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Selection of Plants for Revegetation of Goldmine Residue in the Jarrah Forest of South-Western Australia

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Abstract

Mining at Boddington in the eastern jarrah forest of south-west Western Australia by Boddington Gold Mine and Hedges Gold produces 10 million tonnes of residue annually. This is stored in purpose built dams that will eventually cover 1000 ha. The residue has to support a variety of ecosystems from pasture to native vegetation. As this was the first gold mining operation in the south west of Western Australia, and the problems faced in vegetating the residue were unknown, the present field trial was aimed at selecting species suitable for revegetation. The experiments were conducted in a purpose built one hectare dam with a residue depth of about 1.5 metres. The salinity, sodicity and alkalinity of the residue were ameliorated by using a land preparation procedure selected from previous experiments: ripping, rotary hoeing, amending with gypsum (30 and 60 t/ha), mulching with organic matter (poultry manure) and covering with topsoil.

The 27 species of trees, shrubs, herbs, legumes, grasses and sedges tested were selected on the basis of their ability to tolerate salt-affected seasonally waterlogged clay soil. They were planted in spring 1992 and screened for their survival during the following 12 months. Survival of native species varied. For example, two of the local jarrah forest *Eucalyptus* species, *E. marginata* and *E. patens,* did not survive past the second month of summer. By contrast, salt tolerant species *Atriplex amnicola, Casuarina glauca* and *Casuarina obesa* survived and in some cases flourished. The grasses sown all germinated, grew and produced seed and some germinated the following season.

It was concluded that establishment of pasture or crops, and of non-endemic native vegetation on the amended residue is feasible but re-establishment of jarrah forest requires more investigation.

Key words: gold mining, gold refining residue, salinity, jarrah forest, plant species screening

Introduction

Gold was discovered in the Boddington region of south-western Australia in 1980 and is being mined by Boddington Gold Mine (BGM) and Hedges Gold (HG) which produce 10 million tonnes of residue annually. The residue from the carbon in pulp gold processing is deposited into purpose built dams as a slurry comprising 40% solids in saline process waters. These dams will eventually cover 1000 ha. There are limited revegetation options due to the residue's high salinity (10,000 to 15,000 mg Total Soluble Salts per litre), high pH (about 9.0) and fine texture. Preliminary on-site examinations, initial laboratory testing and published literature indicated that other major constraints to plant establishment are accumulation of excess water during the winter, surface cracking and limited ability of the material to supply plants with water during the summer.

The difficulties of revegetating residue dams are well known. This is due to the adverse properties of the material; lack of organic matter; unfavourable texture and structure [2], adverse physical properties leading to inadequate aeration, low permeability to water and surface crusting;

deficiencies of plant nutrients, toxic levels of salts [4] [3]; and, in this case, high pH.

Success had been reported in growing grasses and halophytes for the purpose of stockfeed and stabilisation of residue [3]. However, revegetating residue storage areas with indigenous vegetation has had varied success. Gold mining occurs in quite different climates. As such the revegetation process of residue can be quite different but common to all is the hostile nature of the material. Experiences elsewhere suggest that the residue surface should be modified by ploughing and contouring; the addition of gypsum, nutrient and organic matter and covering with a layer of topsoil (or overburden) and/or mulch [6] [4]. Finally, planting with tolerant plants is recommended.

The objective of the field experiment reported here was to screen a variety of plant species on the amended residue substrate. The species were selected on the basis of representing the vegetation components of the possible future land uses for the area of crop and pasture based agriculture, agro forestry, or forestry as represented by the eastern jarrah forest. With due regard for the characteristics of the amended residue substrate, a number of salt and waterlogging tolerant native species were also tested. Our main aim was to re-establish local jarrah forest species in some areas and pasture species on others. However salt and waterlogging tolerant native woody species were also tested.

Materials And Methods

Boddington is located within the eastern jarrah forest 125 km south west of Perth, Western Australia. Eighty four percent of the moderately high annual rainfall (average 672 mm/year) falls between the months of April to October. Mean maximum and minimum temperatures range, from 28.5 °C to 13.5 °C in summer, and 15.3 °C and 5.7 °C in winter.

