects of waterlogging. They were single ridge mounds with seedlings planted on one side of the mound 20-30 cm below the ridge top.

A total of nineteen species from the *Eucalyptus, Casuarina* and *Melaleuca* genera. They were set out in two randomised blocks, there being one single row plot (mound) for each species within a block. The blocks was placed either side of a main drainage channel with mounds running at right angles to this channel. The number of trees per plot varied according to the length of mound and ranged from thirty-five to sixty trees. Seedlings were raised in small-volume (24 cm^3) peat-based pots and planted at 3.0 m spacing. Approximately one month after planting seedlings were fertilized with 100 g of Agras No.1 fertilizer (18% N, 7% P).

Results

The trees were 4 years old when measured in July 1990. A summary of results is given in Table 2. An ANOVA showed there was a highly significant difference in survival between the nineteen species (p = 0.0002) . Survival ranged from 96% for *M. rhaphiophylla* to 14% for *E. rubida*. Seven species had good (>70%) survival. Another 3 species had moderate (50 - 70%) survival, while 9 species had poor (<50%) survival.

Table 2 also shows there were large differences in height (p = 0.006) and CVI (p = 0.03) between species. *E. globulus, E. occidentalis* and *C. obesa* were tallest while *E. globulus, E. occidentalis* and *E. viminalis* had the highest CVI.

The biomass index showed that the 4 highest ranking species *E. occidentalis, E. cornuta, C. obesa* and *E. sargentii* had consistently good survival and growth (Table 2). *E. globulus* had poor survival but very good growth of survivors. In contrast *Melaleuca cuticularis* and *M. rhapiophylla* had good survival but poor growth, consequently their ranking was low.

TABLE 2

Survival, Height, Crown Volume Index (CVI) and Biomass Index of species 4 years after planting at the Ricetti Arboretum.

SPECIES	SURVIVAL (%)*	HEIGHT (m)*	CVI (m^3)*	BIOMASS INDEX**
E. occidentalis	71 abcd	3.4 ab	18 ab	1278
E. sargentii	90 ab	2.6 bcde	14 bcd	1260
C. obesa	75 abcd	3.5 ab	16 bc	1200
E. cornuta	84 abc	3.0 bc	14 bcde	1176
E. kondininensis	60 bcdef	2.8 bcd	14 bcde	840
E. globulus	30 efg	4.6 a	28 a	840
E. accedens	75 abcd	1.9 bcdef	9 bcde	675
E. microcarpa	69 bcde	1.7 cdef	7 bcde	483
E. saligna	23 fg	2.6 bcde	18 ab	414
E. sideroxylon	37 defg	2.3 bcdef	11 bcde	407
E. melliodora	58 bcdef	1.6 cdef	7 bcde	406
E. viminalis	20 fg	2.9 bcd	20 ab	400
E. camaldulensis	46 cdefg	1.7 cdef	8 bcde	368
E. wandoo	39 defg	1.8 cdef	9 bcde	351
E. resinifera	27 efg	2.7 bcd	12 bcde	324
M. cuticularis	86 abc	1.0 f	2 de	172
M. quinquenervia	18 g	1.8 cdef	8 bcde	144
M. rhaphiophylla	96 a	1.1 ef	1 e	96
E. rubida	14 g	1.4 def	4 cde	56

* Values with the same letter are not significantly different at ($p<0.05$)

** Biomass Index = Survival x CVI

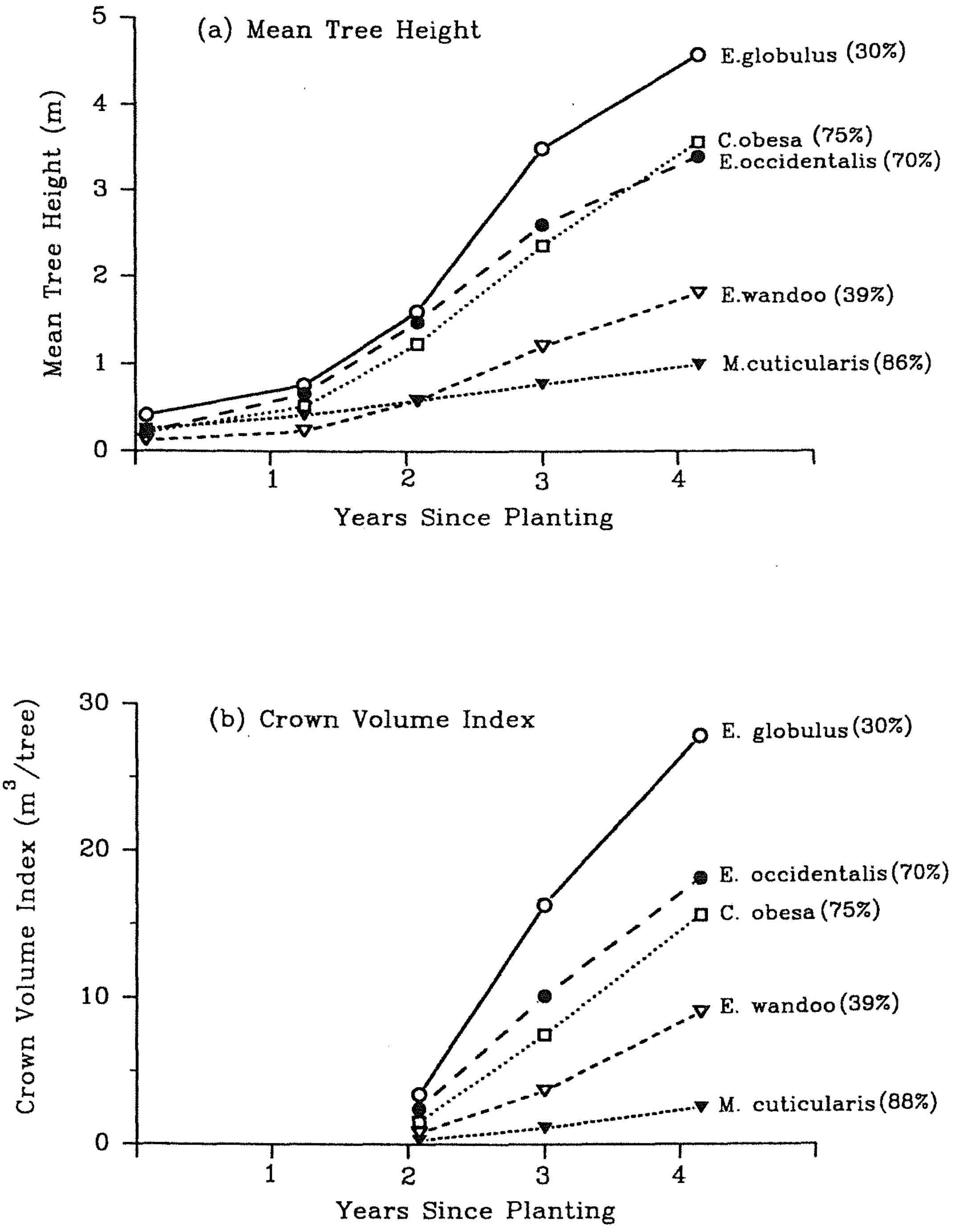


Figure 3: Growth of selected species at Ricetti Arboretum over the four years since planting, (a) Mean tree height and (b) CVI. Included is the survival(%) four years after planting.

Figure. 3 shows height growth and CVI of selected species. The top ranked species for height and CVI (*E. globulus, E. occidentalis* and *C. obesa*) all increased their growth rate each year. However *E. globulus* and *E. occidentalis* have leveled of slightly in the 4th year. The local species, *E. wandoo* also showed noticeable increase in height growth rate over the study period, its early growth being even less than that of *M. cuticularis* which grew consistently slowly.

Discussion

The formation of 1.0 m high mounds on this severely saline and waterlogging affected site did facilitate the establishment of a range of species. However, since the arboretum was planted we have found that better establishment can be achieved with lower mounds provided they are of the double ridge shape rather than the single ridge mounds (Ritson and Pettit 1989a). Therefore the main value of these results is to indicate which species are likely to establish well in saline drained conditions. Such conditions were achieved at the arboretum site in the high mounds but they could possibly also be achieved by deep drainage. Saline conditions also exist in the extensive areas of dry saline lands (no high watertable) formed by such factors as past ingress of the sea or rock weathering (SCAV 1982).

The best performing species, *E. occidentalis*, naturally occurs in environments subject to salinity and/or seasonal waterlogging. It is a species that is widely recommended for rehabilitation of saltland (Hart 1972; FAO 1979; Negus 1984).

Three species to perform well were *C. obesa, E. sargentii* and *E. kondininensis*. They performed well in all three measured parameters. Each of these species occur naturally in areas containing salt and waterlogging affected environments and would be suitable for planting on saline discharge sites.

The fourth ranked species *E. cornuta* does not usually occur in areas affected by salinity. It does grow in poorly drained clayey soils. Adaptation to waterlogging has been found to be a good indicator of salinity tolerance (van der Moezel and Bell 1987).

