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Is Sandalwood Emergence and Growth Inhibited by Waterlogging or Depth of Burial?

by

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Is Sandalwood Emergence and Growth Inhibited by Waterlogging or Depth of Burial?

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Abstract

Santalum spicatum *has been an important part of the Western Australian export industry for over 150 years. The heartwood is fragrant, containing distinctive oils that are valued in many parts of the world. The main uses are pharmaceutical, medicinal and in religious observations. Salinity is one of the most important changes to land cover across the South-western part of Western Australia. Many revegetation programs are under way on wheatbelt farms that are most effected by salinity. Plants such as* Acacia acuminata, *used in these revegetation programs, can also act as a host for the parasitic sandalwood tree.*

This report deals with experiments undertaken in 2000, in both field and glasshouse to determine what levels of salinity sandalwood could withstand in regards to emergence and early growth. A field experiment sought to examine waterlogging effects on emergence and early survival of fresh germinants of S. spicatum. *A second glasshouse trial exposed seedlings to continuous inundation of 1-4 weeks. Of the field seed planting depths used, mounding was superior in both total emergence and in best pattern of planted spots with established seedlings. Seed burial at 10 cm or greater, depressed total emergence and reduced the proportion of occupied spots. All emergent seedlings differed little in height and leaf numbers between treatments. Seedlings had grown in much the same pattern across both experimental sites, suggesting that early growth was mainly dependant on cotyledonary resources.*

Significant differences were found in both height and leaf number between salinity treatments in the glasshouse salinity trial. This suggests that seedlings of S. spicatum *can tolerate low to moderate salinity levels. This finding was also backed up by the emergence and growth of sandalwood in the field-based experiment.*

Inundation of sandalwood for four weeks had no significant effect on shoot growth, however if the experiment had run for a longer period of time the seedlings would probably have died, as the roots disintegrated with waterlogging. Field waterlogging also affects emergence by causing the seeds to rot after germination.

Introduction

Sandalwood (*Santalum spicatum*) has been an important part of the Western Australian export industry since 1845 (Crossland 1981). The distinctive sandalwood fragrance comes from the oil contained within the heartwood. It is this heartwood that is exported and used by many people across the world for a variety of reasons. It is valued for its medicinal qualities, used in religious observations, burned in incense sticks (joss sticks) and the oil is used in the perfume industry (Fox 2000, Brand 1999, Brand & Jones 1999).

Two species dominate the world trade. *Santalum album*, the Indian sandalwood (or santal), which is found in Southern India and Indonesia; and *Santalum spicatum*, which occurs in the western parts of Australia (Fox 2000). This report is only concerned with the latter.

In Western Australia, sandalwood generally ranges in distribution from Carnarvon in the north, to Esperance in the south, and from the eastern Goldfields through the Wheatbelt to the periphery of the forests above the sandplain in the west. It is absent from the Swan Coastal Plain and adjacent jarrah forest (Fox *et al.* 1996). Sandalwood is an obligate root hemi-parasite, of shrub or small-tree form, that may attain 7-8m in height. The usual stature is generally only to between 2-4m in height. The parasitic nature entails sandalwood seedlings developing haustorial connections with other plant roots (hosts) through which the seedlings derive nutrients and water. Hosts commonly include species of *Acacia* (such as: *A. acuminata,* raspberry jam; *A. aneura,* mulga; and *A. tetragonophylla,* curare), *Allocasuarina, Melaleuca* and herbaceous species (Barrett & Fox 1995). Western Australian sandalwoods do not grow well on waterlogged, heavy clay soils or on saline areas. However, the tree does occur on a wide range of substrates: from loamy calcareous soils inland, to slightly acidic sandy loams in *Eucalyptus* woodlands (Fox *et al.* 1996).

One of the most important changes to the land cover in the South-western part of Western Australia has been the development of extensive areas affected by dryland salinity. This is manifest when the concentration of soluble salts near the surface is sufficient to reduce plant growth (on non-irrigated land). It is a result of deep-rooted native vegetation having been replaced with shallower-rooted annual pasture or crops, thus altering the water balance between rainfall, evapo-transpiration and ground water. These annual crops and pastures do not consume as much water as did the native vegetation, consequently the ground water rises, bringing with it dissolved salts (*Anon* 1996).

Salinity results in plants growing poorly, and yields of farm plants (crops and pastures) being reduced by more than 25-30 %. Western Australia is estimated to have nearly 2 million ha of dryland salinity in the southwest zone (9.4 % of cleared land) and it is anticipated that this amount will increase to 3.3 million ha by 2020 (17.1 %), with another 6.1 million ha (31.8 %) at risk (*Anon* 2000).

Salinity is thus a major concern facing farmers today. Many salt-affected sections of farms are being revegetated where the land is no longer viable for cropping due to erosion and salt seepage. One such farm is "Barton Park", located at Quellington, east of York, Western Australia. This is a 1200+ ha property owned by Robyn and Gwen Gentle, who have been revegetating parts of their property for more than 25 years. Included in the revegetation of their farm, Robyn has been planting sandalwood for some 13 years and has been involved in trials run by Curtin University on his property. Also used as part of the revegetation on this farm are the locally occurring species, *Acacia saligna* (orange wattle), *Acacia acuminata* (both useful as hosts of sandalwood), *Eucalyptus loxophleba* (york gum), *E. salmonophloia* (salmon gum) and *Hakea preissii* (Mickle 1999, Wurm & Fox 1990).

Aims

The main aims of this project were to examine early seedling growth of sandalwood in relation to waterlogging and salinity levels. Hypotheses tested are as follows:

Glasshouse Trials: The growth of *Santalum spicatum* is not affected by

1). different salinity levels.
2). waterlogging/flooding of soils.

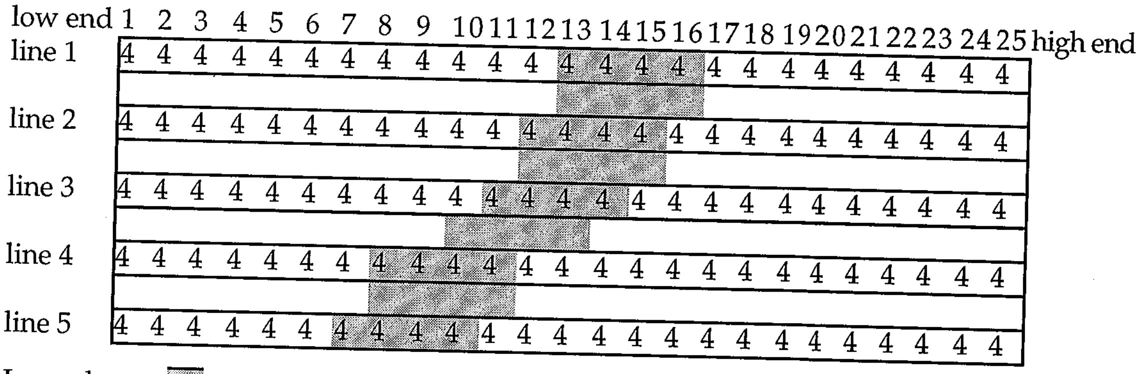
Field Trials: The emergence of *Santalum spicatum* is not affected by
1). salinity.
2). waterlogged soil.
3). depth of sowing.

Materials and Methods

Field Experiments.

Permission was obtained from Robyn and Gwen Gentle, landowners of "Barton Park", to establish two experimental areas on semi-saline land covering 0.125 ha (S 31° 47'3.4"; E 116° 53'6.3"), and to visit these sites between April and October 2000. The area had previously been revegetated with species including *Acacia saligna, Hakea preissii, Casuarina obesa* and some *Eucalyptus*. These had been planted along rip lines running parallel to the creek line. "Barton Park", Quellington is some 20 km east of York, Western Australia. This lies in the agricultural region receiving 400-500 mm of annual rainfall.

Experiment 1: Salinity. The first site is a low-lying, salt affected area, with crusts of salt visible on the surface (salinity 8-11 mS). Soil pH at April was 6.1- 6.4. This experiment examined emergence of sandalwood seedlings in saline areas. Five ± straight rows, running north from the service road and almost parallel to the adjacent creek line, were pegged out for a distance of 25 m with 25 holes per row. A salty drainage line runs through the area (Figure 1). A total of 500 seeds was planted with 4 seeds per hole.



Legend ▨ = approximate position of saline drainage line

FIGURE 1: Experiment 1 layout. 4 seed per spot of *S. spicatum* were planted 21. 04. 00.

Experiment 2: Waterlogging. The second site is between the creek and the service road (30 m from road edge). It is less salty (0.6 -4.46 mS) than the first site but with more variable acidity (pH 5.2- 6.2). This experiment sought to examine emergence of sandalwood seedlings in waterlogged soil. Previous observations led us to anticipate that winter rainfall would cause a certain amount of waterlogging at this site. Seven parallel rows, running between the creek and the service road, were pegged out. A total of 700 seeds was planted.

At both sites, holes were dug to one of five depths: 2, 5, 10 or 15 cm below the soil surface, or a mound 5 cm above soil level; with a post hole digger. Freshly dug soil was used to fill the 25 holes per row. Each hole received 4 evenly spaced seeds (5-10 cm) to allow room for growth of up to 4 seedlings. Where a seed planting spot was located under an existing tree (site 2), it was offset to just outside the drip line of the foliage of the tree. This procedure resulted in planting lines curving slightly around the larger trees.

Both experiments were planted with *S. spicatum* seed on 21 April 2000. The seed used came from a single tree growing in the Field Trial Area (FTA) of Curtin University. This is a prolific fruiting specimen (yield of ~ 6.8 kg in 1999). The sites were checked 157 days after planting (25 September 2000), to record presence of any germinants. Heights were taken (cm) and leaf numbers counted.

Two soil samples were used for conductivity and pH determination (results above) at each of Expts 1 and 2. The surface was scraped back 5 cm, placed in calico bags and returned to the lab where 20 g of soil was mixed with 100 ml of deionised water and placed on a shaker for 24 hours. Samples were left to settle and 10 ml of each solution decanted to derive pH and conductivity using electrical probes.

Laboratory Experiments.
On 9 May 2000, 400 seeds from the same source as used in the field trials, were prepared and set to germinate seedlings for use in the glasshouse trials. The seeds were surface sterilised with 5 % sodium hypochlorite for 1 minute, then thoroughly rinsed twice with deionised water. Paper towels were placed at the bottom of four black seeding trays, half filled with coarse sterilised sand. Seeds were placed in ten rows of ten, not touching. Trays were then filled with sand, covering seed. The prepared seeding trays were placed inside larger, white butcher's trays, partly filled with water.

