MULGA RESEARCH CENTRE

annual report 1981

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OBSERVATIONS ON COMPARATIVE GROWTH AND SURVIVAL OF *ACACIA ANEURA, ACACIA CRASPEDOCARPA* AND *EUCALYPTUS CAMALDULENSIS*

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Introduction

In an earlier report[3] a preliminary account of field studies at Leinster (27°55'S, 120°41'E) to investigate the effects of mine dewatering on the perennial vegetation was presented. In the present report the results of some pot trials to determine the pattern of early seedling growth on typical soil of the area are given. Some preliminary work on response to flooding and saline conditions is also reported.

Seed of three tree species present at Leinster Downs was collected from the Station for use in this study. These were *Acacia aneura, Acacia craspedocarpa* and *Eucalyptus camaldulensis*.

E. camaldulensis seed were sown onto a germination tray of coarse sand and the seed covered with 3-4 mm of sand. Seed of the legumes *Acacia aneura* and *A. craspedocarpa* was placed in beakers and then covered to 2 cm with boiling water. On cooling these seed were also placed in trays as for *E. camaldulensis*.

The first seed was sown in early February, and another set was sown in early June.

Soil Used in the Experiment

Surface soil to a depth of ∿ 15-20 cm was collected from two sites south of the mine shaft. The first was from a study site 4.5 km from the mine affected by mine outflow water more or less continuously. In December 1979, when the soil was collected, standing water lay in low lying parts with surface encrustations of salts in between. The same area had been under water in mid-winter of 1979 and was again flooded in winter of 1980. The second site was 3 km to the south-west in an area unaffected by mine water. This natural soil is denoted Soil A, whereas the salt affected soil is referred to as Soil B.

Several characteristics of the undisturbed soils were determined. Four replicates of each soil were used. Mean values and ranges are summarised in Table 1.

Table 1. Soil properties, Leinster, mean values with ranges in brackets.

Property	Desert Loam Soil A	Salty Soil Soil B
pH	5.1	7.7 (7.5 - 7.9)
Conductivity (mS cm^{-1})	0.73 (0.65 - 0.80)	7.73 (7.0 - 8.1)
Saturation (percentage)	24.1 (23.8 - 24.4)	49.1 (47.8 - 50.0)
Bulk density	1.64 (1.59 - 1.68)	1.57 (1.49 - 1.68)
Nitrogen (percentage)	0.04 (0.034 - 0.045)	0.14 (0.114 - 0.157)
Sodium (p.p.m.)	4.47 (3.9 - 5.2)	95.6 (63 - 142.5)
Potassium (p.p.m.)	7 (6 - 9)	9 (all 9)

Soil particle size distribution for Soil A was as follows (mean of 4 kg samples)

Size	Percentage Weight	(Range)
> 2mm	9.7	(8.8 - 10.6)
< 2mm > 0.71mm	12.2	(9.5 - 17.2)
< 0.71mm > 0.3mm	27.0	(21.7 - 32.1)
< 0.3mm > 0.075mm	45.2	(41.9 - 52.2)
< 0.075mm	5.9	(3.4 - 7.6)

Particle size distribution was not determined for Soil B. Table 1 suggests that the effect of outflow water has been to increase the alkalinity of the surface soil and particularly its sodium concentration. The raw winze water has been tested (pers.comm. D.Greenway) and showed pH of 7.8, sodium 560 p.p.m., potassium 50 p.p.m., with a chlorine level of 1100 p.p.m. Soil flocculation is indicated with lower bulk density and increased saturation capacity in Soil B. The nitrogen and potassium levels were not dramatically different between soils A and B. We refer to Soil B subsequently as the 'saline' soil. The natural soil of the area may be referred to as a desert loam[2] or red earth.

Comparative Growth Study : Soil A

Eighteen plants of each species were transplanted into Soil A on February 23rd and stood on a bench in the greenhouse at Bentley. Black plastic pots of 12 cm diameter were used, with ∿ 82 g of vermiculite in the bottom, and ∿ 816 g of soil.

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Three harvests were planned of 6 plants of each species at 79, 130 and 200 days from transplanting. No deaths occurred in *A.aneura* there was one loss in *A,craspedocarpa,* so that the 130 day harvest was of five plants only. Seven of the *E.camaldulensis* plants died and only three were harvested at 79 days, with four each at the other two harvests. By the final harvest plants of this species were losing leaves and one plant was excluded from some considerations of growth analysis.

The plants were given 100 ml of distilled deionised water in the evenings at intervals sufficient to restore the soil to around field capacity every third day. Frequency of watering depended on the weather conditions.

Plants selected for harvest were chosen to cover the range of size to avoid any bias, At harvest fresh and dry weights of shoots and roots were obtained for each plant, leaf area was measured with a leaf area planimeter.

Results

Individual plant dry weights are plotted against harvest date in Fig.1, and against shoot dry weight in Fig.2. Table 2 summarises mean values for physical measurements for each species at each harvest.

Relative growth rate (R,G.R.), net assimilation rate (N.A.R.) and leaf area ratio (L,A.R.) were calculated for each species using the mean harvest values (Fig.3). Plants harvested at 200 days were analysed for nutrient content. Nitrogen, potassium, phosphorus and sodium levels were determined in each plant, Nitrogen determination was by the Kjeldahl Digestion technique. Potassium and sodium levels in the plants were calculated with the aid of a flame photometer. Phosphorus was determined by the use of a spectrophotometer.

The chemical analyses are presented in Table 3.

A number of seeds present in the soil germinated under the stimulus of moisture. After three weeks seedlings were transplanted into white yoghurt containers with no drainage holes. Five containers each of Soil A and Soil B were given seven seedlings each and water was given at 50 ml every second day.

A total of 392 plants were removed from the pots. Of those transplanted to white containers, vegetative growth in Soil B was poor and all plants were dead by 50 days from transplanting. The species included *Helipterum charsleyae* and *Calandrinia monogyna,* several unidentified grasses and the introduced species *Sonchus oleraceous.*

Discussion

The overall ranking of yield was *E.camaldulensis* > *A.craspedocarpa* > *A,aneura,* for mean weights at all harvests. At first and second harvests there was some overlap amongst individual plants, and consequently an overlap of standard deviation (Fig,1). By the third harvest, at 200 days, the three species were more clearly segregated,

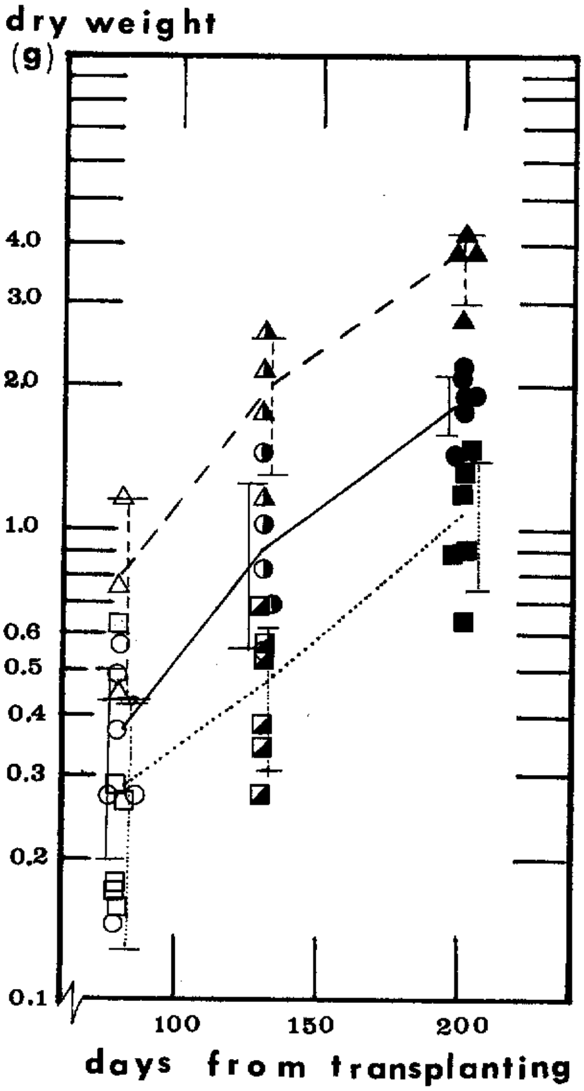

Figure 1 Individual plant total dry weights. Lines join means for species at harvests. Vertical bars are standard deviation.
Acacia aneura square symbols,
Acacia craspedocarpa circles, and
Eucalyptus camaldulensis triangles.
Open symbols first harvest, half-open second harvest and filled symbols third harvest .