Although *E. globulus* showed good early growth of survivors on the high mounds the long term viablity of this species may be doubtful. Eventually their roots must penetrate to the saline watertable (which is likely to cause stress) or they will run out of soil in the mounds. The reduction in height growth rate in the 4th year may be an early indication of this effect. Having poor initial establishment as well would indicate that this species should not be planted on sites such as this.

The poor growth of *M. rhaphiophylla* and *M. cuticularis* may have been due to the mounds drying out during summer and the plants suffering from drought stress. As both species occur naturally in wet areas the mounds may have dried the soil too much for these species. The trenching machine in producing the mounds would throw up the sub-surface clay to the top of the mound which would also make growing conditions difficult for these species. They would be appropriate when faster growing species cannot be established or when fast early growth is not important.

Although there are large specimens of *E. wandoo* growing around this site it appears that seedlings (at least of the seedlot planted) are salt sensitive. It may be that the survivors of this species will persist and grow better over time than some of the higher ranking species.

A species with recorded salt tolerance that did not perform well was *E. camaldulensis*. This may be due to an unsuitable ecotype of the species having been used. The provenance of *E. camaldulensis* for this trial was Lake Buchanan in N.W. Queensland i.e. latitude 22° S compared with latitude 33° S at the arboretum site. As this species has such a wide geographical distribution in Australia obtaining seed stock from at least a similar climatic region is considered essential.

With only four years of monitoring any conclusions on species adaptation should be regarded as tentative. Trees may establish well initially in the mounds where good drainage and loosely structured soil make root growth easy. Examination of the root system of one individual of each of four species (*E. cornuta, E. camaldulensis, E. largiflorens* and *C. obesa*) at this site two years after planting showed that only roots of *C. obesa* had readily penetrated through the mound and into the original land surface. Roots of *E. largiflorens* did this to a limited extent, while roots of *E. camaldulensis* and *E. cornuta* bent at right angles on reaching the original land surface growing horizontally above it. This lack of deep penetration of the roots would render the trees susceptible to windthrow. Also, the failure of roots to penetrate to the water table would mean that they would not be actively lowering the water table. At this site there was no ripping of the original land surface prior to mounding though this is now considered essential site preparation anywhere in the eastern Wellington Catchment.

SPECIES SITE ADAPTATION TRIAL

In this trial we compared thirteen tree species for planting under typical soil and site conditions occuring in the eastern Wellington Catchment.

Site Description and Experimental Design

Six sites were selected to include the main soil types in both seasonally waterlogged/saline and well drained sites of the eastern Wellington Catchment (Table 3). All sites were on farmland cleared prior to 1976.

Table 3 - Trial Site Descriptions

Site No.	Farm	Soil Type[a]	Drainage[b]	TSS content[c] (mg/L)
1	Borlini	Shallow sand over clay	Seasonally waterlogged (WRL = 0.03 m)	27 500
2	Scott/Imrie	Sand over clay	Seasonally waterlogged (WRL = 0 m)	24 900
3	Earnshaw	Gravelly sandy loam	Well-drained (WRL > 1.0 m)	250
4	Earnshaw	Deep sand	Well-drained (WRL > 1.0 m)	250
5	Maxon	Shallow gravelly loamy sand over clay	Well-drained (WRL > 1.0 m)	130
6	Ferrari	Sandy loam	Seasonally waterlogged (WRL = 0.05 m)	92

(a) Detailed soil descriptions given in Appendix 1.

(b) WRL is water rest level below natural surface in shallow(<1.5m deep) bores read August 1988

(c) Total Souluble Salts (TSS) content.

Casuarina obesa and twelve species of *Eucalyptus* were included in this trial. They were chosen for reputed good survival in saline waterlogging affected environments, adaptation to local conditions and high water use or fast growth rates (see Table 1). The trial was set out in a randomized block design with two replicates (blocks) of the thirteen species on each of the six sites. Each block included thirteen row plots (one for each species). The row plots comprised fifteen seedlings spaced 3.0 m apart. The distance between row plots was 4.0 m.

For all sites planting lines were ripped in February 1987 to a depth of approximately 0.3 m. At the saline sites (Sites 1 and 2) standard (0.18 m high) mounds were formed over the rip lines. Strips 1.5 m wide were sprayed along all planting lines with flowable Vorox AA (Amitrole/Atrazine) herbicide in May to give rapid knockdown and residual control of weeds for one growing season. Seedlings were raised in peat based pots and planted out in July 1987. At the time of planting each seedling was fertilized with 100 g of Agras No. 1 fertilizer (18% N, 7% P).

Results

As there was a large difference in salinity levels between the six sites (Table 3) it was decided to treat the results from the saline and non-saline sites separately.

(i) Saline Sites (Sites 1 and 2)

There was no significant interaction between species and site for survival, tree height, or CVI so results for the two sites where combined.

There was a significant effect of species on survival (p=0.0001). Only *C. obesa* had good survival (75%) , the next best species

TABLE 4
Survival, Height, Crown Volume Index (CVI) and Biomass Index of all species three years after planting - Saline Sites (1 & 2)
Species Site Adaptation Trial

SPECIES	SURVIVAL (%)*	HEIGHT (m)*	CVI (m^3)*	BIOMASS INDEX**
C. obesa	75 a	2.4	7	525
E. sargentii	30 b	1.7	4	120
E. camaldulensis	20 bc	1.6	3	60
E. largiflorens	13 c	1.3	4	52
E. sideroxylon	6 d	1.7	6	36
E. cornuta	2 d	2.2	11	22
E. wandoo	5 d	1.2	3	15
E. polyanthemos	5 d	0.9	1	5
E. botryoides	2 d	1.1	1	2
E. globulus	0 d	-	-	0
E. microcarpa	0 d	-	-	0
E. woollsiana	0 d	-	-	0
E. saligna	0 d	-	-	0

* Values with the same letter are not significantly different at ($p<0.05$)

** Biomass Index = Survival x CVI

being *E. sargentii* (33%) and *E. camaldulensis* (20%). There was only one surviving tree of *E. cornuta* and no survivors of *E. globulus, E. saligna, E. microcarpa* and *E. woollsiana* (Table 4).

Differences between species (Table 4) were not significant for height (p=0.08) or CVI (p=0.06). However, real differences may have been masked by the generally low survival rates and high variability in growth rates of survivors.

The species biomass index underlines the superiority of *C. obesa*. Next best for biomass was *E. sargentii* but it was well below the biomass index of *C. obesa*.

(ii) Non saline sites (Sites 3,4,5,6)

Although there was a significant species by site interaction on survival rate (p=0.02), survival was generally good for all species on all sites. The main exceptions were the poor (<50%) survival recorded by *C. obesa* at site 6 (37% survival, probably due to heavy browse damage by sheep) and *E. sargentii* at sites 4 and 6 (47% and 37% survival) (Table 5). Average survival rates of all species have reduced by only 2% after the first year.

The main separation between species was in height and CVI growth rates rather than survival. There were significant species and site interactions for mean tree height (p=0.0002) and CVI (p=0.01) but this was mostly due to variation in the growth rates of the slower growing species. On all sites *E. globulus* had consistently the best height, CVI, and biomass index, followed by a group of four species comprising *E. saligna, E. botryoides, E. camaldulensis* and *E. cornuta*. Some separation between species in the second group were apparent as shown in Table 5 and Figures 4 and 5. For example, in the case of biomass index, some

TABLE 5

Survival, Height, Crown Volume Index (CVI)
and Biomass Index of species three
years after planting on non saline sites
Species Site Adaptation Trial

(a) Site 3 - gravelly sandy loam, well drained

SPECIES	SURVIVAL (%)*	HEIGHT (m)*	CVI (m^3)*	BIOMASS INDEX**
E. globulus	90 a	7.7 a	85 a	7650
E. saligna	73 a	5.4 b	57 b	4161
E. botryoides	73 a	5.1 b	46 bc	3358
E. camaldulensis	80 a	4.0 c	41 bc	3280
E. cornuta	63 ab	3.9 c	29 cd	1827
E. polyanthemos	93 a	3.3 c	14 de	1302
E. wandoo	63 ab	1.9 de	10 e	630
C. obesa	90 a	3.0 cd	7 e	630
E. largiflorens	90 a	1.5 e	4 e	360
E. sideroxylon	77 a	1.5 e	3 e	231
E. microcarpa	93 a	1.2 e	2 e	186
E. woollsiana	83 a	1.2 e	2 e	166
E. sargentii	27 b	1.9 de	5 e	135

(b) Site 4 - deep sand, well drained

SPECIES	SURVIVAL (%)	HEIGHT (m)*	CVI (m^3)*	BIOMASS INDEX**
E. globulus	63	6.5 a	70 a	4410
E. cornuta	73	4.0 b	37 b	2701
E. botryoides	86	3.9 b	30 bc	2580
E. saligna	80	3.8 b	31 bc	2480
E. camaldulensis	87	3.2 bc	20 cd	1740
E. polyanthemos	93	2.4 cd	9 de	837
E. wandoo	83	1.4 efg	4 e	332
C. obesa	93	2.2 de	3 e	279
E. largiflorens	83	1.4 efg	3 e	249
E. sargentii	47	1.8 def	3 e	141
E. microcarpa	97	0.9 fg	1 e	97
E. sideroxylon	80	1.2 fg	2 e	80
E. woollsiana	80	0.8 g	1 e	80