Species selection

Most species trialed (Table 1) were chosen on the basis of their tolerance to the physical properties of the residue especially salinity and waterlogging. Salt tolerant species selected on the basis of previous reports were: *Eucalyptus camaldulensis*, *Casuarina obesa*, *C. glauca*, *Melaleuca halmaturorum* [10], [11] *E. sargentii* and *E. rudis*, [11],[5]. The halophytes *Atriplex amnicola*, *Sarcocornia spp*, *Juncus kraussii* and a succulent *Carpobrotus edulis* were also included. The remainder of the species were cereals, grasses and species recommended by nurseries or species native to the surrounding jarrah forests: *Eucalyptus marginata*, *E. calophylla*, *E. patens*.

Site selection

Three dams were built in 1991 on the HG mine site for the purpose of field trials. One of them, a 1 ha dam known as Cell A, was filled with residue at the end of 1991 and allowed to dry over the summer of 1992. In May 1992, preparations began for two field trials; one to test substrate amendment procedures and the other a species trial. This paper reports on the results of the species trial.

Cell A is shallow (<1.5 m depth of residue) and has an underdrainage system to represent the well drained perimeter of a decommissioned large storage area.

During the period January - April 1992, as the residue dried, cracks developed and a salt crust formed on its surface. Cracks occupied 15 - 20 % of the surface area and 7 - 10 % of the pond volume of Cell A.

Preparation procedure

In mid-April 1992, Cell A was ploughed, ripped where needed in compacted areas and then rotary hoed. In late April, gypsum (60 t/ha) and poultry manure (thickness of 4-6 cm) were spread, followed by mulching with topsoil (thickness, 8 - 10 cm). The site was then left to be leached by winter rains.

The prepared area was divided into four equal blocks. Each block was then split into 30 sections. The species were planted randomly within each of the four replicate blocks. Seedlings and seeds of the selected species were planted in late September/early October 1992 following severe winter flooding and waterlogging.

Table 1. List of Species Planted in the Field Trial

LATIN NAME	COMMON NAME
NATIVE (Australian)	
Acacia saligna	golden wreath wattle
Casuarina glauca	black oak
Casuarina obesa	swamp oak
Eucalyptus calophylla	marri
E. camaldulensis	river redgum
E. longicornis	red morrel
E. marginata	jarrah
E. patens	yarri
E. sargentii	sargents mallet gum
E. rudis	flooded gum
Mairaclera sp.	
Maireana brevifolia	small leafed blue bush
Melaleuca halmaturorum	swamp paperbark
INTRODUCED	
Populus nigra var italica	lombardy poplar
Salix coerulea	cricketbat willow
Sesbania formosa	swamp corkwood
Tamarix sp.	tamarisk
HALOPHYTES	
Atriplex amnicola	river saltbush
Juncus kraussii	
Sarcocornia sp.	
SUCCULENT	
Carpobrotus edulis	pigface
CROPS and PASTURES	
Agropyron elongatum	tall wheat grass
Avena sativa	oats
Lolium multiflorum	wimmera rye grass
Medicago polymorpha	medic
Medicago sativa	lucerne cv trifecta
Triticosecale spp cv Muir	(barley x wheat cross) triticale

Species were planted in various forms: *Atriplex amnicola* as a bare-rooted plant; native and introduced species as nursery-raised seedlings; *Avena sativa, Medicago sativa, Medicago polymorpha, Agropyron elongatum, Carpobrotus edulis, Sesbania formosa* and crop and pasture species were sown as seed and *Juncus kraussii* and *Sarcocornia* sp. were transplanted as rooted plants.

Tree seedlings were transplanted at the rate of three plants per replicate, 0.3 - 0.5 metres apart. The remaining species were sown as 50 seeds in a line covering 1 metre.

Plant performance

Assessment of plant performance was by scoring the plants for survival and growth over the following fourteen months. The scoring system was :

0= dead;

1= severe signs of stress, most leaves are necrotic, no signs of new growth;

2= severe signs of stress, necrosis and chlorosis of leaves with little growth;

3= moderate signs of stress (chlorosis) with little new growth;

Table 2. Electrical Conductivity (1:5 soil extract) and pH of Soil Samples Collected from Cell A.

Sample Type	Conductivity (mS/m)		pH	
	16/9/92	15/2/93	16/9/92	15/2/93
TOPSOIL (0-10 cm)	90	650	5.84	5.99
AMENDED RESIDUE (10-30 cm)	1200	1950	7.04	6.93
BARE UNAMENDED RESIDUE	1160	18600	8.17	8.63

4= some signs of stress but general leaf appearance was good with new growth apparent; and

5= healthy overall appearance with abundant new growth.