The fresh/dry weight ratio fell off between harvests. The stem (shoot, phyllodes or leaves)/root dry weight ratio increased between harvests in the *Acacia* species but fell away in *Eucalyptus camaldulensis* (Table 2).

Linear regression equations were calculated with total plant dry weight as the dependent variable (TDW) and stem height (H), numbers of phyllodes or leaves (P,L), leaf area (A) and shoot dryweight (SDW) as the independent variables,

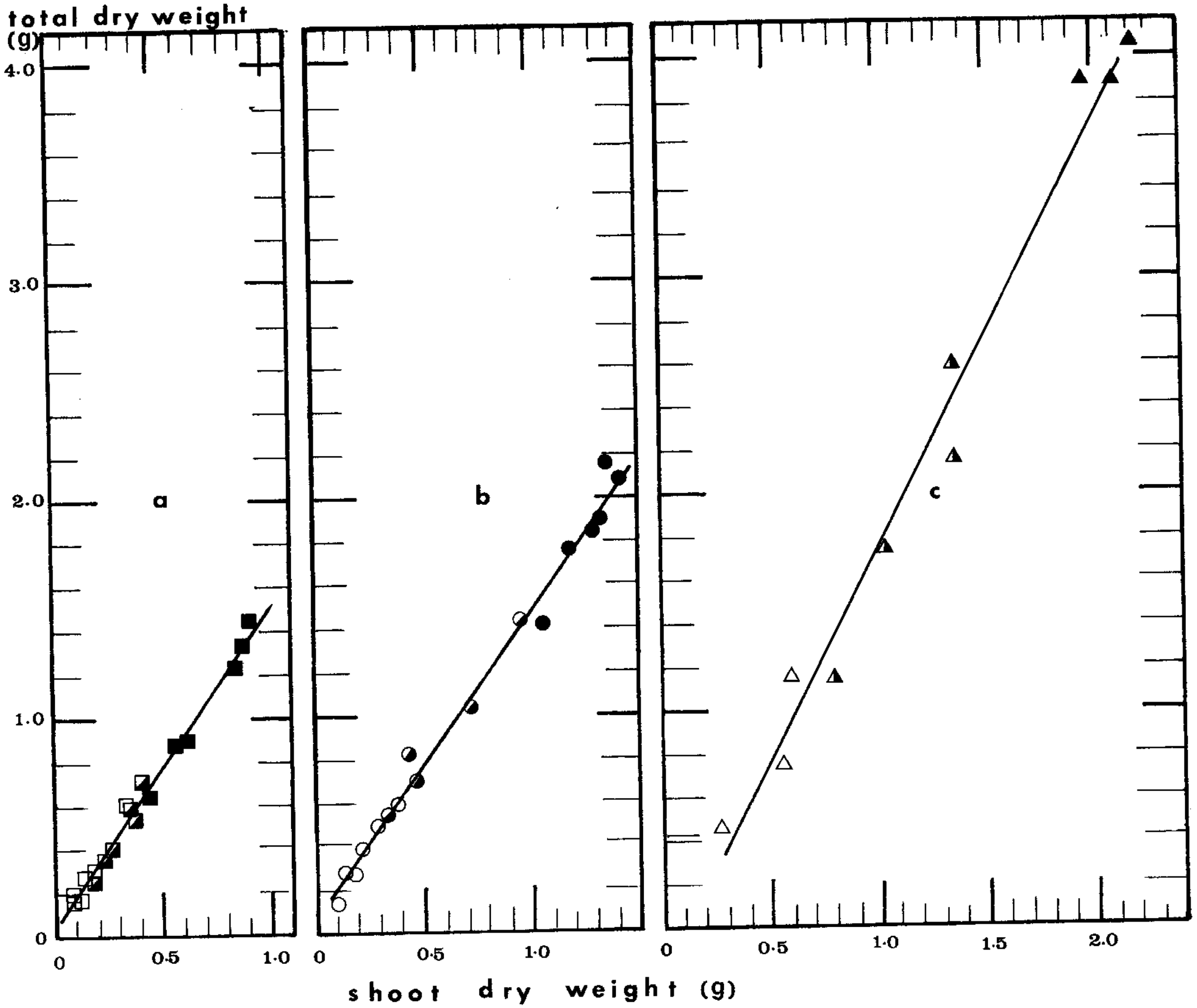

Figure 2 Harvested plant total dry weights plotted against dry shoot weights. a - *Acacia aneura*, b - *Acacia craspedocarpa*, c - *Eucalyptus camaldulensis*. Lines are regression lines. Symbols for harvests as in Figure 1.

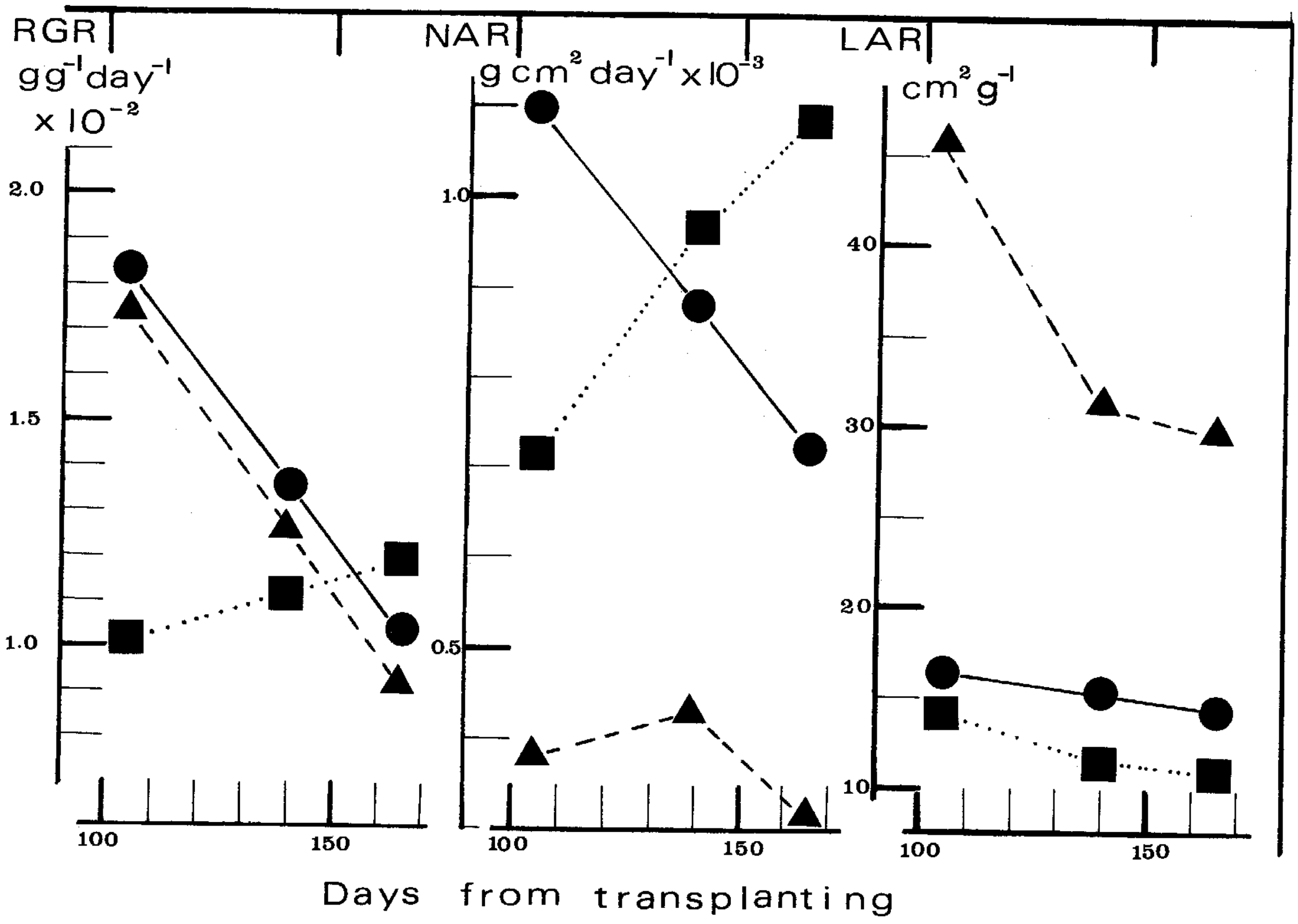

Figure 3 Relative growth rate (R.G.R.), net assimilation rate (N.A.R.) and leaf area ratio (L.A.R.) *Acacia aneura* filled squares, *Acacia craspedocarpa* filled circles and *Eucalyptus camaldulensis* filled triangles.