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

SPECIES	SURVIVAL (%)*	HEIGHT (m)*	CVI (m^3)*	BIOMASS INDEX**
E. globulus	75 bc	5.5 a	49 a	3675
E. botryoides	84 abc	4.1 b	38 b	3192
E. saligna	81 bc	3.6 b	34 b	2754
E. cornuta	60 c	3.9 b	40 b	2400
E. camaldulensis	80 bc	3.0 c	20 c	1600
E. wandoo	77 bc	2.4 de	12 d	924
E. sargentii	77 bc	2.8 cd	11 de	847
E. polyanthemos	80 bc	2.7 cd	10 def	800
E. largiflorens	84 abc	1.7 f	6 defg	504
C. obesa	83 abc	2.7 cd	6 defg	498
E. microcarpa	97 a	1.5 f	4 fg	388
E. sideroxylon	62 c	1.8 ef	5 efg	310
E. woollsiana	90 ab	1.3 f	2 g	180

(d) Site 6 - sandy loam, seasonally waterlogged

SPECIES	SURVIVAL (%)	HEIGHT (m)*	CVI (m^3)*	BIOMASS INDEX**
E. globulus	90	6.5 a	80 a	7200
E. saligna	97	4.4 b	59 ab	5723
E. camaldulensis	97	4.1 b	54 b	5238
E. botryoides	93	4.3 b	48 b	4464
E. cornuta	57	4.0 b	39 bc	2223
E. wandoo	90	2.4 c	16 d	1440
E. sargentii	77	3.0 c	18 cd	1386
E. polyanthemos	83	2.5 c	12 d	996
E. largiflorens	76	2.4 c	12 d	912
E. sideroxylon	50	2.5 c	15 d	750
E. microcarpa	76	1.9 cd	9 d	684
E. woollsiana	84	1.9 cd	6 d	504
C. obesa	37	1.1 d	1 d	37

* Values with the same letter are not significantly different at ($p<0.05$)

** Biomass Index = Survival x CVI

separations were as follows. At the sites with gravelly loam soils (sites 3 and 6) *E. saligna* was the best performer, while at site 5 *E. botryiodes* was best. At site 4 there was little difference in the biomass of *E. cornuta, E. botryoides* and *E. saligna,* all of which were greater than *E. camaldulensis.*

The ranking of the five fastest growing species for height and CVI growth was fairly consistent over the three years of measurement (Figures 4,5). The plotted lines tend to run parallel or diverge. In all cases the absolute differences in tree height and CVI between *E. globulus* and the next fast growing species increased each year.

There were variations in the performance of each species over the four sites. These are shown for the 5 fastest growing species in Table 6. Thus, although *E. globulus* was consistently the fastest growing species at all sites, its growth (and survival) rates were much higher at the two sites with gravelly loam soils (sites 3 and 6) than at the other two sites. For *E. saligna* and *E. botryoides,* survival and biomass index were greatest at site 6, although both these species grew tallest at site 3. Survival and growth of *E. camaldulensis* was best at site 6. Based on biomass index, the performance of *E. cornuta* at sites 4 and 5 was better than at site 3 and slightly better than at site 4.

Species and Site Interaction

Two species (*C. obesa* and *E. camaldulensis*) were selected to show the effect of the interaction between species and site on survival and growth rates (Figure 6). Survival and growth rates of *C. obesa* were similar on the saline and the non saline sites. In contrast the survival and growth rates of *E. camaldulensis* were severely reduced on the saline seasonally waterlogged sites compared with the non saline well drained sites.

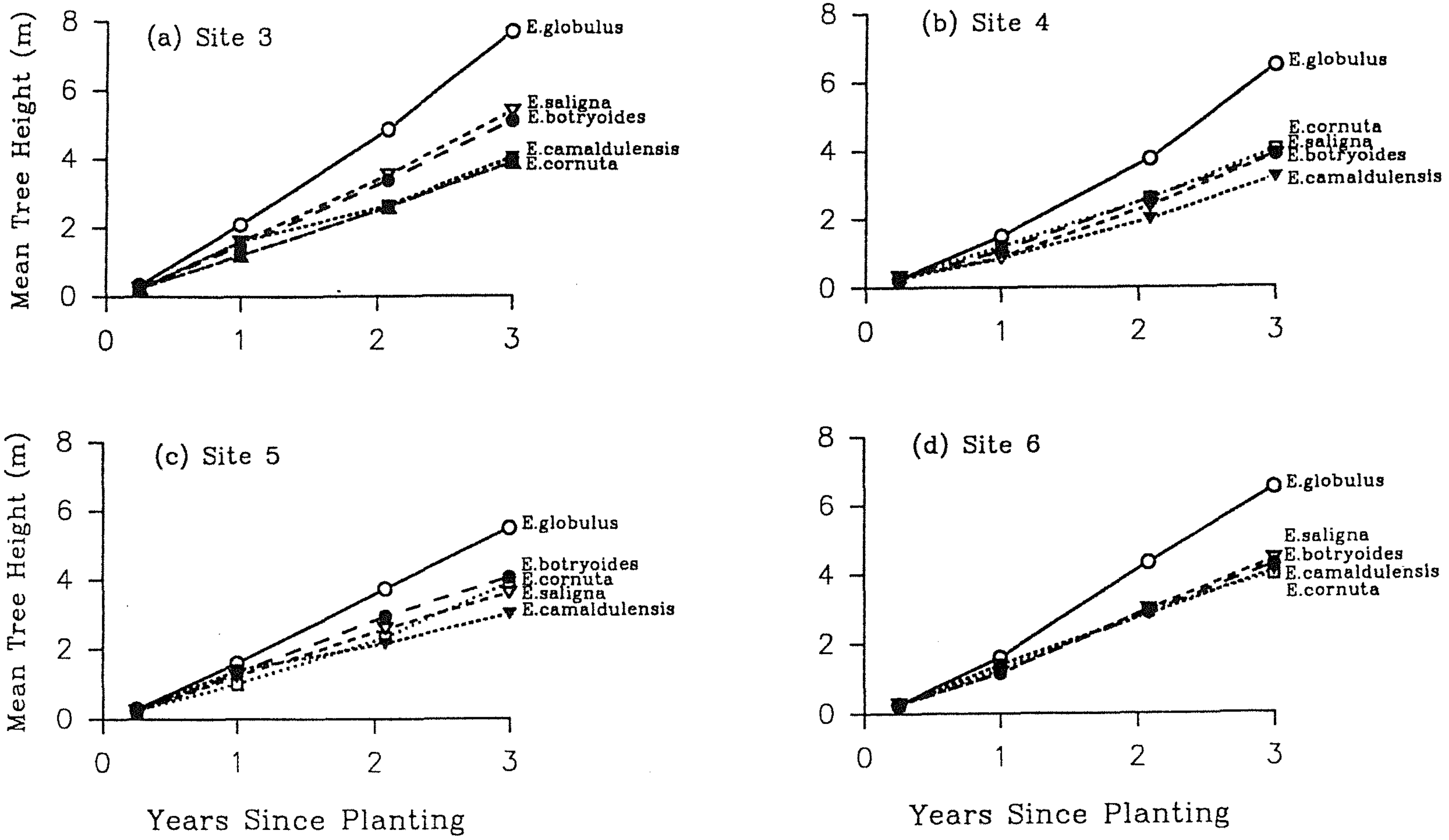


Figure 4: Mean tree height of the five best performing species on the four non saline sites, Species Site Adaptation trial. (a) Site 3: gravelly sandy loam soil, well drained. (b) Site 4: deep sandy soil, well drained. (c) Site 5: shallow gravelly loamy sand over clay soil, well drained.(d) Site 6: sandy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