Seeds commenced to germinate on the 15th June (after 37 days). Germinants with > 2 mm of radicle were planted in cylindrical pots (140 mm tall; 80 mm diameter; volume 650 ml), in a standard potting mixture (1 part coarse sand: 1 part fine sand: 1 part peat moss), with no added fertiliser. By 56 days later (10th August; 93 days from setting out), a total of 76 seeds had germinated (19%). Resultant seedlings were allocated randomly for use in Expts 3 (48); or 4 (24). The control seedlings for Expt 3 were also used for Expt 4.

Experiment 3: Salinity Trial. Five saline solutions (T1- T5: 25, 50, 100, 200 and 400 mM NaCl) were made up with de-ionised water and stored in 20L containers in the glasshouse, to maintain a constant temperature. On 11th August 2000, the 48 pots with seedlings for this experiment, were allocated evenly, by height, to one of six labelled treatment groups (5 saline treatments, T1- T5, and a de-ionised water control). Plants were numbered 1-8 and placed on benches in the glasshouse. Plant height was measured and number of leaves counted. All plants were watered thrice-weekly (Monday, Wednesday, Friday) with 100 ml (field capacity) of the appropriate solution.

At the end of the experiment (39 days), all plants were harvested and dry weights obtained (19 September). Plants were divided into roots and shoots (cutting at soil level). After the fresh (wet) weights were obtained, leaf areas were measured with an electronic planimeter. Plant parts were then placed in individual brown paper bags and dried at 60°C for 3-4 days. Dry weights were then obtained. Heights and leaf numbers were taken at weekly intervals for 5 weeks.

Experiment 4: Flooding Trial. On 15th August 2000, the 24 seedlings for this trial were allocated evenly according to height, amongst 4 flooding treatment groups. These sets were placed in large fibre-glass tanks filled with rain water, so that the level was ~4 cm short of the rim of the cylindrical pots. Flooding treatments were: flooded one week (Fl.-1), then removed (22/08); flooded two weeks (Fl.-2), then removed (29/08); flooded three weeks (Fl.-3), then removed (05/09); flooded four weeks (Fl.-4), then removed (12/09). Following removal from the flooding tank, seedlings were watered thrice-weekly with 100 ml per pot. Measurements were as for Expt 3. At the end of the four-week experiment all plants were harvested (12.09 except control, 19.09).

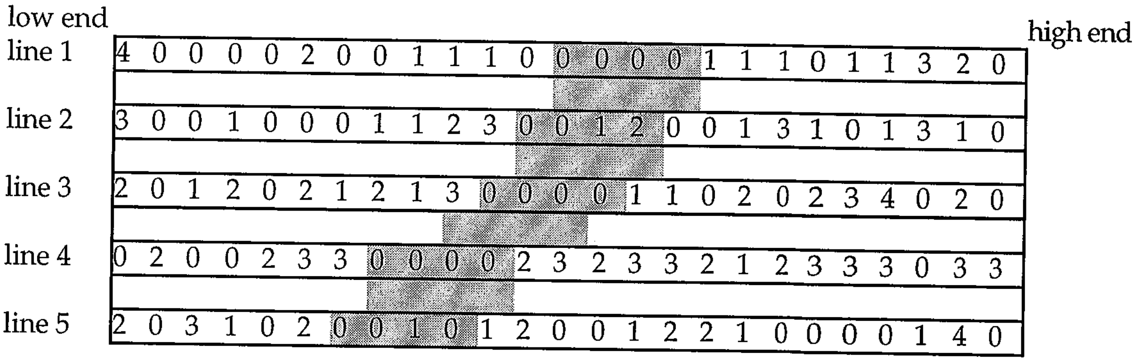
Data Analysis

Field trial results were examined for any differences among position or sowing depth in emergence percentages, mean leaf numbers and seedling heights. Analysis of variance was used. Weekly salinity and flooding data sets were analysed using analysis of variance for mean heights and leaf number. At the conclusion of the glasshouse trials, analyses were performed on harvest data sets. Fishers LSD test was used to discriminate among treatment means where significant differences were found.

Results

Field Experiments.

Experiment 1: Salinity. From the 500 seeds planted at 125 spots, 138 seedlings had established by 25.09.00. Mean establishment in area one was higher (27.6 %) than seedling production obtained in the glasshouse (19 %) but lower than in Expt 2 (37.4 %). Few seedlings emerged in the area affected by the saline drainage line (Figure 2).



low end | high end

line 1	4	0	0	0	0	2	0	0	1	1	1	0	0	0	0	0	1	1	1	0	1	1	3	2	0
line 2	3	0	0	1	0	0	0	1	1	2	3	0	0	1	2	0	0	1	3	1	0	1	3	1	0
line 3	2	0	1	2	0	2	1	2	1	3	0	0	0	0	1	1	0	2	0	2	3	4	0	2	0
line 4	0	2	0	0	2	3	3	0	0	0	0	2	3	2	3	3	2	1	2	3	3	3	0	3	3
line 5	2	0	3	1	0	2	0	0	1	0	1	2	0	0	1	2	2	1	0	0	0	0	1	4	0

Legend ▨ = approximate position of drainage line

FIGURE 2: Layout of lines at Experiment 1. Numbers are emergent *S. spicatum* seedlings at each planting spot (4 seed per spot). Seed planted 21. 04. 00 counted 25. 09. 00 after 157 days.

After the winter rainfall, salt crusting was evident in this area. Rather more establishment had occurred in line 2 (43 %) and fewest plants (19 %) were found in line 5 (Table 1). Planting spots occupied (by one or more seedlings) ranged from 11 to 17 per line, mean of 14. Three of the 125 spots planted (2.4 %) had four seedlings; 18 spots (14.4 %) had three; 22 (17.6 %) had two; 28 spots (22.4 %) had only one seedling. Thus, 54 (43.2 %) of the 125 spots planted had no seedlings.

Seedlings had 1-32 leaves (mean 11), with the tallest seedling in this area being 9.4 cm tall (mean 4.2 cm). Differences in heights between lines were not significant but more leaves were present on plants in line 1 (Table 1). Mean height was also tallest in this line.

The overall relation between height and leaf number was fitted to a linear regression: Height (cm) = 0.220 leaves + 1.799 (r^2 = 0.299). With n= 138, this regression was highly significant.

Table 1: Number of plants (+ %), mean leaf numbers and heights (cm) of established *S. spicatum* by lines at "Barton Park" Experiment 1.

Line number Measure (seed sown)	L1 (100)	L2 (100)	L3 (100)	L4 (100)	L5 (100)	Mean	Statistic F=	 p=
Nos (= %, of 100 seed)	23	43	29	24	19	27.6		
Spots occupied (of 25)	13	17	15	14	11	14		
Leaves (no.)	14.1 a	10.8 b	9.3 b	10.6 b	11.2 b	11.1	3.607	0.008
(SE)	(1.3)	(0.7)	(0.7)	(0.9)	(1.0)	(0.4)		
Height (cm)	4.84	4.13	4.12	3.78	4.45	4.23	1.030	0.394
(SE)	(0.43)	(0.28)	(0.37)	(0.39)	(0.41)	(0.16)		

Different letters in a row indicate values differ at p 0.05, Fishers' LSD test.

The best planting depth was mounding at 5 cm. This treatment gave most establishment (37 %); more planting spots with seedlings (18 = 72 %); seedlings had most leaves (> 12) and tallest plants (4.5 cm), but heights did not differ significantly between planting depth treatments (Table 2). The least favourable planting depth was 2 cm. This gave fewest occupied spots (11 = 44 %); fewest leaves (< 10); and, shortest plants (3.6 cm).

Table 2: Number of plants (+ %), mean leaf numbers and heights (cm) of established *S. spicatum* by planting depth at "Barton Park" Experiment 1.

Planting depth (cm) Measure (seed sown)	2 (100)	5 (100)	10 (100)	15 (100)	+5 (100)	Mean	Statistic F=	 p=
Nos (= %, of 100 seed)	25	28	23	25	37	27.6		
Spots occupied (of 25)	11	14	13	15	18	14		
Leaves (no.)	9.7 b	10.0 b	11.0 ab	11.0 ab	12.9 a	11.1	2.322	0.060
(SE)	(0.8)	(0.8)	(0.9)	(0.9)	(0.9)	(0.4)		
Height (cm)	3.61	4.25	4.24	4.42	4.51	4.23	0.918	0.455
(SE)	(0.37)	(0.36)	(0.40)	(0.42)	(0.31)	(0.16)		

Different letters in a row indicate values differ at p 0.05, Fishers' LSD test.

Division of planting spots into three zones: in the central salty zone (as in Figure 2); above it; and below, revealed that a higher proportion of seed germinated up-slope from that region than below it (Table 3).

Differences in height and leafiness were not significant. However, those seedlings established in the central salty area were shorter and had fewer leaves than those above and below this area.

Table 3: Establishment values for sites above and below the central drainage feature at "Barton Park" Experiment 1.

Planting position Measure	Above salt	In salt zone	Below salt	Statistic F=	p=
Total planting spots	59	20	46		
No. with 1 plant or >1	41	3	27		
Total plants	82	4	52		
% of seed planted	34.7	5.0	28.3		
Leaves (no.)	11.5	10.0	10.5	0.793	0.455
(SE)	(0.5)	(2.2)	(0.7)		
Height (cm)	4.46	3.60	3.92	1.472	0.233
(SE)	(0.20)	(1.16)	(0.28)		

Experiment 2: Waterlogging. Winter rainfall was not as great in 2000 as in 1999 (Figure 3) and, unlike 1999, losses due to waterlogging did not appear to have been a problem.

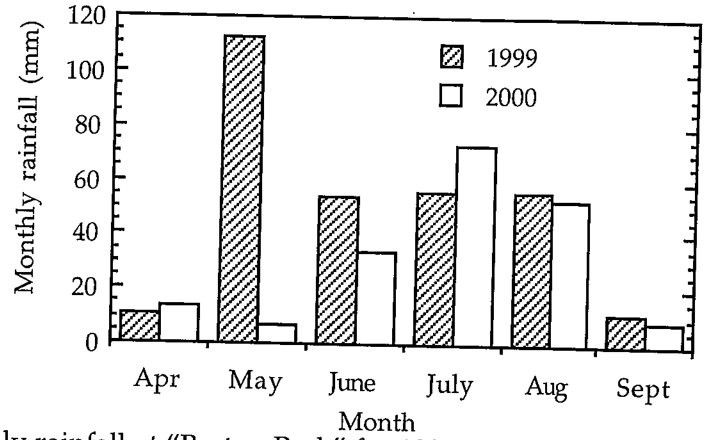


FIGURE 3: Monthly rainfall at "Barton Park" for 1999 and 2000 growing seasons.

road end

creek end

position	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
line 1	0	0	0	0	2	4	3	0	2	3	3	3	4	0	0	0	2	2	4	3	4	2	1	3	1
line 2	3	0	1	0	2	3	3	0	0	0	0	0	4	2	2	0	1	3	4	3	1	3	2	3	3
line 3	0	0	3	3	1	3	0	2	4	2	1	0	0	0	4	3	0	0	3	0	2	0	0	3	3
line 4	0	0	4	2	0	0	0	0	0	0	3	2	2	1	0	3	3	2	0	2	3	3	2	0	0
line 5	4	2	1	0	3	4	2	1	0	0	0	3	4	0	0	3	3	0	2	1	0	2	3	0	3
line 6	0	4	0	1	2	3	1	1	2	1	0	0	0	0	3	3	0	0	0	2	1	3	0	0	0
line 7	2	4	0	1	3	2	1	0	0	2	3	3	0	0	1	4	2	2	0	1	0	3	0	0	2

FIGURE 4: Experiment 2. Numbers of emergent *S. spicatum* seedlings at each planting spot (4 seed planted per spot). Seed planted 21. 04. 00, emergents counted 25. 09. 00 after 157 days.