TABLE 2. Harvest mean values for plants grown in desert loam (Soil A)

	Days from potting								
	79			130			200		
SPECIES HARVEST VALUES	*A.aneura*	*A.craspedocarpa*	*E.camaldulensis*	*A.aneura*	*A.craspedocarpa*	*E.camaldulensis*	*A.aneura*	*A.craspedocarpa*	*E.camaldulensis*
Mean dry wt(g)	0.277	0.358	0.787	0.464	0.905	1.911	1.069	1.853	3.919
(Standard deviation)	(0.169)	(0.155)	(0.345)	(0.158)	(0.340)	(0.612)	(0.315)	(0.264)	(0.124)
Mean fresh wt(g)	1.414	1.662	3.374	2.298	3.767	7.751	4.044	5.694	11.513
Fresh/Dry ratio	5.10	4.65	4.29	4.95	4.17	4.06	3.78	3.07	2.94
Stem dry wt(g)	0.156	0.227	0.471	0.299	0.590	1.144	0.704	1.273	2.090
Root dry wt(g)	0.122	0.131	0.316	0.165	0.315	0.767	0.365	0.580	1.829
Stem/Root ratio(dry)	1.28	1.73	1.49	1.81	1.87	1.49	1.93	2.20	1.14
Stem fresh wt(g)	0.587	0.773	1.597	0.950	1.877	3.487	2.069	3.184	4.895
Root fresh wt(g)	0.827	0.889	1.777	1.348	1.890	4.265	1.976	2.510	6.618
Stem/Root ratio(fresh)	0.71	0.87	0.89	0.70	0.99	0.82	1.05	1.27	0.74
Mean phyllode/leaf Area (cm^2)	4.30	6.68	43.40	6.15	13.60	75.91	10.11	25.27	82.23

TABLE 3. Nutrients recorded after 200 days growth in desert loam (Soil A)

SPECIES / Nutrients	Nitrogen (percentage)	Sodium	Potassium	Phosphorus
		(parts per million)		
Acacia aneura	0.79(0.37)	4367(1101)	5638(3516)	110(221)
Acacia craspedocarpa	0.69(0.09)	1347(495)	3104(1405)	12(5)
Eucalyptus camaldulensis	0.88(1.30)	1208(262)	3150(1167)	19(17)

(standard deviations in brackets)

Acacia aneura

$TDW = -0.364 + 0.111\ H \quad r = 0.971$
$TDW = -0.218 + 0.024\ P \quad r = 0.984$
$TDW = -0.237 + 0.123\ A \quad r = 0.955$
$TDW = 0.021 + 1.509\ SDW \quad r = 0.994$

Acacia craspedocarpa

$TDW = -0.643 + 0.232\ H \quad r = 0.922$
$TDW = -0.132 + 0.052\ P \quad r = 0.972$
$TDW = -0.025 + 0.070\ A \quad r = 0.953$
$TDW = 0.043 + 1.427\ SDW \quad r = 0.995$

Eucalyptus camaldulensis

$TDW = -1.328 + 0.253\ H \quad r = 0.987$
$TDW = 4.031 - 0.138\ L \quad r = 0.269$(not significant*)
$TDW = -0.616 + 0.043\ A \quad r = 0.692(p\ 0.05^*)$
$TDW = -0.210 + 1.948\ SDW \quad r = 0.992$

(* All other equations significant at p 0.001)

Total dry weight was most closely correlated (Fig.2) with shoot dry weight in each species. The poor linear relationship of total dry weight with leaf number and area in *E.camaldulensis* reflects leaf loss prior to harvests. Early leaves tended to be small in area and to be shed when larger leaves developed.

The multiple regressions incorporating both height and phyllode/leaf number were as follows:

Acacia aneura
$TDW = -0.267 + 0.030H + 0.018\ P \quad r = 0.986$
Acacia craspedocarpa
$TDW = -0.419 + 0.089H + 0.036\ P \quad r = 0.991$
Eucalyptus camaldulensis
$TDW = -1.698 + 0.256H + 0.024\ L \quad r = 0.988$

(all significant at p 0.001)

For *Acacia aneura* the multiple regression was marginally more efficient at predicting total plant dry weight than phyllode numbers alone, but not as efficient as shoot dry weight. In a previous experiment, with seedlings of the 'Charleville' variety of *A. aneura*, height was a consistently better predictor than phyllode numbers over a range of soils. The *A. aneura* used in the present work held three times as many phyllodes at 0.5 to 1.0 g total plant weight as did the 'Charleville' variety, reflecting the larger, rounder, phyllodes of the latter. Clearly phyllode numbers cannot be used for *A. aneura* of different varieties. Height regression lines for both sets of *A. aneura* in desert loam were parallel, with the Charleville plants $\sim$0.2 g heavier, over the dry weight range of 0.5 to 1.0 g. Phyllode area was least efficient at predicting total dry weight.

In the case of *Acacia craspedocarpa* the multiple regression was inferior only to shoot dry weight at predicting total plant dry weight. In the earlier experiment *A. craspedocarpa* from the Meekatharra area had a lower correlation coefficient for shoot dry weight and total dry weight, than those for number of phyllodes or plant height with total dry weight. The multiple regression was not derived for that and the most efficient predictor of plant dry weight was height. In the present case height was the least efficient predictor of plant dry weight, though all regressions, as with those for *A. aneura* were highly significant. *Acacia craspedocarpa* shows little variation in foliage or form, and the general pattern of growth between the two sets of plants was similar, especially if plants grown on soils other than desert loam in the earlier experiment are ignored.

Eucalyptus camaldulensis showed as good a relation between height and plant dry weight as in the multiple regression of height and leaf number. Should estimates of productivity have been derived without destructive sampling then plant height could have been selected with little loss of precision. The best relationship between plant dry weight and leaf area was not linear, but took the form

$$\text{TDW} = \cdot 0023\text{A}^{1\cdot 613} \qquad r = 0.763 \ (p\ 0.01)$$

In *Acacia aneura* R.G.R. increased slightly over the course of the trial from 0.010 to 0.012 g $g^{-1}day^{-1}$ in contrast with the other two species. These were initially growing much faster but fell off considerably. L.A.R. declined in all three species, most sharply in *E. camaldulensis* reflecting leaf loss referred to above. However this species had the highest L.A.R. throughout and *A. aneura* the lowest (Fig.3) N.A.R. was between 0.0003 and 0.0004 g cm^2 day^{-1} in *E. camaldulensis*, but varied more widely in the *Acacia* species. Initially *A. craspedocarpa* had the highest N.A.R. at 0.0011 but fell to 0.0007 g cm^2 day^{-1}. In *Acacia aneura* the position was reversed (Fig.3). It would appear useful to determine more intermediate values for all species, over shorter time periods, in order to establish growth patterns in a more precise manner.

Despite the fact that *E. camaldulensis* does not have symbiotic bacterial nitrogen fixing associates and the *Acacias* do (nodules were evident at final harvest in both) this species had the highest overall nitrogen concentration (Table 3). However the range in nitrogen content was much greater in *E. camaldulensis*. Potassium and sodium contents of *E. camaldulensis* and *Acacia craspedocarpa* were similar, but *A. aneura* had much higher concentrations for both, though the variability in potassium was high (Table 3) in this species. The mean levels in all three were higher for potassium than sodium, agreeing well with the usual pattern for Australian conditions[1] Phosphorus content was low in all three species, with the results variable and generally uninformative and unreliable.

Survival in Saline Soil

a) *Comparison with natural soil* Soils A and B

Sets of eighteen plants of each species were transplanted into pots containing 816 g of each of Soil A and Soil B on February 25th. The plants were watered with distilled deionised water as in the comparative growth study. It was particularly difficult to insert transplants into Soil B due to its tacky constituency.

By twenty four days from transplanting all plants in Soil B had died. Percentage survivals by species are illustrated in Fig.4. Death in *Eucalyptus camaldulensis* was most rapid, with all plants in Soil B dead by 7 days from transplanting. In this species 39 per cent of plants in Soil A died by day 7 but no more had died 22 days after plotting.