The scoring system was used primarily to compare the growth of the same plant species in different replicates and on different dates rather than among the species, given the different characteristics of the species grown.

Substrate monitoring

Soil samples were taken regularly over the period at two depths, 0-10 cm, and 15-30 cm from the plots of the adjacent trial testing substrate preparation procedures some of which underwent land preparations identical to the species trial. Soil samples were air dried, hammered to break the lumps of clay and then sieved (2 mm size sieve). The samples were extracted in a 1:5 soil to water ratio and then analysed for conductivity and pH. Sampling was done in September 1993 and February 1994.

Results

Several species failed to establish or survive: *Carpobrotus edulis* failed to germinate and by February, *Salix coerulea, Eucalyptus marginata, E. patens and Populus nigra var italica* had died.

The other eucalyptus species had varied success. *E. calophylla* consistently showed moderate to severe signs of stress throughout the trial period neither dying over the summer when the availability of water was limited nor exhibiting recovery in the following winter and spring when water was available. Some *E. calophylla* rated as high as 3 indicating new growth. *E. longicornis* had a healthy overall appearance with abundant new growth until the November score when it appeared to suffer moderate to severe stress. This may be due to competition from more vigorous species such as *Atriplex amnicola* which formed a ground cover and encroached on the other plants. *E. sargentii, E. camaldulensis* and *E. rudis* all scored consistently well throughout the trial surviving and growing throughout the dry summer and the waterlogged winter.

Casuarina obesa and *C. glauca* rated highly towards the end of the trial following a slow establishment period. *Melaleuca halmaturorum* was strongly persistent but not vigorous in its growth. It apparently is a very slow grower which appeared to have stopped growing through the dry summer and in periods of flooding, when the conditions were unfavourable.

Sarcocornia sp. and *Juncus kraussii,* collected from the Swan River foreshore which is waterlogged for most of the year and saline grew well when water was available and survived the dry summer.

Soil samples were taken to monitor the salinity levels of the substrate. Salinities did increase in the 0-10 cm layer of topsoil and the 10-30 cm layer of amended residue layer from winter to summer (Table 2) but not as markedly as the bare residue which had no amendment at all.

Rainfall for the period of the trial is presented in Figure 1. HG is situated between Dwellingup and Boddington and BGM is

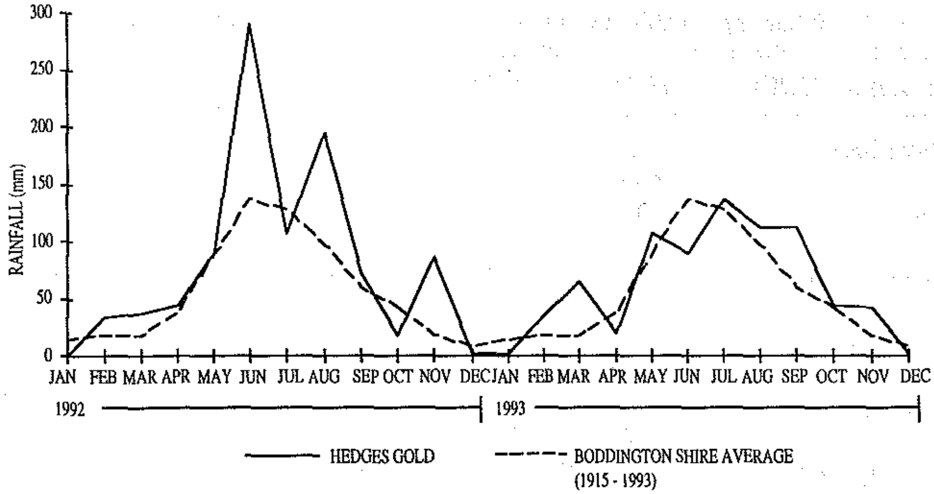

Figure 1. Monthly Rainfall (mm) at Hedges Gold Plant Compared to the Average Rainfall of Boddington Shire

located about 5 kms north of Boddington. Rainfall data were collected at HG plant which is about 1 km away from the trial site. There was significantly more rain in 1992 (978.5 mm) compared to 1993 (775.4 mm) at the HG plant. Rainfall during the first summer after planting was rather higher than average with about 200 mm falling compared to an average of 79 mm between November and March [1].