Establishment was greater than at Expt 1, the saltier site. Considerable variability in emergence was observed across Expt 2 (Figure 4). In total, 262 seedlings were counted from the 700 seed sown (37.4 %). Planting spots occupied ranged from 13 to 17 per line, mean of 15 (one more than Expt 1). Fifteen of the 175 spots planted (8.6

%) had 4 seedlings *versus* 2.4 % in Expt 1; 40 spots (22.9 %) had three *versus* 14.4 % in Expt 1; 31 spots (17.7 %) had two, similar to Expt 1; 20 spots (11.4 %) had one, *versus* 22.4 % in Expt 1; and 69 spots (39.4 %) had no seedlings compared with 43.2 % in Expt 1.

Seedlings had 2-24 leaves (mean 10.5), the tallest seedling was 9.5 cm tall (mean 4.5 cm). Differences in heights between lines were not significant. Slightly more leaves were present on plants in lines 3 and 5 than in line 6 (Table 4).

Height and leaf number of the 262 plants measured were fitted to a linear regression: Height (cm) = 0.179 leaves + 2.616 (r^2 = 0.134). As with Expt 1, this regression was highly significant.

Table 4: Number of plants (+ %), mean leaf numbers and heights (cm) of established *S. spicatum* by lines at "Barton Park" Experiment 2.

Line number Measure (seed sown)	L1 (100)	L2 (100)	L3 (100)	L4 (100)	L5 (100)	L6 (100)	L7 (100)	Mean	Statistic F=	p=
Nos (= %)	46	43	37	32	41	27	36	37.4		
Spots occupied (of 25)	17	17	14	13	16	13	16	15		
Leaves (no.)	10.7	10.7	11.5 a	10.1	11.0 a	8.9 b	10.4	10.5	1.286	0.264
(SE)	(0.6)	(0.7)	(0.7)	(0.8)	(0.6)	(0.4)	(0.7)	(0.2)		
Height (cm)	4.68	4.71	4.57	4.30	4.23	4.36	4.53	4.50	0.353	0.908
(SE)	(0.26)	(0.31)	(0.34)	(0.31)	(0.29)	(0.40)	(0.38)	(0.12)		

Different letters in a row indicate values differ at p 0.05, Fishers' LSD test.

The best planting depth for total emergent seedlings was burial at 2 cm (46 % of seed planted). However, the numbers that emerged were not different from both mounding at 5 cm (44 %) and burial at 5 cm (43 %). Burial at either 10 or 15 cm reduced the total numbers of seedlings established (26 and 28 % respectively). The story differs when considering the proportion of planted spots occupied by one or more seedlings (Table 5). On this criterion, the mounding treatment was superior with 77 % of spots occupied. There were no significant differences in height attained between planting treatments. Seedlings that emerged from 2 cm burial had most leaves and those from 5- 15 cm were least leafy.

Table 5: Number of plants (+ %), mean leaf numbers and heights (cm) of established *S. spicatum* by planting depth at "Barton Park" Experiment 2.

Planting depth (cm) Measure (seed sown)	2 (140)	5 (140)	10 (140)	15 (140)	+5 (140)	Mean	Statistic F=	p=
Nos alive (of 140 sown)	64	60	37	39	62	52.4		
% of 140 seed	46	43	26	28	44	37.4		
Spots occupied (of 35)	23	24	17	15	27	21		
% spots occupied	66	69	49	43	77	61		
Leaves (no.)	11.8 a	10.0 b	10.2 ab	9.7 b	10.6 ab	10.5	2.394	0.051
(SE)	(0.6)	(0.5)	(0.7)	(0.5)	(0.6)	(0.2)		
Height (cm)	4.76	4.18	4.80	4.31	4.49	4.50	0.992	0.413
(SE)	(0.24)	(0.27)	(0.30)	(0.34)	(0.25)	(0.12)		

Different letters in a row indicate values differ at p 0.05, Fishers' LSD test.

Comparison of Expts 1 and 2

At the more saline site (Expt 1), mounding was very effective in enhancing total seedling emergence and proportion of occupied planted spots. Other depths were similar. At the less saline site (Expt 2), mounding and shallow burial (2 or 5 cm) of seed were equally effective in total emergence. Mounding gave more occupied planted spots. Deeper burial (10-15 cm) decreased the number of occupied spots.

Table 6: Number of plants (+ %), mean leaf numbers and heights (cm) of established *S. spicatum* by planting depth at "Barton Park" Experiments 1 and 2 combined.

Planting depth (cm) Measure (seed sown)	2 (240)	5 (240)	10 (240)	15 (240)	+5 (240)	Mean	Statistic F=	 p=
% alive (of 240 sown)	37.1	37.5	24.2	28.8	41.7	33.3		
% spots occupied (of 60)	56.7	63.3	50.0	50.0	75.0	59.0		
Leaves (no.)	11.2 ab	10.0 b	10.5 ab	10.2 ab	11.4 a	10.7	1.964	0.099
(SE)	(0.5)	(0.4)	(0.5)	(0.5)	(0.5)	(0.2)		
Height (cm)	4.68	4.20	4.59	4.35	4.50	4.41	0.628	0.643
(SE)	(0.30)	(0.21)	(0.24)	(0.26)	(0.19)	(0.10)		

Different letters in a row indicate values differ at p 0.05, Fishers' LSD test.

Considering both data sets (Table 6), mounding was the superior planting treatment for both total emergence and for most planted spots with established seedlings. Burial at 10-15 cm reduced total emergence and the extent of occupied spots. Differences in height and leaf numbers were slight between treatments. The distributions of both seedling heights (Figure 5) and leaf numbers (Figure 6), reveal that seedlings had grown in much the same pattern across both experimental sites.

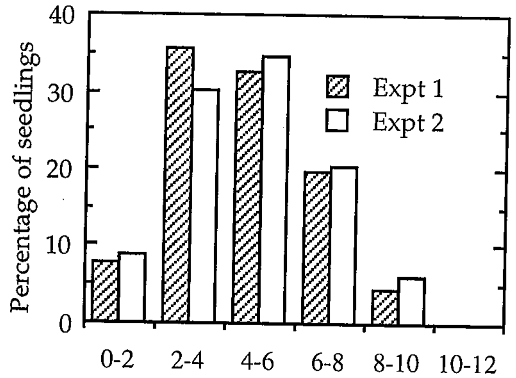


FIGURE 5: Emergent seedlings of *S. spicatum* by height classes Experiments 1 and 2 at 25. 09. 00

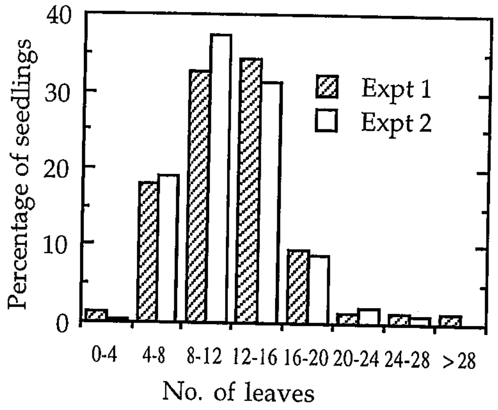


FIGURE 6: Emergent seedlings of *S. spicatum* by leaf number classes Experiments 1 and 2 at 25. 09. 00

Seed Quality

The seed used for both field and glasshouse experiments came from a single tree (tree 3; bed 9), growing in the FTA, Curtin University. This is a handsome, well-grown (5.8 m tall) tree that regularly produces abundant fruit. It was planted from seed in 1984 (source Dowerin). The seed used was collected fresh in December 1999. In the glasshouse a total of 76 (of 400) seeds germinated, giving a percentage germination of 19%.

A set of 100 nuts was weighed and diameters measured. Nuts were then opened and kernel weights obtained. One nut was considerably larger than the others and removed from the data set. Dimensions of this nut were as follows: total wt =4.269 g; 20.9 mm diameter; kernel wt =1.6197; kernel = 37.94 % of the nut wt. Values of the 99 nuts are used to characterise the materials used in this report (Table 7; Figures 7-14).

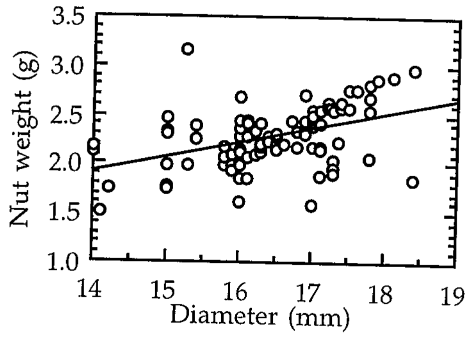


FIGURE 7. Nut weight (g) and diameter (mm) for n= 99 nuts. Nut wt (g) = - 0.236 + 0.153 diam (mm) r^2 = 0.214. F= 26.413 p=0.0001.

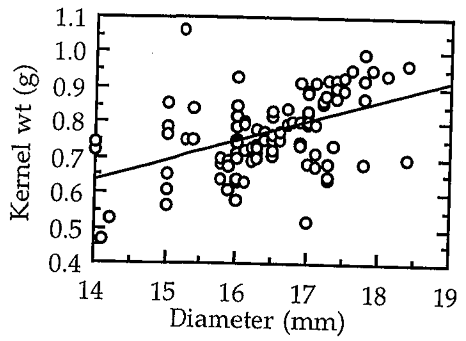


FIGURE 8. Kernel weight (g) and diam (mm) for n= 99 nuts. Kernel wt (g) = -0.146 + 0.056 diam (mm) r^2 = 0.220. F= 27.383 p= 0.0001.