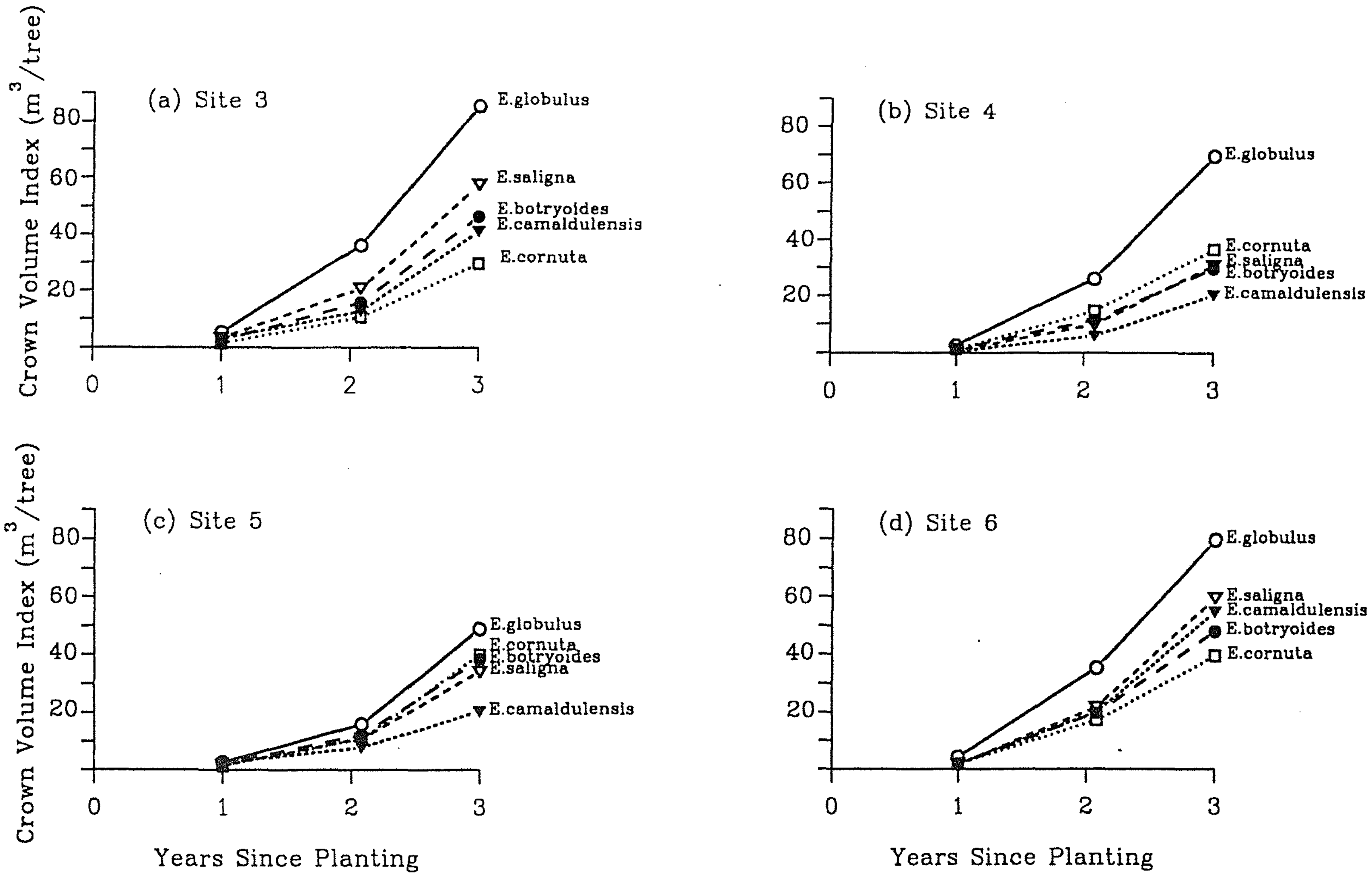


Figure 5: Crown volume index of the five best performing species on the four non saline sites Species Site Adaptation trial. (a) Site 3: gravelly sandy loam soil, well drained. (b) Site 4: deep sandy soil, well drained. (c) Site 5: shallow gravelly loamy sand over clay soil, well drained. (d) Site 6: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

TABLE 6

Survival, Height, Crown Volume Index (CVI) and Biomass Index of the five fast growing species on the non saline sites 3 years after planting.

SPECIES	SITE No.	SURVIVAL (%)	HEIGHT (m)	CVI (m^3)	BIOMASS INDEX
E. globulus	3	90	7.7	85	7650
	4	63	6.5	70	4410
	5	75	5.5	49	3675
	6	90	6.5	80	7200
E. saligna	3	73	5.4	57	4161
	4	80	3.9	31	2480
	5	81	3.6	34	2754
	6	97	4.4	59	5723
E. botryoides	3	73	5.1	46	3358
	4	86	3.9	30	2580
	5	84	4.1	39	3276
	6	93	4.3	48	4464
E. camaldulensis	3	80	4.0	41	3280
	4	87	3.2	20	1740
	5	80	3.0	20	1600
	6	97	4.1	54	5238
E. cornuta	3	63	3.9	30	1890
	4	73	4.0	37	2701
	5	67	3.9	40	2680
	6	57	4.0	39	2223

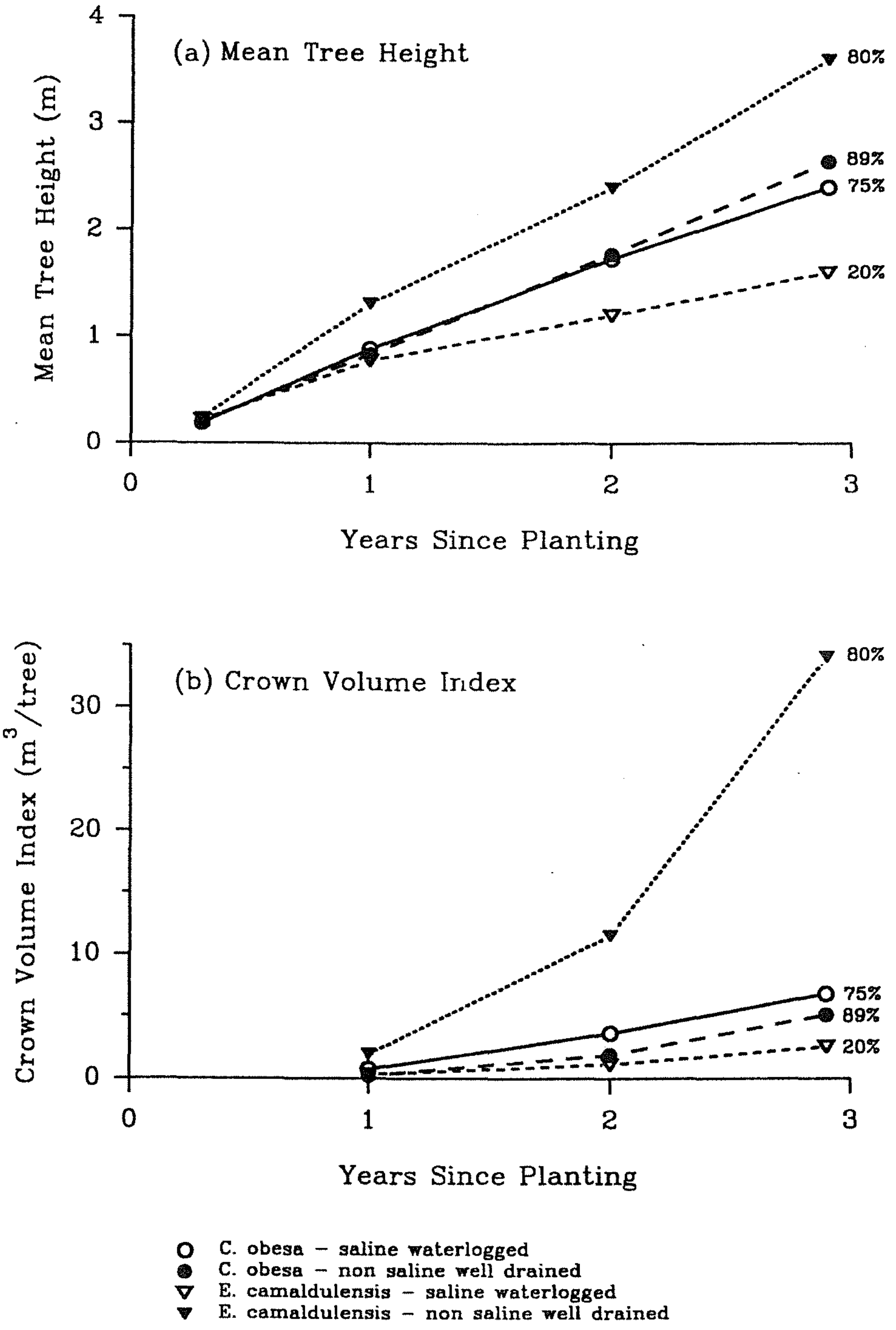


Figure 6: (a) Mean Tree Height and (b) Crown Volume Index of *C. obesa* and *E. camaldulensis* seedlings planted on saline waterlogged sites(sites 1&2) and non saline well drained sites (sites 3,4,5). Site 6 was not included as seedlings of *C. obesa* on this site were damaged by grazing..

Discussion

(i) Saline Sites

These results indicate that of the species planted, *C. obesa* is the best for reforestation of saline discharge areas. It was the only species to perform as well on saline sites as on non saline sites. *C. obesa* occurs naturally on sites with seasonal waterlogging and salinity and therefore is well adapted to the conditions at the saline sites.

The salt river gum *E. sargentii* also showed some promise on saline sites. It is a logical choice as it occurs naturally in saline areas. However Gardner (1979) recommends that *E. sargentii* should not be planted directly on areas showing severe effects of salt. This species has been planted in the Wellington Catchment with 50-75% survival in saline areas with good health and growth of survivors (McArthur and Associates unpublished report).