The rates of death for transplanted *A. aneura* and *A. craspedocarpa* seedlings in Soil B were similar, though total death was reached sooner in *A. aneura*. All *A. aneura* seedlings in Soil B had died by 16 days, and all *A. craspedocarpa* seedlings died by 22 days from transplanting. No plants of either species in Soil A had died by 22 days from transplanting.

b) *Effects of Waterlogging* Soil A

Additional seed of the three species was germinated in June and on July 17th sets of 15 well developed seedlings of about the same size within a species were transplanted into white yoghurt containers of 12 cm diameter, holding $\sim$680 g of Soil A. These plants were held for 14 days to become established in the containers during which only deionised distilled water was supplied. Thereafter the following three treatments were applied: a) control, watered with distilled deionised water sufficient to reach field capacity twice a week; b) waterlogging with distilled deionised water; c) waterlogging with saline solution. Both waterlogging treatments involved maintaining 0.5 cm of liquid above the soil surface. Similar quantities of water were added to each of the pots in a treatment.

The saline solution was obtained by taking 350 g of surface salt crusted soil from the site where Soil B was obtained, and passing fresh distilled and deionised water through it. Six lots of 4 ℓ were used, the first extract had a salinity level of 28.5 p.p.t., the final 0.5 p.p.t., with an overall mean level of 9 p.p.t. salinity.

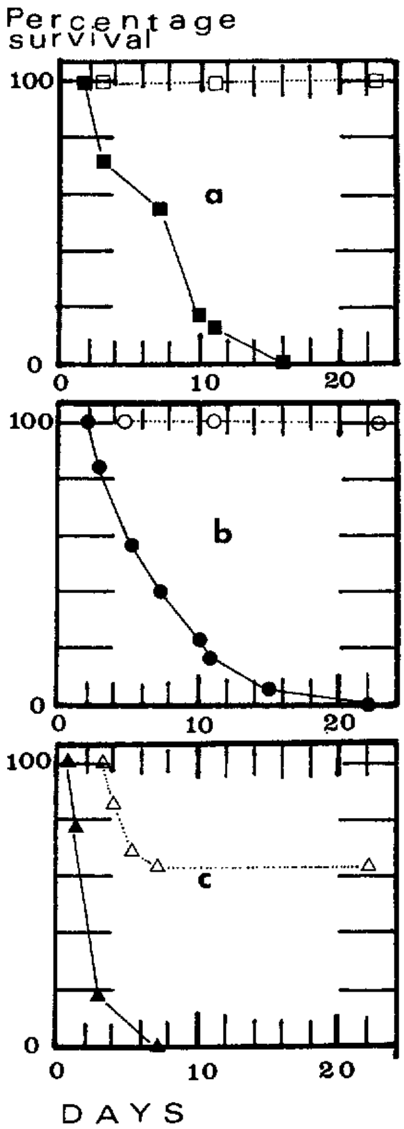

Figure 4 Percentage survivals a *Acacia aneura*, b *Acacia craspedocarpa*, c *Eucalyptus camaldulensis* planted into Soil A (open symbols) and Soil B (closed symbols).

Treatments commenced on August 1st and observations were continued for 80 days. Percentage survivals by species are illustrated in Fig.5. In *Acacia aneura* all plants were dead in the saline waterlogging treatment after 50 days. In waterlogging twenty per cent remained alive at 80 days, and seventy five per cent of the control plants also survived. Deaths in the saline treatment commenced after 23 days and took place over a 27 day period.

In *Acacia craspedocarpa* deaths in saline waterlogged conditions took longer to become evident than with *A.aneura*, with the losses commencing after 50 days. By 80 days only 20 per cent survived. In the waterlogging treatment some 60 per cent survived to 80 days compared with 80 per cent in control.

Early losses of *Eucalyptus camaldulensis* in the saline treatment followed the pattern for *Acacia aneura*, but 40 per cent survived beyond 55 days. The control treatment lost the same percentage of plants, with losses commencing at 55 days. There were no deaths in the non saline waterlogged conditions.

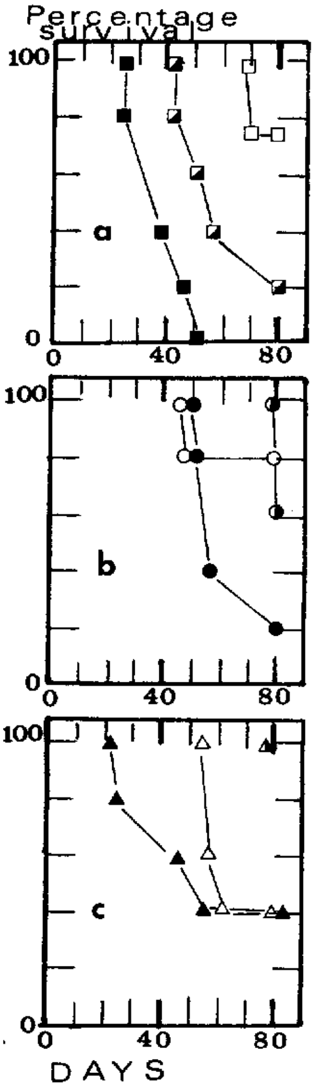

Figure 5 Percentage survivals a *Acacia aneura*, b *Acacia craspedocarpa*, c *Eucalyptus camaldulensis* in relation to water treatment. Open symbols - control watering with distilled, deionised water; closed symbols - waterlogging treatment with saline water; half symbols - waterlogging with distilled, deionised water.

Conclusions

Survival in *E.camaldulensis* was generally poorer than in the two *Acacia* species. This is to be expected in view of the much smaller seed weight of *E.camaldulensis*. In each case initial seedlings were smaller than the *Acacia* seedlings and transplant shock may be presumed to be of greater import. However the response to waterlogging suggests that *E.camaldulensis* has a much greater moisture requirement than the two *Acacia* species. Insufficient moisture in the comparative growth experiment may have led to premature leaf loss in *E.camaldulensis*. This species does however, have the greatest potential growth, as evidenced by dry weight increases.

Over the 200 day growing period *E.camaldulensis* was able to accumulate as much nitrogen as the *Acacia* species, and potassium and sodium to about the same extent as *A.craspedocarpa*, despite the presumable initial low seed levels available. The nutrient levels attained compare well with a broad range given for Australian conditions by Feller[1]. In an earlier competition trial *A.craspedocarpa* yielded 1.51 times as much dry matter production over 12 months as did *A.aneura* when grown in desert loam[2]. In the present study the ratio ranged from 1.29 at 79 days, 1.95 at 130 days, and 1.73 at 200 days. The mean ratio for all harvested plants was 1.73. Despite geographical differences between seed lots the implication is that *A.craspedocarpa* will consistently out-grow *A.aneura* in desert loam soils at the seedling to establishment stage.

Progressive increases in shoot/root ratio may be artefacts of the pot environment with the *Acacia* species. Both produce long roots rapidly and the constraints of the pot size may well restrict root growth when plants are kept in pots for some time. The fall in fresh/dry weight ratio over time must be associated with increasing woodiness of the plants as they age so that high moisture tissues become of a lower proportion of total plant mass. Decline in R.G.R. may have been associated with the method of plant selection for harvest in *A.craspedocarpa* and with premature leaf loss in *E.camaldulensis*.

Annual and other herbaceous plants showed no tolerance to the saline conditions of Soil B. Of the three woody perennials examined *A.aneura* appeared to show least tolerance to waterlogging and *E.camaldulensis* the most resistance. All three species showed little tolerance to waterlogging with saline conditions though *E.camaldulensis* showed most tolerance and *A.aneura* least.

Plant height in *E.camaldulensis*, and a combination of height and phyllode numbers in the two *Acacia* species, may be used to compare performance in future trials. However root dry weight may be of importance if waterlogging or saline conditions are suspected of retarding dry weight production.