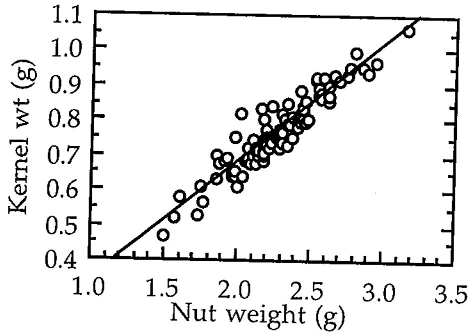


FIGURE 9. Kernel and nut weights (g) for n= 99 nuts. Kernel wt (g) = - 0.00048 + 0.3379 Nut wt (g)
r^2 = 0.885. F= 748.93 p= 0.0001.

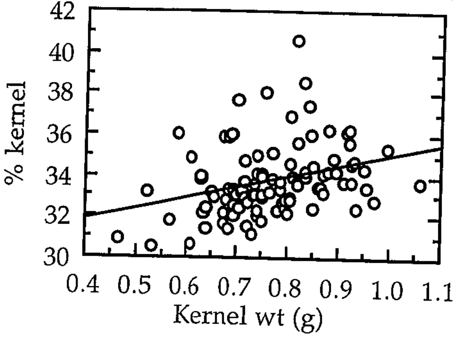


FIGURE 10. Percent kernel and kernel wt (g) for n= 99 nuts. % kernel = 29.583 + 5.433 Kernel wt (g)
r^2 = 0.117. F= 12.901 p= 0.0005.

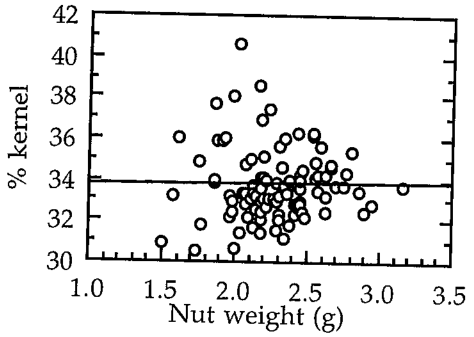


FIGURE 11. Percent kernel and nut weight n = 99 nuts. % kernel = 33.674 + 0.040 Nut weight (g) r^2= 0.000. F= 0.005 p= 0.945.

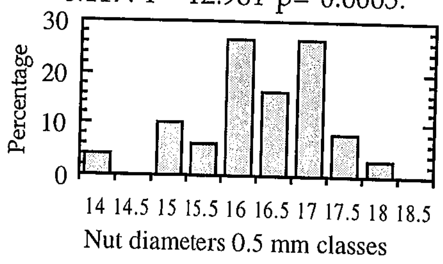


FIGURE 12. Size class distribution of nut diameters n= 99.

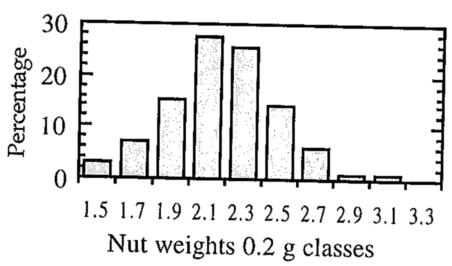


FIGURE 13. Size class distribution of nut weights n= 99.

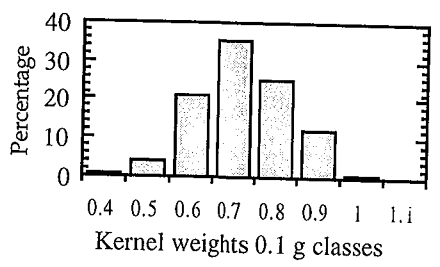


FIGURE 14. Size class distribution of kernel weights n= 99.

Table 7. Mean dimensions of *Santalum spicatum* nuts used (n= 99).

Dimension	Mean	SD	SE	Min$^{\underline{m}}$	Max$^{\underline{m}}$	Range	CV %
Nut weight (g)	2.279	0.305	0.031	1.507	3.152	1.645	13.4
Nut diameter (mm)	16.5	0.9	0.1	14.0	18.4	4.4	5.6
Kernel weight (g)	0.770	0.109	0.011	0.465	1.061	0.596	14.2
% Kernel weight	33.76	1.74	0.17	30.51	40.56	10.04	5.1

Linear regression revealed highly significant relations between nut weight and diameter (Figure 7); kernel weight and nut diameter (Figure 8); kernel and nut weights (Figure 9); percentage kernel and kernel weight (Figure 10); but not between percentage kernel and nut weight (Figure 11). Size class histograms indicate perfectly normal distributions for nut (Figure 13) and kernel (Figure 14) weights. Diameter class distribution (Figure 12) is less well fitted to a normal distribution.

Experiment 3: Salinity Trial. Initial measurements (11/08/00) of both height and leaf number confirmed no significant difference between sets (height F= 0.430; p= 0.825, leaf number F= 0.330; p= 0.894). By week four of the experiment, differences had almost reached significance for height (F= 2.209; p= 0.071) and leaf number (F= 2.140; p= 0.079). Seedlings subjected to higher salinity levels were of shorter mean height and had fewer leaves. By the end of week five, differences between treatments were significant: for both mean height (F= 2.993; p= 0.021) and mean leaf number (F= 4.982; p= 0.001).

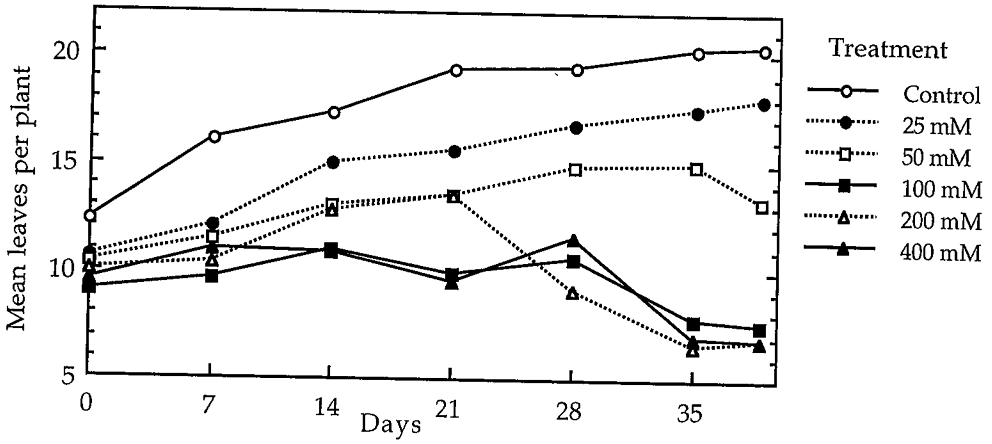


FIGURE 15: Mean leaf numbers in glasshouse salinity trial *S. spicatum* grown for 39 days n= 8 per treatment

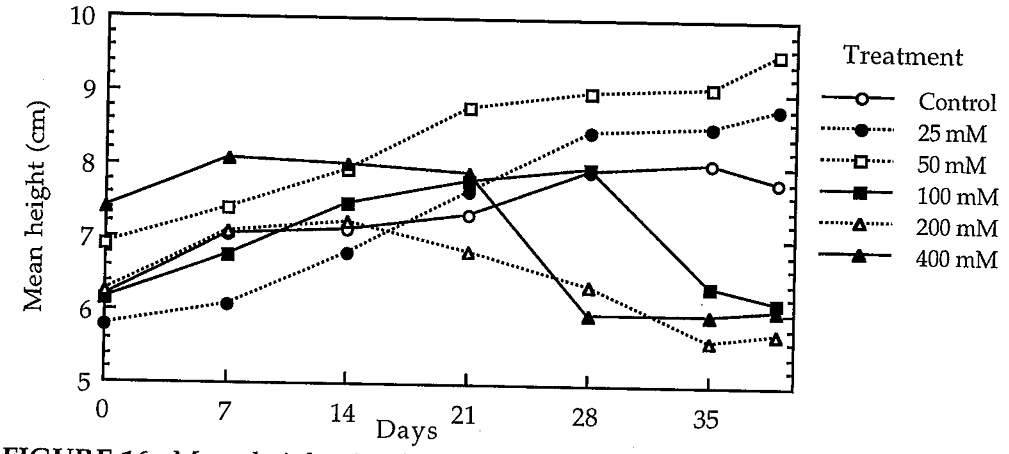


FIGURE 16: Mean heights in glasshouse salinity trial *S. spicatum* grown for 39 days n= 8 per treatment

Changes in leafiness (Figure 15) show little difference in pattern of new leaf addition between the control and the lowest salinity treatment throughout. Treatments at > 50 mM NaCl lost leaves at various times from the second week onwards. By the harvest (39 days) the pattern of mean leaf number was in inverse proportion to salinity level (F= 6.291; p= 0.0001) and the 50 mM treatment had also lost leaves.

The pattern of change in height differed. The control set did not attain the same height as the two lower salinity treatments by the conclusion of the experiment. Whereas the 50 mM set had second tallest mean plants at the start and this may have influenced subsequent height growth, the 25 mM set was initially shortest yet ended at second tallest. Both sets may have been able to utilise sodium in dry matter production. Plants subject to the higher salinity levels lost height from the second week onwards (Figure 16). By the end of the experiment, salt crusts had formed on the soil surface of the higher salinity treatments. Leaves had died in the three highest treatment levels, (100, 200 and 400 mM NaCl), with considerable leaf drop. Some leaves were curled and twisted and in the higher salt levels they had turned brown.

At harvest (39 days), all replicate plants of each treatment were taken (including any dead leaves) though many plants in higher salinity levels may have been technically dead. Plants in the lower salinity treatments had significantly greater fresh shoot weight (Table 8), suggesting that low levels of salt enhance moisture uptake (leaf hydration). This was also reflected in greater leaf areas and higher fresh/ dry weight ratios. The higher salinity levels had least fresh shoot weight suggesting some inhibition of shoot development in comparison with root growth, also seen in low leaf areas. There was little difference in dry weights, although the highest salinity level had surprisingly similar dry root weight to the control treatment: its dry root weight was high in relation to fresh root weight. Root production was least at 50 mM salt and in this treatment the proportion fresh shoot: root weight was greatest.

Table 8: Mean harvest values by treatments glasshouse salinity trial of *S. spicatum*

Harvest Dimension	Treatment (mM NaCl)						Statistics	
	Control	25	50	100	200	400	F=	p=
Samples	n= 8	n= 8	n= 8	n= 8	n= 8	n= 8		
Fresh root wt (g)	1.025 a	1.037 a	0.532 b	0.987	0.609	0.665	1.812	0.131
Fresh shoot wt (g)	0.613 b	1.037 a	0.936 ab	0.542 b	0.384 b	0.479 b	4.945	0.001
Σ fresh wt (g)	1.638 ab	2.074 a	1.468 ab	1.529 ab	0.994 b	1.145 b	2.278	0.064
Dry root wt (g)	0.310	0.313	0.181 b	0.258	0.213	0.360 a	1.578	0.187
Dry shoot wt (g)	0.261	0.295	0.235	0.208	0.190	0.231	0.978	0.444
Σ dry wt (g)	0.571	0.608	0.416	0.466	0.403	0.591	1.381	0.251
Dry shoot/root	0.98	1.09	1.47 a	0.92	0.99	0.86 b	1.252	0.303
Σ fresh/dry	2.84 ab	3.35 a	3.53 a	3.22 a	2.47 b	2.16 b	4.750	0.002
Leaf area mm^2	964 ab	1393 a	1231 ab	798 abc	584 c	702 bc	2.095	0.085

Different letters in a row indicate values differ at p 0.05, Fishers' LSD test.