The provenance of *E. camaldulensis* used was from Lake Albacutya in north-western Victoria where it occurs fringing salt lakes. There has been some success using the Lake Albacutya provenance in the Wellington Catchment on seasonally waterlogged, mildly saline sites. Outside Australia Lake Albacutya has consistently proved to be the superior provenance of *E. camaldulensis* for planting on sites with a Mediterranean type climate (FAO 1979). This indicates it would be the best provenance for south-west Western Australia, although most of the sites where *E. camaldulensis* has been planted overseas have been non saline. The cloning of *E. camaldulensis* trees showing good salt waterlogging tolerance is likely to improve establishment on saline seasonally waterlogged sites.

All other species tested showed little adaptation to the salt and waterlogging affected conditions although some species, namely *E. sideroxylon, E. largeflorins, E. polyanthemos* and *E. botryoides* have been reported as having some salt tolerance (Hall *et al*. 1972; FAO 1979).

(ii) Non Saline Sites

While the results to three years after planting indicate that *E. globulus* would be the best species for planting on all four non saline sites more monitoring is required to confirm this. This is particularly so as deaths of *E. globulus*, 4 to 8 years after planting in the eastern Wellington Catchment have been recorded. However, many, if not all of the deaths can be ascribed to shallow soils or high saline watertables. Therefore careful site assessment is very important when selecting sites for *E. globulus* planting.

Because of the shallow soils (to clay) at site 6, this site may well turn out to be unsuitable for *E. globulus*. It will also be interesting to follow the progress of *E. globulus* on the site with deep sands (Site 4). *E. globulus* does grow naturally on poor sandy soils but its best development is on good quality loams (Boland et al. 1984). Information on the growth of plantation *E. globulus* on sandy soils in the south west of Western Australia is generally lacking. The lower survival of *E. globulus* at site 4 (sandy soil) compared with other sites was not explained but may relate to the susceptibility of *E. globulus* seedlings to drought death in the first summer after planting. That is the sandy soils may have dried more quickly than the loam soils. If this is the case, bigger or better designed seedling containers may improve survival by promoting a healthier root system. Growth of *E. globulus* on deep sands was only slightly slower than on the two gravelly loam sites and there may be more scope for improving growth rates with fertilizer on the sandy soils.

The good performance of *E. globulus* on the seasonally waterlogged site (site 6) suggests that this species need not be restricted to well drained soils. This would depend on the degree and duration of waterlogging especially during early establishment. In this particular case the year of planting (1987) was drier than average (Figure 2) so that seedlings may not have been subject to waterlogging at planting time. However this site was not mounded so that the detrimental affect on survival of increased waterlogging in an average year could be offset by mounding.

As for E. *globulus*, similar caution should be applied in selecting sites for planting species which only occur naturally in areas with higher average rainfall than the 600 - 700 mm/yr of our study sites. This includes *E. saligna, E. botryoides* and *E. cornuta* (Table 1). Of these species *E. saligna* and *E. botryoides* may be particularly at risk in the summer drought conditions of the south west of Western Australia. These species occur naturally in areas with uniform or summer maximum rainfall (Table 1). *E. camaldulensis* which grows naturally in areas with only 250 - 600 mm/yr average rainfall should be well adapted to the low rainfall.

Of the five fast growing species in this trial, *E. globulus, E. botryoides, E. camaldulensis* and a *E. saligna* x *botryoides* cross, were all planted in the Bingham River Arboretum in the eastern Wellington Catchment (average rainfall approximately 750 mm/yr). Only the *E. saligna* x *botryoides* cross has shown signs of stress (loss of lower branches in this case) in the 11 years since planting. This indicates that rainfall on the arborteum site may be adequate for *E. globulus* and *E. botryoides* as well as *E. camaldulensis*.

The local species *E. wandoo* and species from eastern Australia that were indentified as being good water users and well adapted to local conditions, i.e. *E. sideroxylon, E. microcarpa,* *E. polyanthemos, E. woollsiana* (Hookey *et al.* 1987), had good survival on the non saline sites but were fairly slow growing compared with the five fast growing species. They may however have a long term value being better adapted to the lower rainfall conditions than species such as *E. globulus, E. saligna* and *E. botryoides*.

The salt tolerant species *C. obesa* and *E. sargentii* were amongst the least suited to the well drained non saline sites. The value of these species are on the saline seasonally waterlogged sites only, as many other species have shown better survival and growth on the non saline sites.

SPECIES AND MULCH TRIAL

Site Description and Experimental Design

This trial was designed to compare the performance (survival and growth) on two saline seep sites of recognised salt and waterlogging tolerant shrub species (*Melaleuca thyoides, Atriplex cinerea* and *A. lentiformis*) and tree species (*Eucalyptus camaldulensis, E. sargentii* and *Casuarina obesa*). The *E. camaldulensis* plants used were micropropagated from a parent tree growing near Broken Hill, New South Wales. They were from one of a number of *E. camaldulensis* clones selected for salt/waterlogging tolerance (van der Moezel *et al.* 1989a).

The use of a hay mulch was also tested in this trial. Covering the soil with a mulch such as hay would reduce salt accumulation in the surface soils (Smith and Stoneman 1970; Hamilton 1972; Malcolm and Swaan 1985). The effect of mulches is to reduce evaporation by breaking capillary flow paths. Therefore there is less upward water movement (causing salt accumulation) and more downward water movement following rainfall (causing salt leaching). An objective of this trial was to determine if this effect on surface soil would aid tree establishment on saline waterlogging affected land.

Replications were placed on two sites selected as being representative of saline seasonally waterlogged flats that occur in the eastern Wellington Catchment. Site 1 (ex-South farm) had shallow clay soils and Site 2 (ex-Shine farm) had shallow sand over clay soils. At both sites a hardpan (possibly siliceous) occured at a depth of <1 metre. Detailed soil descriptions are given in Appendix 1. Both sites were broad valley flats, cleared prior to 1976, which have become progressively more saline until at the time of commencement of the trial, the areas had little or no vegetation other than the salt tolerant sea barley grass *Hordeum marinum*.

Groundwater depth and salinity were monitored from shallow (1.5 m) bores installed on the sites. At both sites groundwater depth below the natural land surface varied from around 0.1 m in winter to >1.5 m in summer. The salinity of the groundwater at Site 1 ranged from 7 500 mg/L total soluble salts (TSS) in winter to 12 000 mg/L TSS in summer. At Site 2 salinity ranged from 14 000 mg/L TSS in winter to 15 000 mg/L TSS content in summer.

Methods

The trial was set out in a randomized block design. On each site three blocks were placed on areas of varying pasture cover (Table 7). This was done as it was thought that the amount of pasture cover that an area has is a good indicator of the severity of salt and waterlogging stress.

TABLE 7 : Block levels of pasture cover*

SITE	BLOCK 1 (dense cover)	BLOCK 2 (medium cover)	BLOCK 3 (sparse cover)
1. ex-South	100%	53%	8%
2. ex-Shine	100%	42%	11%
mean	100%	~ 50%	~ 10%

* estimates based on point sampling

Each site included three replications of the twelve treatment combinations, that is, six species and two mulch treatments (mulch and no mulch). Each treatment combination was a single row plot of fifteen seedlings placed 2.0 m apart. Row plots were spaced 4 metres apart. At both sites planting lines were ripped to a depth of approximately 0.3 m. Standard (0.18 m high) mounds with a shallow 0.3 m wide trough pressed in the top were formed over the rip lines. Oat hay was spread over the top and sides of half the mounds to a depth of 8-10 cm in the trough where the seedlings were later planted. All mounds were sprayed with Vorox AA herbicide in June 1988 after mulch was applied. All seedlings were raised in 80 cm^3 peat based pots except *E. camaldulensis* which were raised in plastic removable tubular pots (137 cm^3 volume). All seedlings were planted out in July 1988 and each was fertilized with a 50g pellet of DAP (di-ammonium phosphate, 17.5% N, 20% P) fertilizer.

Results

There was no significant first or second order effects on survival, height or CVI for site, so results for the 2 sites are combined.

The survival of *E. camaldulensis* and *C. obesa* was good (>80%), whereas *E. sargentii* had 57% survival and the three shrub species all had <50% survival (Table 8).

There was a significant interaction between species and pasture cover for height ($p=0.005$) and CVI ($p=0.025$) (Figure 7). The interactions gave the same trend for both height and CVI. The growth of *Eucalyptus* spp. decreased with decreasing pasture cover. This reduction in growth was especially marked in *E. camaldulensis* for CVI between blocks with 100% and 50% pasture cover. For *C. obesa* there was little difference in growth between blocks with 100% and 50% pasture cover, but there was a large decrease in growth with only 10% pasture cover. *M.thyoides* grew only very slowly in all blocks but apparently slightly faster on the blocks with the least pasture cover. There were no clear trends for the *Atriplex* spp, although growth was slightly better for these species on the blocks with 50% pasture cover.