Acknowledgements

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SPECIALISED ROOTS IN THE GENUS ACACIA: A REVIEW

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Introduction

With an estimated 1000 total species, *Acacia* is the largest legume genus and perhaps the largest among vascular plants. It is certainly the largest and most widespread genus in Australia, with an estimated 700 species[16]. It is becoming clear that *Acacia* only became prominent very late in the evolution of the Australian flora, as the continent became essentially drier, colder and the soils less fertile starting in the late Pliocene, about 5 million years ago [4,5]. Among the many features of *Acacia* that may account for its preferential speciation under a more stressful environmental regime is its root system. While *Acacia* seedlings rapidly establish a deep tap-root system, it is not as finely-divided nor as hairy as most other groups adapted to impoverished soils[19]. In fact, Barrow[2] found the ultimate roots of *Acacia pulchella* to be on average 280 μm wide (the other four species in the study were on average 180 μm) and lacking root hairs (the other four species had root hairs on average 550 μm long). It is the presence of specialised roots, those modified structures produced optionally on the root system[19], which give a clue to the adaptive advantages of this genus.

Root Nodules

It is usually assumed that nitrogen-fixing root nodules are universally present in *Acacia*. In fact, less than 200 species have been examined for nodules[1,3,6,8,12,19,20,25,29,30]. Of 167 species examined, potted seedlings of three species lacked nodules, but only one of these (*A. stenophylla*) is known from one inspection[3] not to possess them in the field. Their morphology is typical of that in other legumes, including sphaeroidal (annual) and coralloid (perennial) forms[3,20]. The microsymbiont is always the bacterium, *Rhizobium*, especially of the slow-growing Cowpea and Lupin-Soybean cross-inoculation groups[6,21,22].

Some *Acacia* species may have as few as three leaves when nodules are first observed on the root system[3]. Nodule production usually increases when field plants are fertilized[13,29], but a level is reached when their production drops, even though total plant growth may be higher[19]. In seasonal climates, their formation is seasonal and during extended droughts viable nodules may be absent from the root system of *Acacia* species altogether[3,13,20,23,25,27]. They tend to concentrate where new season's roots form: in the uppermost 15 cm of soil in moist soils but below 10 cm in dry soils[3,13] and they have been recorded at a depth of 100 cm in *A. aneura*.

During the last five years, 13 species of *Acacia* have been examined for their ability to fix atmospheric nitrogen, using the acetylene-reduction method (Table 1). The results show an overall range of 0.1-28.0 μm/g fresh wt/h, which is comparable with other legumes[19]. The rates of fixation clearly vary between species (e.g. [25]), age and preparation of nodules (e.g. *A. pulchella* and *A. holosericea*, Table 1) and nutrient status. Generally, nodules from fertilized plants fixed N_2 at a lower rate than the controls (Table 1). Monk et al.[27] found nodules on first season's plants showed highest rates throughout the life of *A. pulchella*. The calculated N_2-fixation accounted from 8% of plant N content in the first year up to 68% (ignoring that lost in litter fall) in the fourth year.

Table 1. Rates of nitrogen fixation (acetylene reduction) on a fresh weight (f.w.) basis by species of *Acacia*.

Species		C_2H_2 reduction (μM/g f.w./h)	References
A. cyclops		2.8	Haxen, 1978
A. ericoides		0.1-2.7	Lawrie, 1981
A. extensa	- fertiliser	1.7	Shea & Kitt, 1976
	+ fertiliser	0.6	Shea & Kitt, 1976
A. holosericea	tops intact	4.0	Langkamp et al., 1982
	tops detached	1.5	Langkamp et al., 1982
	field	0.8-28.0	Langkamp et al., 1982
A. longifolia		0.3- 4.7	Lawrie, 1981
A. mearnsii		0.1-11.9	Lawrie, 1981
A. melanoxylon		0.2- 6.8	Lawrie, 1981
A. myrtifolia	- fertiliser	2.0	Shea & Kitt, 1976
	+ fertiliser	1.7	Shea & Kitt, 1976
A. oxycedri		0.1- 6.4	Lawrie, 1981
A. paradoxa		0.2- 3.6	Lawrie, 1981
A. pulchella	- fertiliser	3.8	Shea & Kitt, 1976
	+ fertiliser	2.8	Shea & Kitt, 1976
	greenhouse	9.5-13.7	Monk et al., 1981
	sandplain	3.9-17.4	Monk et al., 1981
	- fertiliser	11.3	Hingston et al., 1982
	+ superphosphate	7.0	Hingston et al., 1982
A. saligna		1.0	Haxen, 1978
		4.0	Nakos, 1977
A. strigosa	- fertiliser	3.1	Shea & Kitt, 1976
	+ fertiliser	3.1	Shea & Kitt, 1976

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Table 2. Incidence of specialised roots in selected species of *Acacia*.

Species	Nodules	Mycorrhizas	Other	References
A. aulocarpa	–	+	0	Langkamp & Dalling, 1982
A. confusa	+	+	0	Asai, 1944
A. floribunda	+	+	0	Bowen, 1956; Khan, 1978
A. holosericea	+	+	0	Langkamp & Dalling, 1982; Langkamp et al., 1982
A. latescens	–	+	0	Langkamp & Dalling, 1982
A. mearnsii	+	+	0	Sward, 1978; Lawrie, 1981
A. melanoxylon	+	+	0	Sward, 1978; Lawrie, 1981
A. mucronata	+	+	Proteoid	Sward, 1978
A. myrtifolia	+	+	0	Bowen, 1956; Khan, 1978
A. oxycedrus	+	±	0	Sward, 1978; Lawrie, 1981
A. pulchella	+	+	0	Barrow, 1977; Monk et al., 1981
A. senegal	–	+	0	Diem et al., 1981
A. suaveolens	+	+	0	Khan, 1978
A. torulosa	–	+	0	Langkamp & Dalling, 1982
A. yirrkallensis	–	+	0	Langkamp & Dalling, 1982

+ = present
– = not mentioned, presumed present
± = present or absent
0 = not mentioned, presumed absent

Langkamp et al [24] considered 19% of N in three year old plants of *A. holosericea* could be attributed to N_2-fixation. The conversion rates between C_2H_2 and N_2 are somewhat arbitrary and should be treated with some caution. These authors and Hingston et al [13] and Lawrie[25] also showed severe reduction in N_2-fixation rates during extended droughts in the field, as well as providing figures on number of nodules per plant. Nakos[28] demonstrated considerable reduction in N_2-fixation after withholding water from *A. saligna*. *A. ericoides* has a temperature optimum of 20-35°C for N_2-fixation and a diurnal maximum rate in the early afternoon[25]. Mature stands of *Acacia* species (exceeding 500 plants/ha) have been estimated to contribute from 0.04 to 15 kg N/ha/yr[13,19,24,25,27]. In infertile soils, there can thus be little doubt that Acacias play an important part in raising soil N.

Mycorrhizas

Of 15 *Acacia* species examined, all have been found to possess mycorrhizas (Table 2). These are all of the vesicular-arbuscular (internal hyphae) type[19], though there is one record of ectomycorrhizas (external hyphae) in an unidentified *Acacia*[15] that requires confirmation. Khan[17] found, of 26 species colonizing coal spoils, that the three *Acacia* species had the highest incidence of mycorrhizas (59-88% of the root system). Langkamp and Dalling[23] recorded six species with vesicular-arbuscular mycorrhizas in open forest, although 11 non-*Acacia* species (including five other legumes) had a greater intensity of infection. Although the number of *Acacia* species examined is small, they are from widely-disparate geographical locations and, like nodules, they will probably be shown eventually to be regular componenets of the root system. Only Langkamp and Dalling[23] have attempted to identify the micro-symbionts (three species of *Gigaspora*). Non-mycorrhizal *A. holosericea* seedlings responded to phosphate fertiliser and Langkamp and Dalling[23] consider mycorrhizas could substitute for P application through their well-known ability to enhance P uptake[19]. However, direct evidence for *Acacia* is still wanting.

Other Specialised Roots

Sward[30] recorded proteoid root-like structures, bunches of densely-packed rootlets, on seedlings of *Acacia mucronata*. This makes it the third legume that appears to form proteoid roots[18,31]. It has been argued that, functionally, proteoid roots substitute for vesicular-arbuscular mycorrhizas[19] as the latter legumes are non-(*Viminaria juncea*) or poorly-(*Lupinus*) mycorrhizal. However, *A. mucronata* may also possess mycorrhizas (Table 2) so it would be of interest to know if the two structures occur simultaneously on the one root system; if so, whether the proteoid roots provide an additional advantage, such as capillary capture of water and nutrients[19].

Summary

The genus *Acacia* appears to share with a number of other legumes, an 'unbeatable' combination of specialised roots for giving the group a competitive advantage: nodules for maximizing N uptake and mycorrhizas for maximizing P uptake. Proteoid roots are of rare occurrence and their significance has yet to be assessed.