The experiment clearly suffered from a lack of hosting. The differences between initial and harvest dimensions were not great and seedlings may well have been surviving only on their seed resources (Figure 17). However, it can be concluded that young seedlings do have the potential to survive on cotyledonary nutrition in the presence of saline solutions and that moisture uptake may be enhanced by low levels of soil sodium.

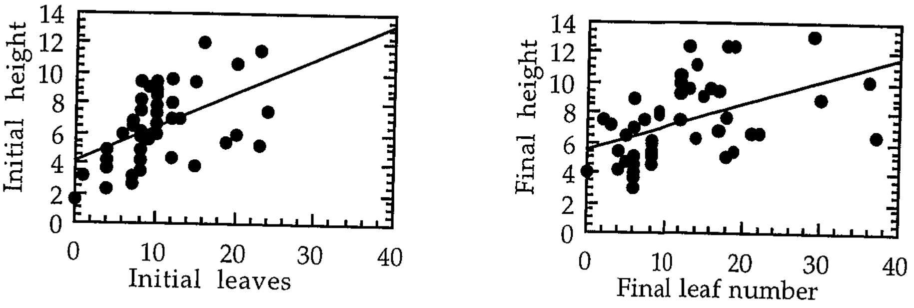


FIGURE 17: Initial (A) and final (B) height and leaf numbers in salinity trial *S. spicatum* n= 48; initial height (cm) = 4.102 + 0.226 leaf number $r^2 = 0.249$; final height (cm) = 5.458 + 0.154 leaf number $r^2 = 0.243$

Experiment 4: Flooding Trial. Flooding had little obvious effects on plants, other than depressing mean leaf number compared with the control. However much of this effect was probably associated with greater leafiness in control plants at the start. Mean plant leaf number was 10.2 at the start and 11.6 after 4 weeks (n=30). Single 'plants' in each of the 2-, 3-, and 4-wk flooding treatments where germination had occurred, but no leaves had emerged, failed to develop further. The plant in the 2-wk treatment may have died after one week of flooding. No leaves were observed and there was no measurable height. This 'plant' was not included in the harvest. The others would have died if the trial had lasted longer.

The order of leafiness among treatments at the start remained much the same for the first 3 wk (Figure 18). Leaf numbers did not exhibit any significant differences at any date. Plants in the 4-wk set lost a number of leaves during the fourth week of exposure. Plants flooded for 1-wk had more leaves at each week after removal from flooding. There was no corresponding effect on mean height (Figure 19). The 2-wk treatment set lost leaves over the following two weeks. Each of control, 1-wk and 3-wk flooded plants had more leaves at the end of the trial.

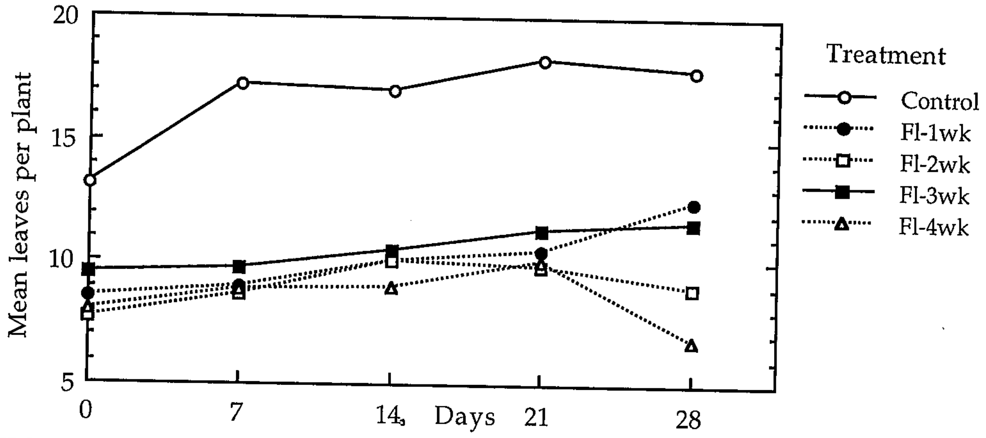


FIGURE 18: Mean leaf numbers in flooding trial *S. spicatum* grown for 28 days n= 6 per treatment

Heights did not differ between treatment sets during the course of the experiment. Mean height increased from 6.7 cm to 7.4 cm. All treatments appeared to increase slightly during the first week of flooding, as did the control. The implication here is that environmental conditions were generally favourable and the momentum of early growth, dependant on mobilisation of cotyledonary reserves, was not upset by one week of flooding. This interpretation does not explain the apparent loss in height of control plants over the following week. The order of mean height remained identical throughout the period of observation (Figure 19). Plants exposed to flooding for 2-wk declined in mean height after removal, a similar tendency may be discerned in the 3-wk treatment.

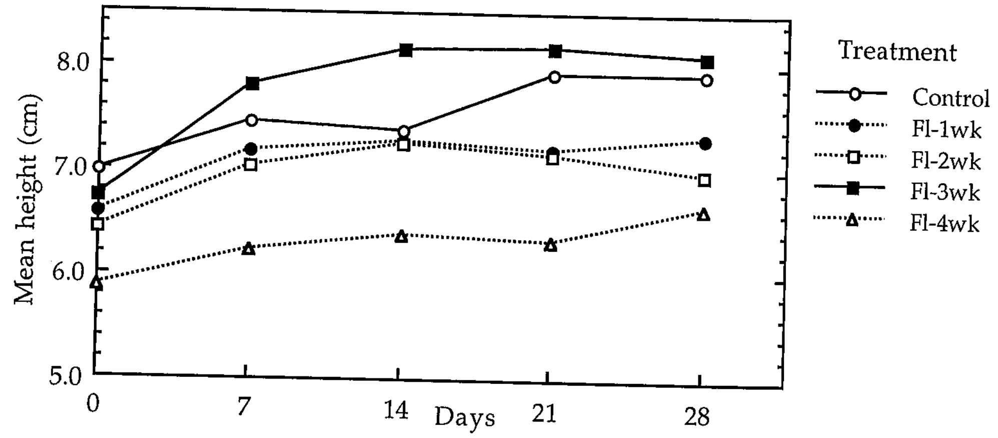


FIGURE 19: Mean heights in flooding trial *S. spicatum* grown for 28 days n= 6 per treatment

Table 9: Mean harvest values by treatments flooding trial of *S. spicatum*. Treatments on 12. 09. 00, control on 19. 09. 00 (as in Table 8).

Harvest Dimension	Treatment: flooding duration in weeks					Statistics	
Samples	Control n= 8	1 week n= 6	2 weeks n= 5	3 weeks n= 6	4 weeks n= 6	F=	p=
Fresh root wt (g)	1.025	0.827	0.621	0.743	0.778	0.667	0.621
Fresh shoot wt (g)	0.613	0.664	0.706	0.572	0.666	0.173	0.950
Σ fresh wt (g)	1.638	1.491	1.326	1.315	1.445	0.314	0.866
Dry root wt (g)	0.310 a	0.162 b	0.146 b	0.194 ab	0.149 b	2.843	0.044
Dry shoot wt (g)	0.261	0.250	0.299	0.217	0.207	0.564	0.691
Σ dry wt (g)	0.571 a	0.412	0.445	0.410	0.356 b	1.253	0.314
Dry shoot/root	0.98 b	2.21 a	2.29 a	1.24 ab	1.41 ab	2.476	0.069
Σ fresh/dry	2.84 b	3.56 ab	3.04 b	3.45 ab	4.50 a	2.190	0.098
Leaf area mm^2	964	1081	1089	691	611	1.039	0.406

Different letters in a row indicate values differ at p 0.05, Fishers' LSD test, other values intermediate.

All treatment plants were harvested at 28 days from the start of flooding and the control set a week later (Table 9). This difference is assumed to have not affected the outcomes of analysis of variance. Few differences among means were significant at $p < 0.05$. Flooding appears to have depressed dry root weight in all flooding durations, apart from the 3-wk flooding treatment.

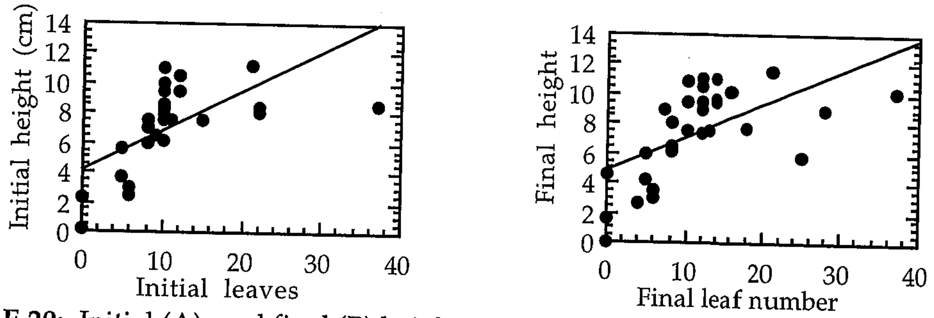


FIGURE 20: Initial (A) and final (B) height and leaf numbers in flooding trial *S. spicatum* n= 24; initial height (cm) = 3.938 + 0.268 leaf number r2 = 0.411; final height (cm) = 4.791 + 0.225 leaf number r2 = 0.353

The dry shoot: root ratio for this treatment was closest to unity among the flooding treatments. Lack of differences among shoot weights suggests that flooding did not reduce photosynthesis. All treatments had higher fresh: dry ratios than control. Flooding of > 2-wk reduced leaf area below that of control but shorter durations (and longer recovery times) were similar to that of control.

As for Experiment 3, lack of hosts meant seedling development was dependant on cotyledonary resources (Figure 20). This experiment suggests that limited periods of soil saturation during the germination/ early establishment phase do not detrimentally affect emergent seedlings. However, this is not so where leaves have not developed and where root growth is not great. Under these circumstances flooding may lead to premature death due to rotting induced by moist conditions.

Comparison of Expt 3 and Expt 4: Although the two pot trials were not designed to be directly compared, it is instructive to examine all harvest values together, especially as controls were shared. When all harvest values for both pot trials were combined in analysis of variance, each of fresh shoot weight, dry root weight, shoot: root (dry weight) ratio and total fresh: dry weight ratio had significant differences among means (Table 10).