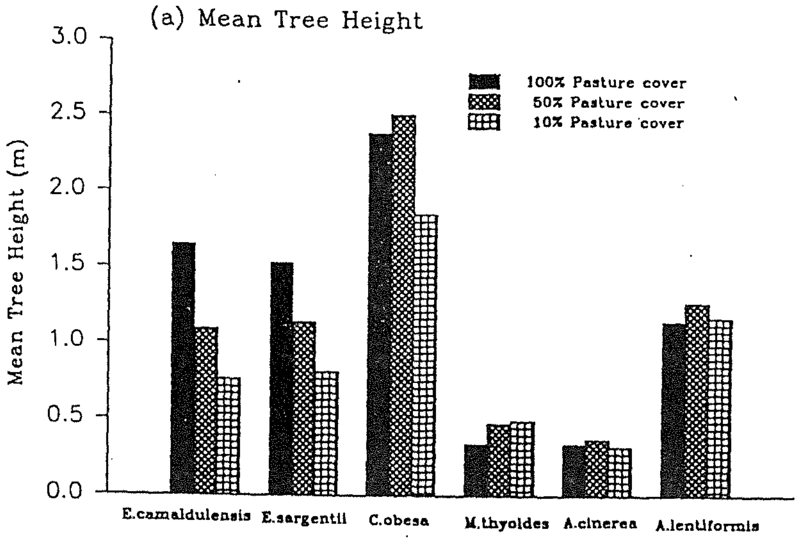
TABLE 8
Survival, Height, Crown Volume Index (CVI)
and Biomass Index for Species and Mulch
Trial 2 years after planting.*

SPECIES	SURVIVAL (%)**	HEIGHT (m)**	CVI (m^3)**	BIOMASS INDEX***
C. obesa	81 a	2.2 a	5 a	405
E. camaldulensis	88 a	1.2 b	3 ab	264
A. lentiformis	38 b	1.2 b	5 a	190
A. cinerea	47 b	0.3 c	3 b	141
E. sargentii	57 b	1.2 b	2 b	114
M. thyoides	37 b	0.4 c	0.1 c	4

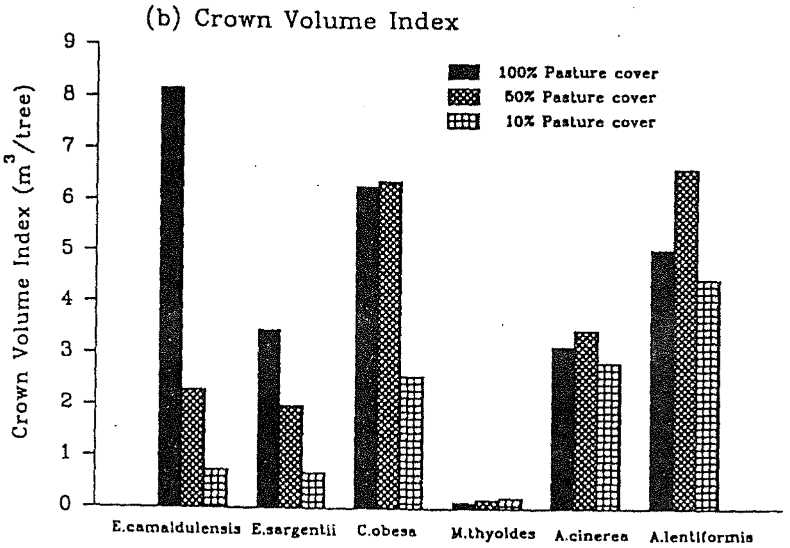
* Data are averaged for all levels of pasture cover.

** Values with the same letter are not significantly different at ($p<0.05$)

*** Biomass Index = Survival x CVI



(a) Mean Tree Height



(b) Crown Volume Index

Figure 7: Effect of pasture cover on species, two years after planting for (a) mean tree height and (b) CVI. Data are averaged for both sites in the Species and Mulch Trial.

For data averaged over all three levels of pasture cover *C. obesa* was over 1.0 metre taller than all other species (Table 8). *A. lentiformis* had a slightly higher CVI compared to *C. obesa*, these being the species with highest CVI. *A. cinerea* and *M. thyoides* both had heights of <0.5 metres. However the crown spread of *A. cinerea* was extensive reflecting the prostrate habit of this species. *A. cinerea* had a similar CVI to that of the eucalypts though not as large as *A. lentiformis* and *C. obesa*. The biomass index indicates the good performance of *C. obesa* (Table 8). The biomass index of the saltbush species was affected by their poor survival as they had comparable CVI to *E. camaldulensis*.

There was a significant interaction between mulch and pasture cover on survival ($p=0.024$). With decreasing pasture cover the benefit of mulching increased (Figure 8). Thus, on the blocks with 100% or 50% pasture cover there was little advantage of mulch whereas on blocks with 10% pasture cover there was a large improvement in survival. The greatest benefit of the mulch was in the first 2 months after planting (Figure 9). After this period the difference in survival between mulch and no mulch treatments increased only slightly. The use of a mulch had no significant effect on tree height ($p=0.99$) or CVI ($p=0.57$).

Discussion

Although there is some difficulty in comparing tree and shrub species this trial gives an indication of the best adapted species to plant on saline discharge sites. It was considered that it would be difficult, if not impossible, to establish trees on these sites. Only halophytes such as *Atriplex* species were thought to be suitable. This trial indicated that some tree species can be established, at least initially, on these sites. *C. obesa* and *E. camaldulensis* showed good survival and growth and generally did better than the shrub species.

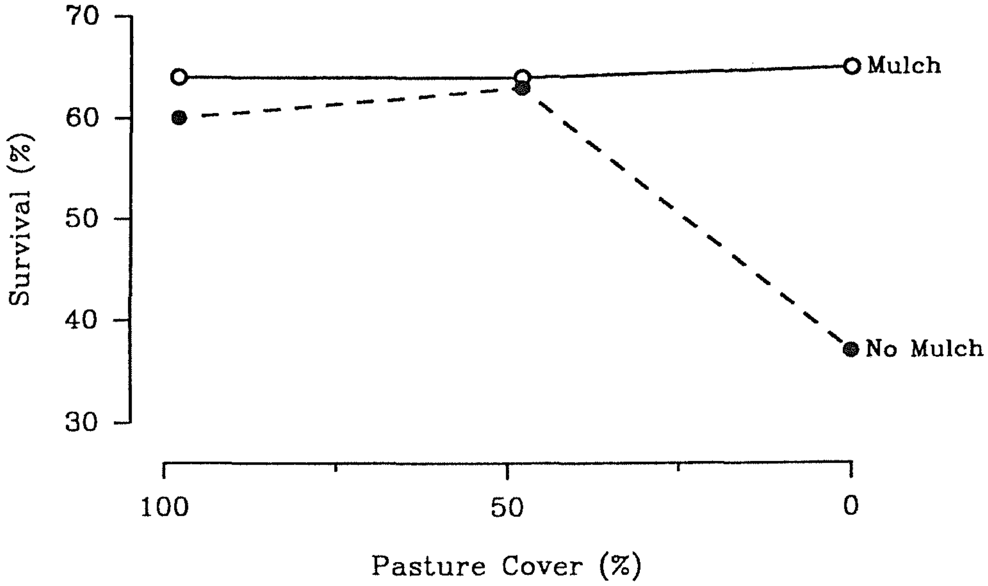


Figure 8: Effect of hay mulch on seedling survival two years after planting at three levels of pasture cover. Most scolded ground (least pasture cover)indicates most severe salt/waterlogging stress. Data are averaged for all species and both sites in the Species and Mulch Trial.

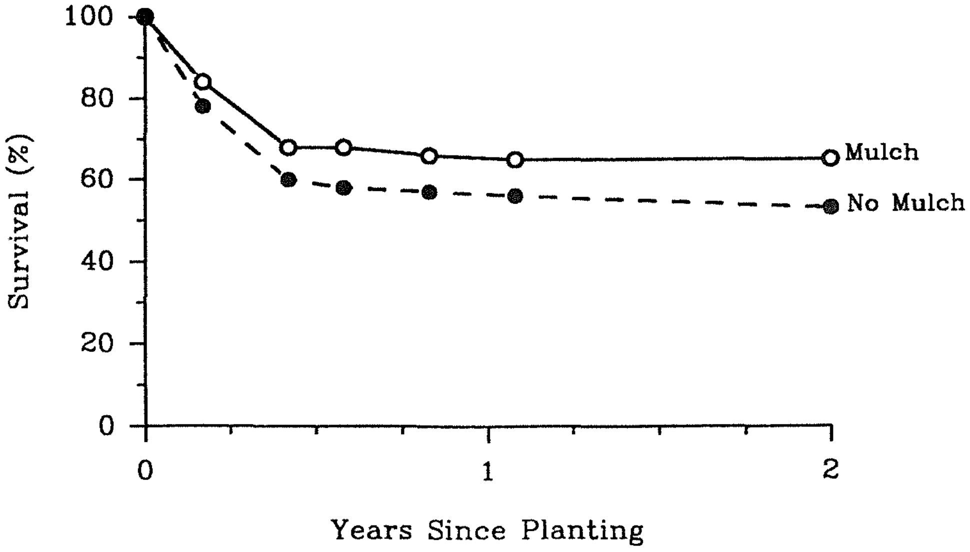


Figure 9: Survival of seedlings with and without mulch treatment over the 25 months since planting. Data are averaged for all species, blocks and sites in the Species and Mulch trial.