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RESPONSE TO FERTILISER TREATMENT BY SEEDLINGS OF SANDALWOOD, *Santalum spicatum* (R.Br.) DC.

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Introduction

The current investigation into the germination and establishment of the Australian sandalwood,[1] *Santalum spicatum* (R.Br.) DC. was commenced in October 1980.

This paper is a report on the effects of several different types of commercial fertilisers added to sandalwood seedlings in pots. It has been suggested that a seedling needs to attach to suitable host roots within 12 months of germination for continued healthy growth. The addition of fertiliser may be advantageous in prolonging the time a potted seedling can survive without a host. Fertilisers may also promote the development of a healthier seedling that could become established more quickly when planted in the field.

Materials and Methods

Seed collected from Leinster Downs was shelled and an incision (5-8 mm in length) made in the hard endocarp by means of a band saw. The seeds were then dusted with a fungicide powder, Thiram, and placed between hessian bags, that had been soaked in 5% benlate, on a bench under an overhead sprinkler system in a glasshouse. Once germinated, the seeds were planted in 12.5 cm diameter black plastic, horticultural pots filled with a 3:1 mixture of sand and peat. Thirty (30) seedlings were set up under each of the following conditions:

Experiment number	Fertiliser treatment*
B1	no addition
B2	osmocote** (9 month pellets)
B3	superphosphate with Cu,Zn,Mo
B4	superphosphate
B5	agran (37% nitrogen)
B6	blood and bone
B7	hoof and horn

* All fertilisers were added at the rate of 50 kg ha^{-1}.

** Osmocote contained 18% nitrogen; 2.6% phosphorus, 10% potassium and 4% sulphur.

Plants were grown in a glasshouse with an overhead sprinkler system. Measurements of shoot height; leaf length and leaf number were taken over a period of 240 days. Five to ten representative plants from each condition, were harvested at 120 days and 240 days. For these plants, leaf area was measured and fresh weights and dry weights of roots and shoots were taken. Roots and shoots were analysed separately for nitrogen, phosphorus and potassium content. Total nitrogen content was determined using the Kjeldahl method (Tecator).[3] Phosphorus content was determined using the ammonium molybdate and stannous chloride method.[4] Potassium content was determined using a flame photometer.

TABLE 1 Summary of 120 day harvest measurements

Harvest values* (per plant)	Fertiliser treatment						
	B_1	B_2	B_3	B_4	B_5	B_6	B_7
Shoot height (cm.)	13.5	12.1	13.6	9.6	8.7	11.2	12.4
Height increment (cm.)	10.8	9.5	11.2	6.8	6.4	8.6	10.1
Fresh weight (g)	2.72	2.76	1.78	1.13	1.18	2.12	2.65
Dry weight (g)	0.58	0.71	0.47	0.28	0.32	0.59	0.71
Dry shoot weight (g)	0.38	0.54	0.35	0.21	0.24	0.45	0.54
Dry root weight (g)	0.20	0.17	0.12	0.07	0.08	0.14	0.17
Fresh/dry weight ratio	4.7	3.9	3.8	4.0	3.7	3.6	3.7
Dry shoot/root weight ratio	1.9	3.2	2.9	3.0	3.0	3.2	3.2
Leaf area (cm^2)	39.1	53.6	53.2	20.3	33.0	44.2	74.0

* Values are the mean of 5 to 10 individual plants.

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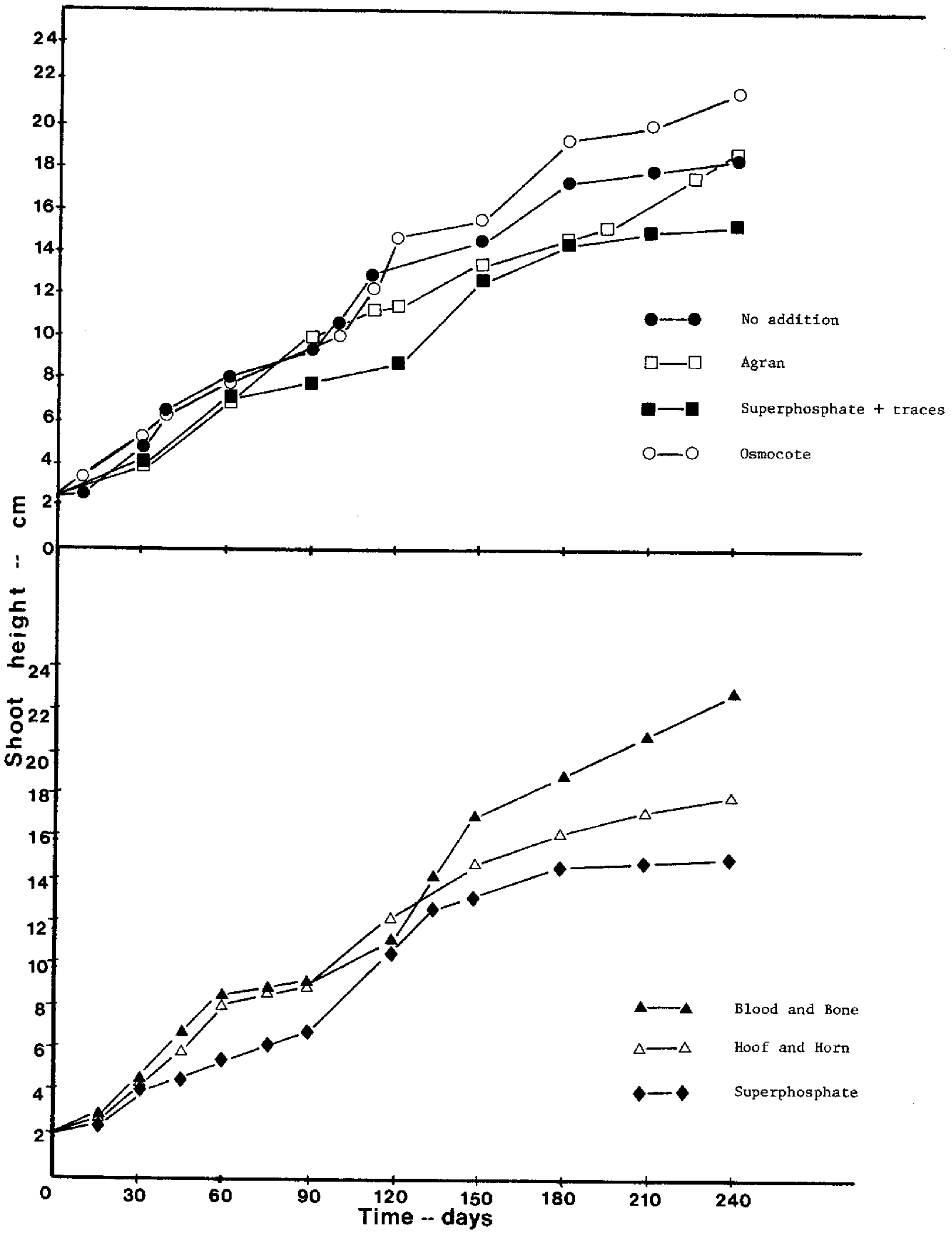

Figure 1. Response of shoot height to fertiliser treatment over a period of 240 days.

TABLE 2 Summary of 240 day harvest measurements

Harvest values* (per plant)	Fertiliser treatment						
	B_1	B_2	B_3	B_4	B_5	B_6	B_7
Shoot height (cm.)	18.4	21.7	15.5	15.7	18.6	23.2	18.2
Height increment (cm.) from day 0	15.7	19.1	13.1	12.9	16.3	20.6	15.9
Height increment (cm.) from day 120	4.9	9.6	1.9	6.1	9.9	12.0	5.8
Fresh weight (g)	3.06	7.47	1.78	3.04	3.85	7.42	7.52
Dry weight (g)	0.81	1.86	0.40	0.83	1.00	1.99	1.79
Dry shoot weight (g)	0.57	1.33	0.33	0.68	0.80	1.52	1.45
Dry root weight (g)	0.24	0.53	0.07	0.15	0.20	0.47	0.34
Fresh/dry weight ratio	3.8	4.0	4.5	3.7	3.9	3.7	4.2
Dry shoot/root weight ratio	2.4	2.5	4.7	4.5	4.0	3.2	4.3
Leaf area (cm^2)	57.6	138.1	36.1	70.4	68.8	176.3	162.2

* Values are the mean of 5 to 10 individual plants.