Fresh shoot weights were greatest in the two lower salinity treatments and the 2-wk flooding treatment; all flooding treatments were not less than the control; lowest weights were associated with the more concentrated salinity levels. All flooding durations significantly depressed dry root weight below that of control, whereas most salinity treatments had similar root weights to control: the exceptions were 50 and 200 mM NaCl. Shoot: root ratios were particularly high after 1- or 2-wk flooding; most flooding treatments had significantly greater ratios than the control (3-wk flooding did not); salinity treatments generally did not affect this ratio, except for 50 mM NaCl in which the ratio was elevated. The fresh: dry weight ratio in all flooded treatments (3-4.5) was greater than control (2.8), but only reached significance after 4-wk; values were lower in saline treatments (2.2-3.5), with this ratio generally declining with greater salinity.

Table 10: Mean harvest dimensions of characteristics with significantly different values by combining salinity and flooding treatments (as in Tables 8 and 9).

Treatment	n=	Dimension			
		Fresh shoot wt (g)	Dry root wt (g)	Dry shoot/root	∑ Fresh/∑ dry
Control	8	0.613 bc	0.310 abcd	0.98 b	2.84 bcd
25 mM NaCl	8	1.037 a	0.313 abc	1.09 b	3.35 bc
50 mM NaCl	8	0.936 ab	0.181 de	1.47 a	3.53 ab
100 mM NaCl	8	0.542 c	0.258 abcde	0.92 b	3.22 bc
200 mM NaCl	8	0.384 c	0.213 bcde	0.99 b	2.47 cd
400 mM NaCl	8	0.479 c	0.360 a	0.86 b	2.16 de
Flooding 1 wk	6	0.664 bc	0.162 e	2.21 a	3.56 ab
Flooding 2 wk	5	0.706 abc	0.146 e	2.29 a	3.04 bcd
Flooding 3 wk	6	0.572 c	0.194 cde	1.24 b	3.45 b
Flooding 4 wk	6	0.666 bc	0.149 e	1.41 ab	4.50 a
F=		2.965	2.411	2.963	3.592
p=		0.006	0.021	0.006	0.001

Lumping together all salinity and flooding harvest values reveals the flooding treatments as significantly different to control for each of 4 dimensions, where analysis of variance revealed differences among means (Table 11).

Table 11: Mean harvest dimensions of characteristics with significantly different values comparing control with all salinity harvest means (Expt 3) and all flooding means (Expt 4).

Harvest Dimension	Major grouping of treatments			Statistics	
Samples	Control n= 8	Salinity n= 40	Flooding n= 23	F=	p=
Dry root wt (g)	0.310 a	0.265 a	0.136 b	5.484	0.006
Σ dry wt (g)	0.571 a	0.497 ab	0.404 b	2.549	0.086
Dry shoot/root	0.98 b	1.07 b	1.77 a	6.649	0.002
Σ fresh/dry	2.84 b	2.95 b	3.66 a	4.228	0.019

In this analysis, differences among fresh shoot weights were no longer significant (F= 0.111; p= 0.895, not shown). Total dry weight reached significance at p= 0.1 and is included. Flooding reduced both dry root weight and total plant weight. Although salinity mean values were less than control, these did not differ significantly from control. Flooding also significantly increased the shoot: root and fresh: dry weight ratios.

Discussion

Fresh (1999) sandalwood seeds used in both field and glasshouse trials came from a single tree to reduce variability. One abnormally large seed was found. With this removed, coefficients of variation for nut dimensions were < 15 %. Nut diameter distribution was less normal than nut weights. It is possible that differential field emergence or glasshouse growth may occur with seed of different weights. This possibility was not investigated but could be the subject of future research.

Fresh seeds are preferred for planting as they give greater germination (Crossland 1982). Seeds planted at "Barton Park" had a higher apparent germination than those used in the glasshouse. Seed planted in the field were left for a longer period prior to emergents being counted. The winter diurnal temperature range may have been more conducive to germination than that experienced in the glasshouse. The loamy soil at "Barton Park" may also have contributed to higher field germination as sandalwood grows best in loam soil (Brand & Jones 1999), neutral to mildly acidic in reaction (Fox *et al.* 1996). Coarse sand was used in the glasshouse as the germination medium for convenience and as good germination is usually obtained with this medium (Fox & Brand 1993).

Two field sites were chosen. A saline drainage line runs through area one. This area was chosen to test the hypothesis that field emergence of *Santalum spicatum* is not affected by saline conditions. Results confirmed that field emergence is affected by saline conditions. Field emergence was not observed in the most saline parts of this area. Some 43 % of planted spots here had no sandalwood emergence. Those seedlings that did establish in the central saline area were shorter and had fewer leaves than those above and below this area. It is suggested that planting sandalwood seed in obvious saline patches, particularly near drainage, should be avoided. This may be particularly important prior to any good host establishment. Planting seed in the landscape above saline patches will produce better results than planting below such locations.

In the previous year, Mickle (1999) had observed that a number of planted sandalwood seed appeared to have rotted in waterlogged sites at "Barton Park". It was hypothesised that field emergence of *Santalum spicatum* is not affected by waterlogged soil. Area two was selected to test the hypothesis that field emergence of *Santalum spicatum* is not affected by waterlogged soil. This area is on the opposite side of the creek to area one, and usually with winter rainfall the soils become waterlogged. Winter rainfall was not as great in 2000 as in 1999 and perhaps, as a consequence, loss due to waterlogging was not observed. This hypothesis could not be tested. Low winter rainfall may have provided seedlings more of an opportunity to emerge than under more usual rainfall conditions. Slightly fewer (39 %) planted spots at area two had no emergence. However, rather more multiple germinations had taken place, suggesting that area two may be much less saline than area one. It is not clear whether the previously established potential hosts here were parasitised by the new sandalwood seedlings. If the germinants survive and attach themselves onto a host they may be able to withstand future inundation. It will be instructive to continue observations into 2001 at these field sites.

Following the observations of Mickle (1999), seed of sandalwood was planted at different depths. Mounding was anticipated to reduce possible losses due to flooding. It was hypothesised that field emergence of *Santalum spicatum* is not affected by depth of sowing. This hypothesis was shown to be untrue and field emergence is affected by sowing depth. At the more saline site (Expt 1: area one), mounding was effective in enhancing total emergence and proportion of occupied planted spots. Mounding at 5 cm had most establishment (37 %); more planted spots with seedlings (72 %); seedlings had most leaves (> 12) and tallest plants (4.5 cm), but heights did not differ significantly between planting depth treatments. The least favourable planting depth was 2 cm with fewest occupied spots (44 %); least leaves (< 10); and shorter plants (3.6 cm).

At area two, the less saline section (Expt 2), slightly more emergents came from burial at 2 cm (46 % of seed), but proportions were similar to both mounding at 5 cm (44 %) and burial at 5 cm (43 %). Deeper burial (10 - 15 cm) reduced the total numbers of seedlings established (26 and 28 % respectively). The proportion of planted spots with one or more seedlings was greater with the mounding treatment (77 % of spots occupied). There were no significant differences in heights attained between planting treatments. Seedlings that emerged from 2 cm burial had most leaves and those from 5- 15 cm were least leafy.

Considering both areas, distributions of both seedling height and leaf number, revealed that seedlings had grown in much the same pattern across both experimental sites. Overall, mounding was the superior planting treatment for both total emergence and for most planted spots with established seedlings. Burial at 10-15 cm reduced total emergence and the extent of occupied spots.

Pot trials were undertaken to seek confirmation or rebuttal of the field results. Tolerance to irrigation with saline water varies greatly between plants (Lantzke & Calder 1999). In relation to salinity it was hypothesised that growth of *Santalum spicatum* is not affected by different salinity levels. Results suggest that low salinity levels are not detrimental to sandalwood and may benefit early growth. Seedlings in the control and lower saline treatments (0, 25 and 50 mM NaCl) appeared to increase in height and leaf number, suggesting that *Santalum spicatum* is tolerant of slightly saline water. This finding confirms field establishment results.

At higher levels of salinity, growth and survival of *S. spicatum* seedlings were profoundly affected. Watering seedlings with high levels of saline irrigation water impacts on plant growth by the osmotic effect reducing the ability of plant roots to take up water. In between irrigation, as the soil moisture decreases, the salts in the soil solution have the ability to concentrate between two and five times their initial value in the irrigation water. For example, watering with 400 mM NaCl produced a salinity reading of 7.02 mS by the end of 5 weeks. As the salt levels in the soil increased to more toxic levels (i. e. over the course of the experiment), scalding or burning on the tips and edges of leaves occurred. Leaf death and abscission follow this (Lantzke & Calder 1999). This was evident at the highest salinity levels by the end of the third week. Considerable leaf deaths in higher saline treatments were occurring by the end of the fourth week.

In pot trials it is important to start with plants of similar sizes. This is particularly difficult with sandalwood as germination occurs over a variable period. A further problem is that for longer-term survival, early host attachment is required and no hosts were used in the glasshouse trials reported here. In the salinity pot trial, although initial seedling dimensions were not statistically different, treatments did differ and some of those initial differences may have influenced the pattern of early seedling development. For example, control seedlings did not attain the same height as the two lower salinity treatments by termination of the experiment. Whereas the 50 mM set had second tallest mean plants at the start and this may have influenced subsequent height growth, the 25 mM set was initially shortest yet ended at second tallest. Both lower salinity treatment sets appear to have been able to utilise sodium in dry matter production. Plants subject to the higher salinity levels lost height from the second week onwards.

Changes in leafiness revealed little difference in pattern of new leaf addition between control and the lowest salinity treatment. Other salinity treatments were impacting on plant health from 14 days onwards, manifest by the loss of foliage. Leaves had died in the three highest treatment levels, with considerable leaf drop. Symptoms included leaf curl and twisting with leaves turning brown. By the conclusion (39 days) the pattern of mean leaf number was in inverse proportion to salinity level.

At harvest, plants in the lower salinity treatments had significantly greater fresh shoot weight, suggesting low levels of salt enhance moisture uptake (leaf hydration). This was also consonant with greater foliage area and high fresh: dry weight ratios. Higher salinity levels had least fresh shoot weight suggesting some inhibition of shoot development in comparison with root growth, also seen in low leaf areas. There was little difference in dry weights, although the highest salinity level had surprisingly similar dry root weight to the control treatment: its dry root weight was high in relation to fresh root weight.

The salinity experiment clearly suffered from a lack of hosting. Differences between initial and harvest dimensions were not great and seedlings were surviving only on their seed resources. However, young seedlings do have the potential to survive on cotyledonary nutrition in the presence of saline solutions and moisture uptake may be enhanced by low levels of soil sodium.