C. obesa is well adapted to saline waterlogged sites and has proved to be the best performing species of the six tried in this trial. The good performance of the *E. camaldulensis* clone is an indication of the successful establishment by eucalypts that can be achieved on these sites with selection of appropriate genetic stock. The *E. camaldulensis* clone used here did not have very good form. Where trees are cloned for a particular characteristic such as salt tolerance other desirable characters such as form should be considered in the selection process. Other clones with equally good salt and waterlogging tolerance have much better form (P. van der Moezel personal communication). If the tree species can do well on these sites they would be preferred to the shrub species for their generally superior longevity, better growth rates and greater potential for drawing down the water table to prevent the discharge of saline groundwater into streams.

The results also show that the growth of *E. camaldulensis* was much reduced on the blocks which had some areas of bare ground. This may indicate that this species is best suited to planting on less severe sites. As the growth of the saltbush species did not appear to be affected by increasing salinity there may be a use for species such as *A. cinerea* planted on the most severe sites in conjunction with trees. This would provide quick-growing ground cover to reduce evaporation from the soil while the trees are establishing. Saltbushes may also be useful in providing stock fodder and improve productivity of salt affected land. The overall poor survival of the *Atriplex* species may be due to the waterlogged conditions. They are usally grown in areas with lower rainfall than experienced in this trial (Malcolm 1983). Also the *Atriplex* seedlings were very small when planted and better survival may have been achieved using larger, more robust seedlings.

M. thyoides had poor survival and growth and it appears that there would be many species better suited for rehabilitation of saline sites. Because of its slow growth it also suffered from weed competition on the better sites. The locally occurring *Melaleuca* species, *M. cuticularis* and *M. priessiana*, may be better suited for sites such as these.

Our results indicate that a hay mulch can be used to improve seedling survival (but not growth rate) where saline waterlogged conditions are severe (in this case 10% pasture cover). Therefore careful assessment of a site should be made to decide whether using a mulch would be worthwhile. If mulching is to be used to improve seedling establishment on saline waterlogging affected sites a cost effective technique of obtaining and applying a suitable mulch material still needs to be developed.

The amount of barley grass cover on a site appears to indicate quite well it's severity and therefore the likely success of establishment and growth of seedlings. This is an area that warrants further investigation.

GENERAL DISCUSSION

These trials give an indication of the performance of a selection of tree and shrub species planted on saline discharge sites and the adjoining recharge areas. Data presented here are from only two to four years of monitoring so only tentative conclusions can be made. Confirmation of species suitability for particular sites will depend on long term (at least 10 years) monitoring.

Once promising species are identified further progress is likely with intra specific selection. Also, the use of clonal material can ensure that preferred characteristics are retained. A thorough site assessment should be done prior to selecting species for a particular site. An accurate evaluation of soil type, level of salinity, drainage and nutrient status should be carried out.

Tree establishment can also be improved by better site preparation techniques and planting practices. A short discussion on some of the species tested in these trials and methods for improving establishment is given below.

Species Review

On salt and waterlogging affected sites only *C. obesa* and the clone of *E. camaldulensis* had satisfactory establishment. *C. obesa* shows very good potential for the reforestation of saline discharge areas. In glasshouse studies seedlings of *C. obesa* have grown with their roots submerged in water with salinities up to 5600 ms/m (van der Moezel *et al.* 1989b). The water use characteristics of *C. obesa* are not known and this is an area that should be investigated. It has been assumed that water use of this species would not be high judging by its xerophytic characteristics such as greatly reduced leaves and small stomata. However root excavations have shown good root penetration, a promising indication of a good ability to access soil water in the capillary fringe of groundwater tables or the groundwater directly.

The *E. camaldulensis* clone had much better survival than the Lake Albacutya provenance of *E. camaldulensis* on saline waterlogged sites. This gives an indication of the potential improvements in salinity and waterlogging tolerance that can be made using cloning techniques. Also planting clones in saline areas should produce uniformly good success rates compared to seedlings which tend to have variable performance (van der Moezel *et al.* 1989a).

C. obesa also performed well in saline drained conditions. Of the other species to perform well under saline drained conditions, *E. sargentii* and *E. cornuta* showed poor tolerance of saline waterlogged conditions. This would be due to the greater stress of waterlogging in combination with high salinity. *E. occidentalis* was not tested under saline waterlogged conditions. This species occurs naturally in poorly drained areas and warrants further investigation as a potentially useful species for planting on saline discharge sites.

E. globulus performed the best of all species on recharge areas (well drained soils) and the only non saline discharge site. Within these sites *E. globulus* had best growth on sites with lateritic gravel soils. Although *E. globulus* was the fastest growing species on the saline drained site its height after four years on this site was 2 metres less than its average height after three years on the non saline sites. This, coupled with its poor survival would indicate that *E. globulus* should not be planted in saline conditions.

So far in the Wellington Catchment there has been little planting of local species. Where these have been planted there has not been a very good success rate, possibly because the environment has been altered by agriculture. This may be a factor, for species such as *E. rudis* which frequently suffers heavy leaf miner (*Perthidia* spp) infestation. *E. wandoo* was another species which commonly grew on low lying sites prior to farm clearing.

However they appear intolerant of salt and waterlogging stress and are difficult to re-establish once a saline seep has developed. This species may be useful in the longer term planted immediately upslope of the saline seep. *E. marginata* and *E. calophylla* may be grown on well drained sites but are comparatively slow growing and are very palatable to farm livestock. Therefore they must be protected from grazing for long periods after establishment. This leads to pasture build up causing fire control and weed problems. However, with careful management these species could have long term benefits because of their local adaptation and potential commercial use.

Improving Establishment

The greatest mortality of seedlings of all species seems to occur in the first year after planting. This could be reduced by appropriate nursery practises and site amelioration.

Investigations are currently underway to test the effectiveness of seedlings raised for planting on saline seasonally waterlogged areas being watered with gradually increasing concentrations of saline water in the nursery. The objective of this is to condition the seedlings to salinity prior to outplanting.

The size and type of container used affects mortality rates when seedlings are planted out. Larger volume pots and therefore larger seedlings can reduce mortality in seedlings planted on saline sites (Ritson and Pettit 1989b).

An area that should be investigated to improve seedling survival and growth is the use of root symbiots. Mathur and Sharma (1984) commented that the differential growth and development exhibited by different species on two sites suggests a need to determine the correct mycorrhizal fungi that should be used in the establishment and early growth of species on saline sites. For *Casuarina* species optimal salt tolerance requires the inoculation of trees with salt resistant strains of the nitrogen-fixing symbiot *Frankia* sp. (Redell *et al.* 1986).

Seedling survival can also be improved by appropriate site amelioration. Double ridge mounds with the seedling planted in the trough between the ridges are better than the commonly used single ridge mound shape (Ritson and Pettit, 1989a).

Drainage is another important way of improving site conditions. This can be achieved in the mounding process by ensuring mounds are on an appropriate grade (1.5% is suggested).

The present study has shown that the application of hay mulch can also increase seedling survival. There are problems with the practicablity of spreading mulch on an operational scale. The use of different mulch types and its effectiveness versus cost requires further study.

Weed control is also important in improving seedling establishment, not only in the non saline sites but also on saline sites where mounding and drainage has improved conditions.

Effective ripping of the soil is considered essential before planting. A winged tyne ripper would be the most effective in breaking up a wide area of soil. Ripping should be to as greater depth as possible to assist root penetration.

CONCLUSIONS

Good species selection needs to be combined with appropriate nursery, site amelioration and planting practices. This is to ensure the success of reforestation on groundwater discharge zones and the adjoining lower slope portion of groundwater recharge areas.

E. occidentalis is the best species for saline drained conditions. Unfortunately this species was not tested on saline waterlogged sites. Other species that show promise under saline drained conditions are *C. obesa, E. kondininensis* and *E. sargentii.*

C. obesa is the best species to plant on the most severe salt and waterlogging affected sites. The salt tolerant clone of *E. camaldulensis* also shows good adaption to these sites.

The good establishment of clonal *E. camaldulensis* on the salt and waterlogging affected site indicates the value of refining the species selection process through cloning techniques.

E. globulus shows the best growth and good survival after 4 years on non salt affected sites. This includes a seasonally waterlogged non saline site. Some sites such as those with shallow soils may not be suitable for *E. globulus*. Careful site assessment is recommended. Other fast growing species suitable for non saline sites include *E. saligna, E. botryoides, E. camaldulensis* and *E. cornuta.*

The use of a mulch can improve seedling establishment on the most severe salt and waterlogging affected sites. A cost effective method of obtaining and applying mulch needs to be developed.

Tree species can successfully be established on saline discharge areas. For stream salinity control trees would be preferred to salt tolerant shrubs because of their longevity, higher water use and faster growth rates.

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APPENDIX 1

Detailed Soil Descriptions at the Trial Sites.

Descriptions are from a single auger hole drilled at each site, except at Ricetti Arboretum site where the soil description was taken from an existing vertically exposed face. For an explanation of terms used see Northcote (1971) and McDonald *et al.* (1990).