Discussion

The establishment and growth of grass, crop and pasture species was generally very successful. Growth and sustained vigour of the salt and waterlogging tolerant species varied. Three of the four species of eastern jarrah forest tree species exhibited the poorest survival or growth vigour of all species tested. One of the four however, *E. rudis*, had 100% survival and exhibited high vigour scores. *E. rudis* also rated well in a similar experiment with 100% survival in waterlogged or saline conditions [11]. Survival dropped to only 16% under combined salinity and waterlogging but those plants that did survive grew quite well. However, this species occurs only along the wetter drainage lines of the eastern Jarrah forest and never covers significant areas of the forest. Use of *E. rudis* is limited to fuel wood, the establishment of a hardwood timber crop on these residue areas, based on species of the eastern jarrah forest will require further extensive research.

When the estabishment success of the other non-forest species is considered, it may prove fruitful to investigate a successional process of establishment of jarrah forest overstorey. Use of the salt and waterlogging tolerant species as pioneer plants to reduce the salinity levels of the residue over time may with the associated accumulation of organic matter and general imporvement in soil physical conditions, render the substrate more conducive to the jarrah forest hardwood species tested. This longer term successional concept using pioneer species should be investigated further.

Of the salt and waterlogging tolerant species a number grew well. The vigorous growth of *E. sargentii* is consistent with that reported by Van der Moezel *et al* [11] who rated *E. sargentii* as one of the most tolerant eucalypt species to salt/waterlogging trials when the plant was grown at a salinity of 3500 mS/m for 5 weeks. *Carpobrotus edulis* germinated in one of the replicate blocks but did not survive. By contrast, when C. *edulis* was

Table 3. The scores of 21 species ranked on the final scoring in November, 1993 (ranging from severe stress (1) to abundant, healthy growth (5)). Values are means of four replicates. Where applicable the range of scores is given in parentheses.[A]

SPECIES	12/1/93	18/2/93	15/4/93	11/5/93	2/11/93
Atriplex amnicola	4.75 (4-5)	4.75 (4-5)	5.00	5.00	5.00
Maireana brevifolia	4.00 (4-4)	4.25 4-4.5	5.00	4.00	5.00
Casuarina glauca	3.50 (2.5-3)	4.00 (3.5-4.5)	4.00 (3-5)	4.00 (3-5)	5.00
Mairaclera sp	5.00	5.00	5.00	4.75 (4-5)	4.75 (4-5)
Acacia saligna	4.25 (4-5)	4.75 (4.5-5)	5.00	4.75 (4-5)	4.75 (4-5)
Eucalyptus rudis	4.25 (4-5)	4.75 (4.5-5)	4.75 (4-5)	4.50 (4-5)	4.75 (4-5)
Casuarina obesa	2.75 (2.5-3)	3.25 (2.5-4)	3.25 (3-4)	3.25 (2-4)	4.75 (4-5)
Eucalyptus sargentii	3.75 (3-5)	4.00 (3.5-4.5)	4.25 (3.5)	3.75 (3-4)	4.00 (3-5)
Eucalyptus camaldulensis	4.00 3.5-5	4.50 (4-5)	4.75 (4-5)	4.00 (3-5)	3.75 (3-4)
Tamarix sp	4.50 (3.5-5)	3.50 (3-4)	4.75 (4-5)	3.75 (3-5)	3.50 (3-4)
Juncus kraussii	0.00	0.50 (1-3.5)	1.25 (0-3)	1.25 (0-3)	3.25 (0-5)
Sarcocornia	2.50 (1-3.5)	2.50 (1-3.5)	3.75 (3-4)	2.50 (0-4)	3.00 (0-5)
Melaleuca halmaturorum	1.00 (1-2)	2.00 (2-2.5)	1.75 (1-2)	3.00	2.50 (0-4)
Eucalyptus longicornis	4.00 (3.5-4.5)	4.00 (3.5-4)	4.00 (3-5)	4.00	2.50 (2-3)
Eucalyptus calophylla	2.25 (1-3)	2.25 (2-3)	2.00 (1-3)	2.00 (0-3)	2.00 (1-3)
Salix coerulea	3.25 (1.5-4)	0.25 (0-1)	0.50 (0-2)	0.00	0.00
Sesbania formosa	1.00 (0-3)	1.00 (0-3.5)	1.50 (0-5)	1.00 (0-3)	0.00
Eucalyptus patens	3.00 (2.5-3.5)	0.00	0.00	0.00	0.00
Eucalyptus marginata	2.00 (1.5-3)	0.00	0.00	0.00	0.00
Populus nigra var italica	1.50 (0-3.5)	0.00	0.00	0.00	0.00
Carpobrotus edulis	0.00	0.00	0.00	0.00	0.00