Mickle (1999) reported rotted seed in planting spots of *S. spicatum* following winter waterlogging at "Barton Park" in 1999. Waterlogging occurs when there is excess water in the root zone of a plant. The roots cannot absorb enough oxygen to function and the plant stops growing. Other gases, such as carbon dioxide and ethylene may also accumulate and affect the plant adversely (McFarlane & Belford 1999, Atwell *et al.* 1999). A pot trial was set out to test the hypothesis that growth of *Santalum spicatum* is not affected by waterlogging. The results suggest that flooding of 1-wk duration had little effect on established seedlings, but longer exposures, and flooding of newly emergent seedlings affected development.

Leaf numbers did not differ significantly at any date. Plants flooded for longest (4-wk) lost leaves during the fourth week of exposure. Plants flooded for 1-wk had more leaves at each week after removal from flooding but there was no similar effect on height. The 2-wk treatment set lost leaves over the following two weeks. Each of control, 1-wk and 3-wk flooded plants had more leaves at the end of the experiment. Mean heights in all treatments increased slightly during the first week of flooding, as did the control. One week of flooding appears to have no detrimental effect on the momentum of early seedling development, dependant on mobilisation of cotyledonary reserves. In contrast, plants exposed to flooding for 2-wk or 3-wk declined in mean height after removal.

A foul odour, most likely hydrogen sulphide, was smelt on disruption of the soil in pots at the time of harvesting (McFarlane & Belford 1999, Atwell *et al.* 1999). Harvesting revealed that roots had started to rot on treatments flooded for 3 and 4 weeks. Oxygen is an essential requirement for root growth, without it plants can loose 85-95 % of their capacity to produce energy and therefore they stop growing (Atwell *et al.* 1999). Poor root growth was evident in all flooding treatments. Root rotting follows the depletion of oxygen around the roots. Oxygen stimulates the activity of anaerobic microbes, so when it becomes depleted (through water displacing air in the soil), the soil redox potential becomes very low (below -200 mV) and toxic forms of micro-elements such as iron and manganese appear. This effect could have occurred if the trial had run for longer. The oxygen is not replaced and eventually all but the top few mm of the soil becomes anaerobic.

Harvest analysis indicated that flooding depressed dry root weight. Lack of differences among shoot weights suggested that flooding does not reduce photosynthesis. All treatments had higher fresh: dry ratios than control. Flooding of > 2-wk reduced leaf area below that of control but shorter durations (and longer recovery times) were similar to that of control. This experiment suggests that limited periods of soil saturation during the germination and early establishment phase do not detrimentally affect emergent seedlings. However, this is not so where leaves have not developed and where root growth is not great. Under these circumstances flooding may lead to premature death due to rotting induced by moist conditions.

Due to root rotting, the shoot: root ratios for the flooding trial were all much higher than the control; shoot weights were greater than root weights. Longer flooding periods would have resulted in plant death. The question of whether the flooded plants could have recovered was not examined. This would have depended on the availability of host plants.

A comparison of the potting trials suggest fresh top weights were greatest in the two lower salinity treatments and the 2-wk flooding treatment; all flooding treatments were similar to the control; least weights were associated with higher salinity levels. All flooding durations significantly depressed dry root weight below the control, whereas most salinity treatments had similar root weights to control. Exceptions were 50 and 200 mM NaCl.

Shoot: root ratios were particularly high after 1- or 2-wk flooding; most flooding treatments had significantly greater ratios than the control (3-wk flooding did not); salinity treatments generally did not affect this ratio, probably due to greater leaf death. The fresh: dry weight ratio in all flooded treatments was higher than the control, but only reached significance after 4-wk; values were lower in saline treatments and this ratio generally declined with higher salinity.

Conclusions

It was found that growth of *Santalum spicatum* is affected by different salinity levels in both the field and in glasshouse irrigation with saline solution. Field emergence of *Santalum spicatum* is prevented by highly saline conditions. Low levels of salinity appear to enhance growth. Higher levels result in early leaf loss and then death of the plant. This occurs sooner on seedlings that have only just emerged at the time of salinity impact.

Field emergence of *Santalum spicatum* is affected by depth of sowing. In the field, best establishment from planted seed can be obtained by planting at levels less than 10 cm, or on a mound 5 cm above the surface level. Planting in the mound 5 cm above soil level was the superior planting treatment for both total emergence and for most planted spots with established seedlings. Burial at 10-15 cm reduced total emergence and the extent of occupied spots. Differences in height and leaf numbers were slight between treatments. Seedlings grow in much the same pattern (mean height and leaf number) across all locations once emerged.

Growth of *Santalum spicatum* is affected by waterlogging in that root growth is rapidly retarded, probably due to oxygen depletion. Flooding reduced both dry root weight and total plant weight. Flooding also significantly increased the shoot: root and fresh: dry weight ratios. Flooding results may reflect that seedlings used in the flooding experiment were the last to be taken from the pool available. There would have been more, smaller (younger) individuals in the flooding sets. The flooding experiment suggested that limited periods of soil waterlogging during the early establishment phase does not detrimentally affect emergent seedlings. However, flooding may lead to premature death of small seedlings due to rotting induced by moist conditions.

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References

Anon (2000) Dryland Salinity, an introduction. Revegetation on farms project, Agriculture Western Australia.

Anon (1996). Western Australian Salinity Action Plan. Prepared for the Government of Western Australia by Agriculture Western Australia, Department of Conservation and Land Management, Department of Environmental Protection and the Waters and Rivers Commission.

Atwell, B., Kriedemann, P. & Turnbull, C. (Eds) (1999). Plants In Action Adaptation in Nature, Performance in Cultivation. MacMillan Education Australia, South Yarra.

Barrett, D. R. & Fox, J. E. D. (1995). Geographical distribution of Santalaceae and botanical characteristics of species in the genus *Santalum* pp. 3-23. *In*: Gjerum, L., Fox, J. E. D. & Ehrhart, L. (eds). Sandalwood Seed Nursery and Plantation Technology. FAO, Suva, Fiji. Field Document No. 8. RAS/92/361.

Brand, J. (1999) Conserving Sandalwood (*Santalum spicatum*) in the rangelands, Western Australia. CALM, Sandalwood Information Sheet Issue 2. August 1999.

Brand, J. & Jones, P. (1999) Growing Sandalwood (*Santalum spicatum*) on Farmland in Western Australia. CALM, Sandalwood Information Sheet, May 1999.

Crossland, T. (1981). Preliminary investigations into germination and establishment of Sandalwood, *Santalum spicatum* (R. Br.) DC. *Mulga Research Centre Journal* **4**, 61-65.

Crossland, T. (1982). Response to fertiliser treatment by seedlings of sandalwood, *Santalum spicatum* (R. Br.) DC. *Mulga Research Centre Journal* **5**, 13-16.

Crossland, T. (1982). Germination of sandalwood seed. *Mulga Research Centre Journal* **5**, 49-50.

Fox, J. E. D. (2000) Sandalwood: the Royal Tree. *Biologist* **47** 31-34.

Fox, J. E. D., Barrett, D. R. & Gentle, R. (1996). Sandalwood for saline sites. Proceedings 4th National Conference and Workshop on the Productive Use and Rehabilitation of Saline Lands. Albany 25-30 March 1996. pp. 335-343.

Fox, J. E. D. & Brand, J. E. (1993). Preliminary observations on ecotypic variation in *Santalum spicatum* 1. Phenotypic variation. *Mulga Research Centre Journal* **11**, 1-12.

Lantzke, N. & Calder, T. (1999). Water Salinity and Crop Irrigation. Farmnote 46/99. Agriculture Western Australia, Perth.

McFarlane, D. & Belford, B. (1999). Waterlogging and inundation: Why they could be costing you money. Farmnote 78/93. Agriculture Western Australia, Perth.

Mickle, D. (1999) Is Sandalwood Salt Tolerant? Biology 302 Report, Curtin University.

Wurm, P. A. S. & Fox, J. E. D. (1990). Research and Demonstration of Sandalwood for Restoration of Degraded Sites in the Avon Valley, WA, Report to National Afforestation Program Commonwealth D. P. I & E. 08. 06. 1990, pp. 47.

Appendix 1. Sandalwood Seed Data Sheet

Seed	Nut weight (g)	Diameter (mm)	Kernel weight (g)
1	2.807	17.8	0.9936
2	2.667	17.8	0.9230
3	2.750	17.5	0.9253
4	2.302	16.9	0.7377
5	2.618	17.4	0.8956
6	2.579	17.2	0.8630
7	2.454	17.0	0.8333
8	2.278	16.4	0.7694
9	2.582	17.4	0.9182
10	2.767	17.6	0.9508
11	2.420	17.1	0.7915
12	2.549	17.8	0.8681
13	2.557	17.5	0.8907
14	2.181	16.8	0.8058
15	2.180	16.5	0.7065
16	2.156	16.5	0.8303
17	2.132	16.3	0.7115
18	2.068	15.8	0.6797
19	2.015	16.0	0.8171
20	2.211	16.4	0.7521
21	2.194	16.6	0.7707
22	2.327	16.8	0.8048
23	2.300	16.9	0.7422
24	2.114	16.3	0.6991
25	2.456	17.0	0.7973
26	2.288	16.1	0.7206
27	1.920	15.9	0.6914
28	2.206	16.5	0.7198
29	2.442	16.9	0.8029
30	1.755	15.0	0.6113
31	2.301	16.5	0.8197
32	2.426	16.7	0.7974
33	2.626	17.4	0.8708
34	1.775	15.0	0.5646
35	2.623	17.2	0.8521
36	2.955	18.4	0.9686
37	2.199	16.6	0.7485
38	2.536	17.1	0.9146
39	2.080	16.2	0.6933
40	2.890	18.1	0.9357
41	2.851	17.9	0.9539
42	2.281	16.5	0.7505
43	4.269	20.9	1.6197
44	2.434	17.0	0.8818
45	2.201	16.3	0.7288
46	2.093	15.9	0.6745
47	2.307	16.5	0.7645
48	1.973	15.8	0.6347
49	1.507	14.1	0.4653
50	2.569	17.2	0.8608
51	2.068	16.1	0.7168
52	2.416	16.1	0.7937
53	2.181	16.3	0.7335
54	2.370	15.4	0.7522
55	1.863	16.1	0.6320
56	2.172	17.1	0.7157
57	2.444	16.1	0.803
58	2.141	16.0	0.7112
59	2.340	16.2	0.729
60	2.175	15.8	0.6968
61	1.983	16.0	0.6419
62	2.058	17.8	0.6858
63	2.703	16.9	0.9103
64	2.381	17.0	0.8084
65	2.344	16.0	0.8453
66	2.139	16.0	0.6960
67	1.996	15.9	0.6108
68	1.987	15.0	0.6551
69	1.982	15.3	0.7530
70	1.853	16.0	0.6278
71	2.131	17.1	0.6740
72	2.479	17.0	0.7990
73	2.470	15.0	0.8510
74	1.860	18.4	0.7007
75	3.152	15.25	1.0610
76	1.956	17.3	0.6480
77	2.441	17.0	0.8210
78	2.339	15.0	0.7874
79	1.877	17.1	0.6730
80	2.419	16.3	0.7800
81	2.224	17.35	0.7350
82	2.572	17.25	0.8790
83	2.669	16.0	0.9280
84	2.127	14.0	0.7172
85	1.616	16.0	0.5810
86	2.239	15.4	0.8380
87	1.908	17.3	0.6850
88	2.274	16.0	0.7520
89	2.033	17.3	0.6390
90	2.295	15.0	0.7630
91	2.170	14.0	0.7390
92	1.572	17.0	0.5220
93	2.541	17.3	0.9200
94	2.352	16.0	0.7850
95	2.114	16.0	0.7400
96	2.423	16.0	0.8180
97	2.174	17.0	0.6830
98	2.545	17.0	0.8880
99	2.447	16.7	0.8360
100	1.734	14.2	0.5290