Ricetti High Mounds - Arboretum

Valley floor; Saline.
0-4 cm Dark greyish brown (10YR4/2) sandy loam; massive; porous; firm (force 3); hardsetting; pH 6.
4-10 cm Bleached, pale brown (10YR6/3) loamy fine sand; massive; very porous; firm (force 3); sharp change to
10-40 cm Light yellowish brown (10YR6/4) sandy clay; some yellow mottles; very firm (force 4); pH 6.
40-70 cm Light yellowish brown (10YR6/4) sandy clay; some yellow and light grey mottles; weak polyhedral structure; dense peds; very firm (force 4); pH 7.
70-100 cm Light yellowish brown (10YR6/3) sandy clay; moderate polyhedral structure; dense; very firm (force 4); pH 7.
Northcote Classification: Dy 3.42
Note: Clay is sometimes grey-brown (10YR5/2) or reddish brown (5YR5/3). Some areas have a siliceous pan within 1 metre of the surface.

Species Site Adaptation Trial

Site 1:

Valley floor; saline crust 1-2mm thick on the surface.
0-4 cm Very dark grey (10YR3/1) loamy sand; massive; porous; firm (force 3); pH 6. 4-25 cm Brown (10YR3/1) fine sand; massive; porous; few rusty root channels; weak (force 2).
25-40 cm Very pale brown (10YR7/3) fine sand; few yellow-brown mottles; massive; porous; weak (force 2); pH 6;
sharp change to
40-60 cm Pale brown (10YR6/3) sandy medium clay; few faint brown mottles; massive; dense; very firm (force 4); pH 7; some iron concretions; sharp change to
60 cm pan, very firm (force 5); dense; waxy appearance, probably siliceous.
Northcote Classification: Dy 3.82

Site 2 :

Valley floor; saline crust 1-2mm thick on the surface.
0-5 cm Very dark greyish brown (10YR3/2) sandy loam; some grey mottles; porous; massive; weak (force 2); pH 6.5; hard setting when dry.
5-10 cm Dark brown (10YR4/3) loamy sand; few rusty root channels; massive; porous; weak (force 2).
10-30 cm Pale brown (10YR6/3) loamy sand; few rusty root channels; few pores; massive ; weak (force 2); pH 6.
30-50 cm Light yellowish brown (10YR6/4) fine sand; porous; massive; weak (force 2).
50-70 cm Pale brown (10YR6/3) fine sand; large mottles of 10YR7/6; porous; massive; weak (force 2).

70-90 cm Light yellowish brown (10YR6/4) fine sand with large dark brown (10YR3/3) mottles; massive; porous; few iron concretions.
90-110 cm Light yellowish brown (10YR6/4) coarse sand; few dark brown mottles (10YR3/3); very weak (force 1); some iron concretions, quartz grit and gravel.
110-150 cm Brown (10YR5/3) sandy clay loam; massive; dense; firm (force 3); sodic feel. 150-170 cm Brown (10YR5/3) sandy clay; few dark brown mottles; indurated (force 4); dense; massive.
170-200 cm Pale brown (10YR6/3) fine sandy clay; some yellow brown mottles; firm (force 3); massive; dense; few iron concretions; pH 7.
Northcote Classification: Dy 3.82

Site 3:

Gentle slope (2%) to the north.
0-10 cm (Plow layer) Dark brown (10YR4/3) loamy sand; massive; porous; weak (force 1); 5% ironstone gravel; pH 6.
10-30 cm Yellowish brown (10YR5/6) loamy sand; loose single grain; force 1; 30% gravel.
30-50 cm Yellowish brown (10YR5/8) sandy loam; massive; porous; force 2; 50% gravel; pH 6.5.
50-70 cm Strong Brown (7.5YR5/8) sandy loam; massive; porous; force 2; 20% gravel.
70-90 cm Strong brown (7.5YR5/8) sandy clay loam; massive; porous; firm (force 3); few yellow brown mottles; 10% gravel; pH 6.5.
90-100 cm Strong brown (7.5YR 5/8) sandy clay; massive; dense; force 3; 60% gravel.
100 cm Not penetrable; indurated ironstone pan tending to have horizontal platy structure.
Northcote Classification: Dy 5.51

Site 4:

Gentle Slope (2%) to the north

0-10 cm Dark brown (7.5YR4/3) loamy sandy; loose single grain; force 1; pH 6. (plough layer)

10-30 cm Yellowish brown (10YR5/8) fine sand; loose single grain; force 1.

30-50 cm Brownish yellow (10YR5/8) fine sand; loose single grain; force 1.

50-70 cm Brownish yellow (10YR6/8) fine sand; loose single grain; force 1.

70-90 cm Brownish yellow (10YR6/8) fine sand; loose single grain; 5% ironstone gravel.

90-110 cm Brownish yellow (10YR6/8) fine sand; loose single grain; force 1; 10% ironstone gravel.

110-130 cm Brownish yellow (10YR6/8) fine sand; loose single grain; force 1; 30% ironstone gravel.

130-150 cm Brownish yellow (10YR6/8) fine sand; loose single grain; force 1; 50% ironstone gravel.

NB. (i) Gravel ranges in size from 2mm to 25mm.
(ii) Sand grains are mainly angular, sand is poorly sorted.

Northcote Classification: Uc 5.11

Site 5:

Moderate Slope (4%) to the east.

0-10 cm Dark brown (7.5YR3/3) sandy loam; massive; porous; force 2; pH 6; 15% gravel (plough layer).

10-25 cm Reddish brown (5YR4/5) loamy sand; loose; force 2; 50% gravel.

25-40 cm Reddish brown (5YR4/6) loamy sand; loose; force 2; 40% gravel; sharp change to

40-60 cm Yellowish red (5YR5/7) medium clay; weak polyhedral structure (1-2cm diameter); dense;
firm (force 3); slight gravel ; pH 7.

60-90 cm Yellowish red (5YR5/8) medium clay; moderate polyhedral structure; dense; firm (force 3).

90-130 cm Yellowish red (5YR5/8) medium clay; some yellow brown mottles; moderate polyhedral structure; very firm (force 4).

130-180 cm Yellowish red (5YR5/6) medium clay; some red brown mottles; moderate polyhedral structure; dense; very firm (force 4); pH 7.

Northcote Classification: Dr 2.22

Site 6:

Valley floor in upland depression; seasonally waterlogged.

0-10 cm Very dark greyish brown (10YR3/2) fine sandy loam; massive; porous; firm (force 3); many rusty root channels; hard setting; pH 5.5; (plough layer).

10-30 cm Yellowish brown (10YR5/4) sandy loam; massive; porous; weak (force 2); 10% gravel.

30-50 cm Light yellowish brown (10YR6/4) medium clay; few brown mottles; massive; dense; very firm (force 4); pH 6.5; 30% gravel.

50-80 cm Light yellowish brown (10YR6/4) medium clay; few brown mottles; massive; dense; very firm (force 4); pH 6.5.

80-110 cm Pale brown (10YR6/3) medium clay; some yellow brown and light grey mottles; massive; dense; very firm (force 4); pH 7.

110 cm Not penetrable; indurated ironstone pan tending to have horizontal platy structure.

Northcote Classification: Dy 3.62

Species and Mulch Trial

Site 1 - Souths

Valley floor <1% slope
0-5 cm Dull yellowish brown (10YR4/3) loamy sand; massive; porous; weak (force 2); hard setting; pH 6.5.
5-10 cm Grayish yellow brown (10YR4/2) loamy sand; massive; porous; weak (force 2); pH 6; sharp charge to
10-20 cm Grayish yellow (2.5Y6/2) medium clay; massive; dense; very firm (force 4).
20-40 cm Grayish yellow (2.5Y6/2) medium clay; massive; dense; very firm (force 4); pH 6.
40-60 cm Grayish yellow (2.5Y6/2) medium clay; massive; dense; very firm (force 4).
60-70 cm Grayish yellow brown (10YR5/2) sandy medium clay; massive; porous; firm (force 3); pH 7.
70 cm Pan; rigid (force 7); probably siliceous.
Northcote Classification: Dy 3.82

Site 2 - Shines

Valley floor; <1% slope; saline crust (1-2mm) on the soil surface.
0-5 cm Brownish gray (10YR4/1) loamy sand; massive; porous; weak (force 2); pH 5.5; saline crust.
5-10 cm Light gray (10YR7/1) sand; massive; porous; weak (force 1).
10-20 cm Light gray (10YR7/1) sand; massive; porous; weak (force 1).
20-30 cm Light gray (10YR7/1) sand; massive; porous; weak (force 1); pH 6.
30-40 cm Light gray (10YR7/1) sand; massive; porous; weak (force 1); sharp change to
40-60 cm Grayish yellow brown (10YR6/2) medium heavy clay; massive; dense; very firm (force 4);

60-80 cm Grayish yellow brown (10YR6/2) medium heavy clay; massive; dense; very firm (force 4); pH 6.

80 cm Pan; rigid (force 7); probably siliceous

Northcote Classification: Dy 3.81