[A] The crops and pastures all germinated, flowered, set seed, and regenerated the following season. Their scores have not been included in the above table as they are annuals and therefore not scored in the January to April period.

transplanted as a seedling (by mine staff from domestic stock) in an adjacent area it survived well over the summer and winter periods. The apparent discrepancy between these two observations is consistent with previous reports that there was no relationship between tolerance to salinity at the germination and seedling stage [9][5].

Casuarina obesa and *C. glauca* rated highly towards the end of the trial following a slow establishment (Table 3). Both have been reported to grow under waterlogged, saline conditions (up to a concentration of 5600 mS/m for twelve weeks) [11]. Their salt and waterlogging tolerance was attributed to exclusion of sodium and chlorine in contrast to the salt sensitive species which accumulated salt in the shoots. Similarly Van der Moezel and Bell [10] observed that the main mechanism of salt tolerance in non-halophytes was Na and Cl exclusion from growing shoots. They further suggested that the most tolerant *Casuarina* and *Melaleuca* species were considerably more tolerant than the best performed *Acacia* and *Eucalyptus* species. By contrast, in the present study *Acacia saligna* was as vigorous as the *Casuarina spp*. and the best *Eucalyptus* and much more so than the only *Melaleuca* tested.

Further attempts to grow those species which failed to survive in the present study, *Salix coerulea, Eucalyptus marginata and Populus nigra var italica,* may involve altering the time of planting. Planting in May/June after the first reliable rains, or at the beginning of spring, rather than the end of spring may improve plant survival if enough root mass persists for uptake of water and nutrients to sustain the plants through the summer.

The second objective of this experiment, to grow grass, crop and pasture species, was successful. In the present study the crop and pasture species all germinated, survived, and set seed which re-established the following season. *Agropyron elongatum* performed particularly well in this trial and in other glasshouse and field trials. Moreover it is reputed to be salt tolerant in the cooler areas [8].

That the salinity in Cell A was considerably less than what was forecast for a decommissioned dam suggests that the species survival in the present study represents a best case scenario. The electrical conductivity of the topsoil at 500 mS/m in a 1:5 extract was saline [9]][7] and the amended residue surface was strongly saline at 2000 mS/m. However salt is usually not uniformly distributed throughout the soil profile. After a period of dry weather there may be a concentration of salt at the surface of the bare soil due to evaporative concentration and capillary migration. Conversely, after a period of rain, the highest salt concentration may be in the lower root zone due to leaching. Leaching of Na^+ is controlled by the hydraulic conductivity of the clay and the ionic composition of the solution in the matrix.

However a successful species will not only have to tolerate near drought and increasing salinity in summer but also waterlogging conditions in winter. It was observed during winter that the dry residue clay does not resorb water. Instead, excess water would either run off the surface to fill cracks or pond on the surface.

However it is more likely that a period of further amelioration of the residue, possibly by colonization with a combination of salt-tolerant pioneer vegetation, will be necessary for the successful re-establishment of jarrah forest species. The beneficial effects of a vegetation cover of pioneering species can be several fold : firstly because of the rapid growth during the winter they would consume excess water and thereby help reduce soil water content; secondly, during the succeeding summers the cover would prevent excessive drying of the residue surface which would lead to a reduction in capillary migration of salt on to the surface; thirdly, the root channels formed would act as a pathway for downward movement of water during subsequent winters which would help leaching of excessive salt from the rooting zone.

Conclusions

Our aim is to grow crops and pasture or native vegetation on the residue storage areas. The former appears to be achievable but the latter requires more experimental work. The failure of *Eucalyptus marginata* and *E. patens* to survive and the poor vigour of *E. calophylla* suggests the need for further amelioration of the residue possibly by long term colonisation with a combination of salt tolerant pioneer species which would improve the conditions of this harsh environment. Hence a sequential revegetation program is proposed with salt and waterlogging tolerant grasses and *Atriplex* species in the initial phase followed by the introduction of tree species when conditions are favourable with regard to salt and water content in the upper layers of the residue. On-going research is aimed at achieving this objective.

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