Appendix 2 Germinants from field trial saline soil at "Barton Park". Sown 21 April, assessed 25 September 2000. Heights: cm

Area 1 Line 1

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	+5	2.4	12	4	14				
2	15								
3	10	8.5	14	6.5	10	3.8	12		
4	5	7.5	14						
5	2								
6	+5	7.4	32	2.5	24				
7	15								
8	10								
9	5	2.6	10						
10	2								
11	+5	3.5	8						
12	15	6.8	8	4	20				
13	10								
14	5								
15	2	3	6						
16	+5	6.2	12	4	24				
17	15	8.5	16	6.5	18				
18	10	4	10						
19	5								
20	2								
21	+5								
22	15								
23	10	7	14						
24	5	3	12	4.1	10	2.5	12	3	12
25	2								

Line 2

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	+5	2	10	2.3	10	0.5	4		
2	15	6	16	2.5	12	2.5	8		
3	10								
4	5	5.1	12	5.9	12	2	4		
5	2	5.4	10	4	10	6.5	11		
6	+5	7	10	4	28	6.5	14		
7	15	3	10	4	8				
8	10	2.9	8						
9	5	4	12	2.4	6				
10	2	9	18	7.1	12	4	10		
11	+5	6.2	14	3.4	10	5	14		
12	15	3.7	14	1.5	6				
13	10	5.5	14	3	8	2.3	6		
14	5	5.2	10	4.5	8				
15	2								
16	+5								
17	15								
18	10								
19	5	4	6	2	6	1.4	4		
20	2	3.5	20	4.5	10	3	10		
21	+5	5	16	4	10				
22	15								
23	10								
24	5	6.3	10	5.1	14				
25	2								

Line 3

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	2(cm)	5(cm)	8	4(cm)	10				
2	5								
3	10	1.8	4						
4	15	4	8	2	4				
5	+5								
6	2	2.4	6	1	4				
7	5	2	2						
8	10	2	6	3	10				
9	15	4	10						
10	+5	9.4	12	6	11	6	12		
11	2								
12	5								
13	10								
14	15								
15	+5	5	8						
16	2	3	6						
17	5								
18	10	5.9	14	3.7	12				
19	15								
20	+5	3	12	3.5	12				
21	2	2	8	24	8	2	6		
22	5	6.5	12	7	16	6	14	5	12
23	10								
24	15	6.2	14	5.8	10				
25	+5								

Line 4

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	+5(cm)								
2	15	8(cm)	12						
3	10	3	5	4(cm)	12	5(cm)	14		
4	5	0.5	1						
5	2								
6	+5	5	10						
7	15	5	14	4.5	14	4	16		
8	10	4	16						
9	5								
10	2								
11	+5	7	14	3	12				
12	15	1.8	4						
13	10								
14	5								
15	2	2.5	6	1.8	8	2.6	14		
16	+5	4	12	3.8	12				
17	15	8	16						
18	10	1	4						
19	5								
20	2								
21	+5								
22	15	2.7	6						
23	10								
24	5								
25	2	3	10	3.5	14	3	8		

Line 5

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	+5(cm)	1.4(cm)	4	3(cm)	8	4(cm)	12	6.4(cm)	14
2	15								
3	10								
4	5								
5	2								
6	+5	4.3	8	5.2	14				
7	15								
8	10								
9	5	2.8	6						
10	2	2	10						
11	+5	5	14						
12	15								
13	10								
14	5								
15	2								
16	+5								
17	15	1.5	6						
18	10	6	14						
19	5	5.9	10						
20	2								
21	+5	6	10						
22	15	4	4						
23	10	6.8	18	2.7	10	5	18		
24	5	6	16	6.6	16				
25	2								

Appendix 2 Germinants from waterlogging field trial at "Barton Park". Sown 21 April, assessed 25 September 2000.

Area 2 Line 1

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	2								
2	5								
3	10								
4	15								
5	+5	5	12	4	8				
6	2	5	11	5	16	3	8	7	10
7	5	6	10	4.5	10	2.8	12		
8	10								
9	15	7	12	4	10				
10	+5	4.5	16	3	6	2.6	6		
11	2	3	8	4	10	5	18		
12	5	6	10	5.3	14	6	18		
13	10	6	8	6.5	12	5.8	14	4	24
14	15								
15	+5								
16	2								
17	5	9.5	14	5	6				
18	10	5	12	3	10				
19	15	6	10	4.5	8	6.5	12	4	6
20	+5	4	8	5	8	4	4		
21	2	8.5	18	5	14	6	14	7	16
22	5	3.5	12	2	8				
23	10	4	6						
24	15	3	6	1	4	0.6	6		
25	+5	3	6						

Line 2

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	2	6	16	6	14	6.1	12		
2	5								
3	10	4.8	6						
4	15								
5	+5	2	20	2.1	5				
6	2	3	8	5.5	18	3	10		
7	5	6	14	5	12	4	18		
8	10								
9	15								
10	+5								
11	2								
12	5								
13	10	8.5	14	5	16	6	8	5(cm)	10
14	15	4	6	3	8				
15	+5	4	18	4	16				
16	2								
17	5	3	10						
18	10	7	12	8	16	4	6		
19	15	5	10	3.8	14	8.1	10	8.2	10
20	+5	1.5	5	1.2	4	0.7	4		
21	2	3	14						
22	5	7	10	3	8	2	6		
23	10	7	12	6.8	14				
24	15	3	6	4.2	8	6.1	10		
25	+5	4	6	8	10	5	6		

Line 3

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	2								
2	5								
3	10	2.1	8	7.8	12	5.3	14		
4	15	4	8	3.8	12	1.3	6		
5	+5	4.9	8						
6	2	5.6	12	7.1	12	6.4	14		
7	5								
8	10	3.1	6	2.2	4				
9	15	7	10	8.1	12	4.5	11	3.3	8
10	+5	6	12	6.2	12				
11	2	4.3	24						
12	5								
13	10								
14	15								
15	+5	8	12	6.1	12	7.1	16	4.8	14
16	2	5.5	8	6.1	8	5.3	12		
17	5								
18	10								
19	15	6	10	2.1	14	1.9	12		
20	+5								
21	2	1.4	4	1.8	6				
22	5								
23	10								
24	15	6	8	2.1	14	1.9	16		
25	+5	3	22	3	20	4	12		

Line 4

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1									
	2	2							
3	5	8.9	14	2.9	8	5.8	14	4.7	8
4	10	6	10	4.9	6				
5	15								
6	+5								
7	2								
8	5								
9	10								
10	15								
11	+5	7	12	5	8	3.8	14		
12	2	4	8	3	4				
13	5	6	10	2.4	6				
14	10	2.2	8						
15	15								
16	+5	8	12	4.1	10	4.5	12		
17	2	4.5	20	2.4	12	2.3	24		
18	5	4.1	10	1.8	6				
19	10								
20	15	6.2	12	2.4	8				
21	+5	2.4	4	4.5	8	5.2	8		
22	2	3	10	2.6	10	5	14		
23	5	5.1	8	2.8	4				
24	10								
25	15								

Line 5

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	2	6	16	5.2	12	7	14	3.6	8
2	5	7.8	6	2.4	4				
3	10	2.1	4						
4	15								
5	+5	5	10	3.1	10	1.8	6		
6	2	2	18	3.7	10	3.1	14	1.1	6
7	5	2.2	16	1.8	12				
8	10	2.5	16						
9	15								
10	+5								
11	2								
12	5	7.1	10	5.6	12	1.2	4		
13	10	5.1	8	1.8	8	4.1	8	3.4	6
14	15								
15	+5								
16	2	4.6	10	5	8	7	14		
17	5	2.7	14	2.8	12	3.4	16		
18	10								
19	15	4.5	14	5.3	12				
20	+5	5.2	10						
21	2								
22	5	7.1	12	6.7	14				
23	10	7.4	14	4.2	12	3.8	12		
24	15								
25	+5	5.6	18	5.5	8	4.1	12		

Line 6

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	2								
2	5	4.4	10	1.1	6	2.6	8	3.1	8
3	10								
4	15	3.8	8						
5	+5	7.1	12	4.8	10				
6	2	9.1	14	7.8	14	5.6	12		
7	5	7	10						
8	10	3.6	6						
9	15	7.6	8	2.1	10				
10	+5	5.9	8						
11	2								
12	5								
13	10								
14	15								
15	+5	4.1	8	1.9	6	1.6	10		
16	2	5.1	8	3.9	6	3.4	8		
17	5								
18	10								
19	15								
20	+5	2.8	10	3.1	10				
21	2	5.6	8						
22	5	5.1	8	2.4	6	3.1	8		
23	10								
24	15								
25	+5								

Line 7

Position	Depth	Height	Leaves	Height	Leaves	Height	Leaves	Height	Leaves
1	2	4.1	5	2.7	4				
2	5	6.2	14	3.3	14	3.1	12	2.9	10
3	10								
4	15	2.1	8						
5	+5	5.9	8	4.1	8	2.7	12		
6	2	1.5	6	2	12				
7	5	0.5	2						
8	10								
9	15								
10	+5	9.3	14	5	12				
11	2	8.4	14	6.9	14	4.1	16		
12	5	3.9	12	1.3	10	2.3	8		
13	10								
14	15								
15	+5	8.8	14						
16	2	5.6	12	5.4	10	6.3	10	7.1	14
17	5	6.9	12	5.1	6				
18	10	5.6	8	4.1	6				
19	15								
20	+5	9	20						
21	2								
22	5	4.8	10	3.8	8	1.7	5		
23	10								
24	15								
25	+5	3.7	16	2.8	8				

This report should be referred to as:
Fox, J. E. D. & Millar, K. L. (2000). Is sandalwood emergence and growth inhibited by waterlogging or depth of burial? Report to Department of Conservation & Land Management 29. 12. 2000. pp. 31.