Results

The seedlings were seven (7) and eleven (11) months old when harvested and had four (4) or eight (8) months growing in fertilised soil mixture. Summaries for mean values of plants harvested at 120 and 240 days are given in Tables 1 and 2. The parameters include final plant mean height for all remaining seedlings and the mean height increment over 120 days or 240 days. For the harvested plants, the mean fresh weight and dry weight of the whole plant; dry shoot and root weights separately and mean leaf areas are given. Also, values are given for the fresh/dry weight ratio and the dry shoot/root ratio.

Figure 1 shows the change in shoot height as a response to the different fertiliser treatments over a period of 240 days.

The total nitrogen, potassium and phosphorus contents of the sandalwood seedlings, after harvesting at 120 days and 240 days, are shown in Table 3.

Discussion

The results shown in Table 1 and Figure 1 indicate that the growth of the sandalwood seedlings was similar under most of the fertiliser treatments, up to a period of 120 days. However, the total dry weight results show a 22 per cent increase in the presence of osmocote or hoof and horn; no difference with blood and bone but a 23 per cent to 51 per cent decrease in the presence of the other fertilisers. In all treatments, except the control, the dry weight of shoot material was approximately three times greater than the dry weight of root material.

At the 240 days harvest, the patterns of growth of the sandalwood seedlings had changed in the following ways. The total dry weight of the seedlings was 129 per cent greater than the control for plants treated with osmocote, hoof and horn or blood and bone, and 23 per cent greater when treated with agran. There was no difference in dry weight between control seedlings and those treated with superphosphate but a 50 per cent decrease in those treatment with superphosphate plus trace elements. With both kinds of superphosphate, agran or hoof and horn, the dry weight of the shoots was four times greater than the dry weight of the roots. The shoot dry weight was three times the root dry weight with hoof and horn but twice the weight with osmocote.

In general, the plants growing in superphosphate, with or without trace elements, were smaller with less leaves and less abundant root growth than any of the other plants. This indicates that superphosphate is not a suitable fertiliser to use with sandalwood seedlings.

Seedlings treated with agran were initially repressed but showed a gradual improvement over the 240 days. Agran is a quick release nitrogen fertiliser. This quick release of nitrogen was not beneficial to the young (60 days old) seedlings but may have promoted growth in the older (120-240 days old) seedlings.

All seedlings treated with fertiliser had higher amounts of nitrogen, phosphorus and potassium (expressed as a percentage of total dry weight) than the controls. The levels of phosphorus and potassium were fairly constant from 120 to 240 days but the

TABLE 3 Total nitrogen, potassium and phosphorus content of sandalwood seedlings at 120 days and 240 days.

Fertiliser treatment	% Nitrogen		% Phosphorus		% Potassium	
	120	240	120	240	120	240
B_1	2.34	1.30	0.041	0.049	0.017	0.016
B_2	4.42	3.29	0.039	0.056	0.023	0.030
B_3	3.14	2.48	0.062	0.082	0.031	0.035
B_4	2.94	1.64	0.099	0.114	0.026	0.028
B_5	3.82	2.51	0.068	0.075	0.025	0.030
B_6	2.58	1.46	0.044	0.051	0.021	0.027
B_7	3.02	2.90	0.045	0.051	0.020	0.025

levels of nitrogen decreased over the same time period. Phosphorus promotes root growth but this did not occur with the sandalwood seedlings. Nitrogen promotes shoot growth and an increase in leaf numbers, and this is shown by the higher shoot weights for plants treated with hoof and horn; blood and bone or osmocote. More definitive work needs to be carried out on the nutrient status of sandalwood seedlings supplied with different fertilisers.

As the continued growth of sandalwood seedlings eventually depends on an attachment to a suitable host, the production of roots would be more advantageous than the production of numerous shoots and leaves. Thus, the use of the slow-release fertiliser, osmocote, applied at the rate of 50 kg, ha^{-1} was the most beneficial of the fertilisers used in this series of experiments. Hirano[2] reported the effects of osmocote on the growth of *Santalum album; S. haleakalae* and *S. paniculatum* seedlings over a period of 18 months. He concluded that the addition of chelated iron was essential for continued healthy growth. Yellowing leaves and a general decline in health were alleviated by the addition of chelated iron. Up to the time of this report, *Santalum spicatum* seedlings, treated with osmocote, are 15 months old and showing none of the symptoms described by Hirano.

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PLANT SPECIES SUCCESSFULLY RECOLONISING REHABILITATED BAUXITE MINES

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Introduction

Information on plant species colonising mined areas is important in relation to investigations aimed at ensuring the continuing survival of revegetated sites to the stage of self regeneration.[7] In the present account we give details of colonising plants recorded in mined sites in relation to an exercise mainly concerned with ant recolonisation and reported elsewhere.[4]

Early attempts at revegetating bauxite pits have been detailed in several recent papers.[6,7]

More recent work seeks to incorporate a greater variety of species in early growth following mining by careful handling of topsoil.[1,6,8]

This report is concerned with two bauxite mining areas, Jarrahdale and Del Park worked by Alcoa of Australia. Both are jarrah (*Eucalyptus marginata*) forest localities in Western Australia approximately 45 km and 90 km SSE of Perth respectively.

The range of tree species which may be used for rehabilitating mined areas is restricted by the presence of the pathogenic fungus, *Phytophthora cinnamomi*. *P. cinnamomi* is the causal agent of jarrah dieback disease and is widely distributed in both mining areas.

The earliest forms of rehabilitation (Jarrahdale, 1966), were not ripped and often the top soil was not replaced evenly. Nursery reared, *P. cinnamomi* resistant trees, such as *Pinus pinaster*, *Eucalyptus maculata* and *Eucalyptus saligna* were planted as monocultures in rows and fertilizers were applied.

Later on rehabilitation involved battering down pit faces, general landscaping, more attention to top soil return, and deep ripping. Recently attention has been paid to the restoration of understorey vegetation. Research has shown that the majority of seed is in the top 2 cm of forest soil.[1,2,5,6,8] Currently direct seeding[1] and double stripping[8] are now employed together to restore the understorey vegetation and at least five tree species are selected for each pit.[4] This contrasts with the usual single species used earlier.[1] Trees are planted along contours and fertilizer is spread over the pit to aid understorey development.

Table 1 Plot number, main species, year, location and method of revegetation used.

Plot No.	Main Species	Year	Location	Method
1.	*Pinuspinaster*	1966	J	P
2.	*Pinus pinaster*	1970	J	P
3.	*Eucalyptus maculata*	1966	J	P
4.	*Eucalyptus maculata*	1970	J	P
5.	*Eucalyptus maculata*	1971	J	P
6.	*Eucalyptus maculata*	1976	D	P
7.	*Eucalyptus saligna*	1966	J	P
8.	*Eucalyptus saligna*	1969	J	P
9.	*Eucalyptus wandoo*	1969	J	P
10.	*Eucalyptus resinifera*	1970	J	P
11.	*Eucalyptus resinifera*	1973	J	P
12.	*Eucalyptus resinifera*	1974	J	P
13.	*Eucalyptus resinifera*	1974	D	P
14.	*Eucalyptus globulus*	1969	J	P
15.	*Eucalyptus calophylla*	1973	D	P
16.	*Eucalyptus calophylla*	1975	J	P
17.	Mixed *Pinus* spp.	1969	J	P
18.	Mixed *Eucalyptus* spp.	1970	J	P
19.	*Pinus pinaster*	1969	J	P
20.	*E.calophylla + Eresinifera*	1976	J	S
21.	*Trifolium subterraneum*	1976	J	S
22.	*E.calophylla + E.wandoo*	1977	J	P
23.	*E.calophylla*	1975	J	P
24.	Mixed *Eucalyptus* spp.	1976	D	P
25.	*Eucalyptus meullerana*	1968	J	P
26.	Nil	1978	D	-
27.	*Eucalyptus globulus*	1969	J	P
28.	*Eucalyptus resinifera*	1973	D	P
32.	*Eucalyptus resinifera*	1973	J	P
33.	Mixed *Eucalyptus* spp.	1973	J	P

Location J - Jarrahdale, D - Del Park
Method P - Planted, S - Seeded
Plots 29, 30, 31 were Forest Controls

The following variations were included in these plots:

Plot 19 : area cleared but not mined, so revegetation occurred on original soil.
Plot 20 : a considerable diversity of understorey vegetation induced by use of a variety of seeds.
Plot 21 : appeared pasture-like.
Plot 22 : was mulched with bituminised straw.
Plot 23 : incorporated double stripped topsoil.
Plot 27 : fresh topsoil used.
Plot 26 : no plant species recorded.

Method of sampling

For the survey twenty-three rehabilitated plots and two forest controls were selected at Jarrahdale, and seven mined plots and one control at Del Park.[4] Most of the mined plots had been ripped, topsoil returned, and planted at different times with either *P.pinaster* or a range of *Eucalyptus* species (Table 1).

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Table 2 Species recorded in plots

(*not found in mined plots, only in forest control).

Acacia browniana
A.extensa
A.horridula
A.pulchella
A.saligna
A.urophylla
Adenanthos barbigerus
*Agrostocrinum scabrum**
Aira caryophyllea
Albizia lophantha
Astroloma ciliatum
Banksia grandis
Boronia spathulata
Bossiaea aquifolium
Bossiaea ornata
Briza maxima
B.minor
Casuarina fraserana
Centaurium spicatum
*Clematis pubescens**
*Comesperma virgatum**
*Conostylis serrulata**
Conostylis setosa
Cyathochaete avenacea
Danthonia setacea
Daviesia pectinata
Daviesia pressii
*Dryandra nivea**
Dryandra sessilis
Eucalyptus calophylla
E.marginata
E.muellerana+
E.resinifera+
Gompholobium knightianum
G.marginatum
G.preissii
Gnaphalium candidissimum
Grevillea wilsonii
*Hakea amplexicaulis**
Helipterum cotula
Hibbertia amplexicaulis
Hibbertia montana
Hovea chorizemifolia
*Hovea trisperma**
*Hypochoeris radicata**
Isotoma hypocrateriformis
Kennedia coccinea
Lasiopetalum floribundum
*Lechenaultia biloba**
Lepidosperma angustatum
*L.gracile**
L.tenue
Leucopogon capitellatus
L.oxycedrus
*Lomandra caespitosa**
*L.endlicheri**
L.hermaphrodita
*L.micrantha**
*L.preissii**
L.purpurea
L.sonderi
*Loxocarya flexuosa**
Macrozamia riedleii
Mirbelia dilatata
Neurachne alopecuroides
Opercularia echinocephala
Orobanche australiana
Oxylobium lanceolatum
*Patersonia sericea**
Persoonia longifolia
Phyllanthus calycinus
Pinus halepensis+
Pinus pinaster+
Platysace compressa
Platysace tenuissima
Podolepis gracilis
*Pteridium esculentum**
Scaevola pilosa
S.striata
Solanum nigrum
Sollya heterophylla
Stylidium amoenum
S.hispidum
Tetrarrhena laevis
Tetratheca viminea
Thysanotus dichotomus
Thysanotus multiflorus
Trachymene pilosa
Trymalium ledifolium
Waitzia paniculata
*Xanthorrhoea gracilis**
X.preissii
Xanthosia candida
X.heugelii
X.peltigera

\+ *E.muellerana* only in Plot 25
E.resinifera only in Plot 20
P.halepensis only in Plot 17
P.pinaster in Plots 1,2.

All field work was performed between December 1978 and February 1979. Each plot was halved and a 100 metre transect was marked out in each half. Only one transect was established in plot 33.

At 10 metre intervals along each transect, 1 metre square quadrats were established. Within each quadrat the number of individuals for each species was recorded. The plant species lists for each transect were summed by numbers of plants and tabulated for the plot sets. Table 2 lists 95 plant species identified. A further 24 were not identified to species, of which 3 did not occur in mined sites. Of the species listed 18 were not represented in mined plots and 4 were exotic tree species seedlings (see footnote to Table 2).

Some 64 species were recorded in the forest controls with 45 in plot 29, 29 in plot 30 and 26 in plot 31 or a mean for the three of 33 species. Plot 7, one of the oldest examined of the mined sites had the highest number of species recorded at 29, twelve years from planting (Fig.1). There was a trend of increased number of species with time from treatment. For example *Eucalyptus maculata* plots, numbers 6,5,4, and 3 had 11,17,14 and 22 species recorded respectively. The seeded plot, number 20 with 18 species at two years from treatment, and the double-stripped sample (number 23) with 24 species at 3 years, gave better species counts than others of the same age.

As techniques differed for the different sites no further consideration is given here to the development of species diversity as between plots in relation to time.

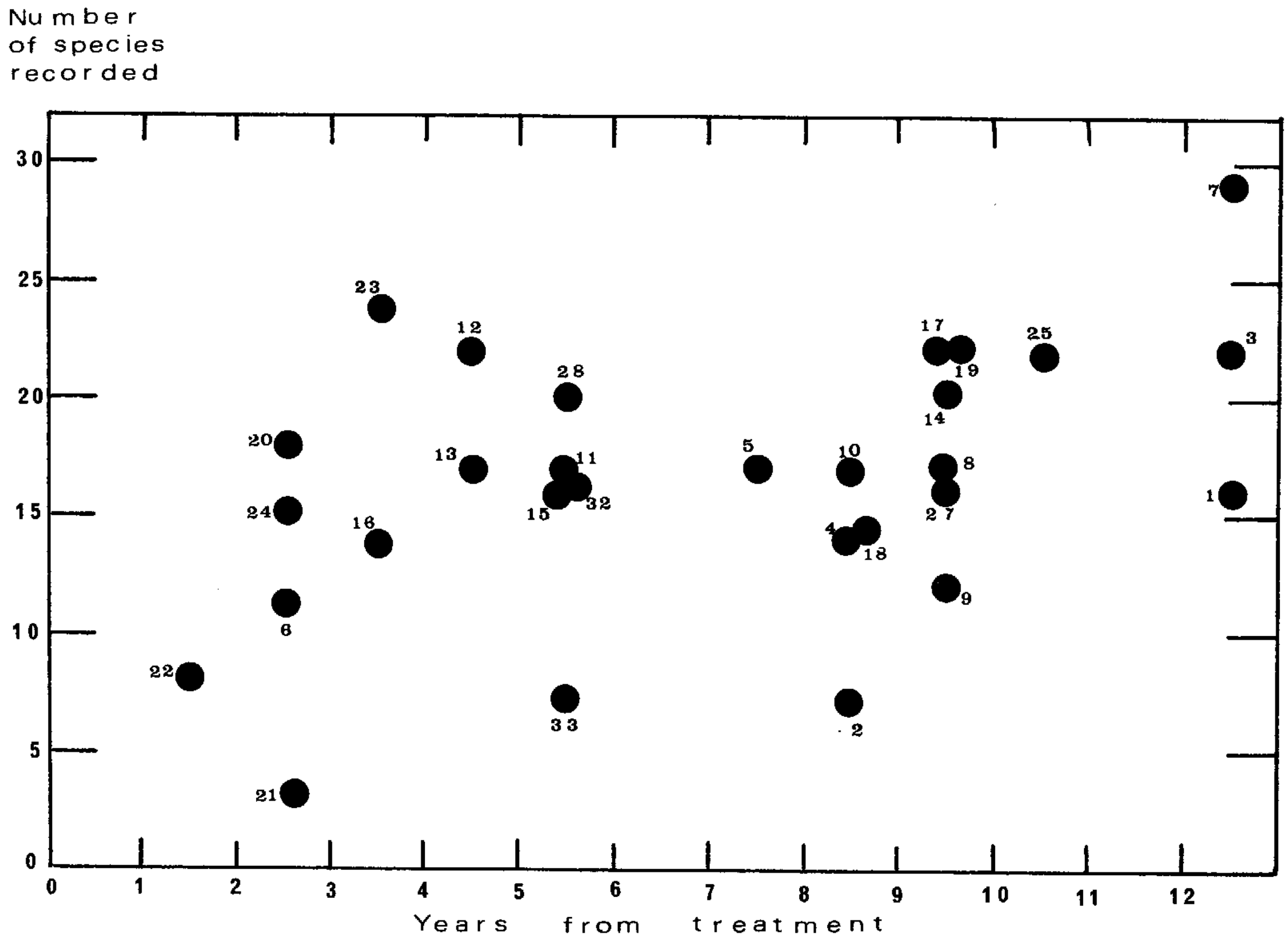

Figure 1 Numbers of species recorded for each site plotted against years from post-mining rehabilitation treatment. (Numbers as in Table 1).

Species frequencies and colonisation status

Firstly we consider the abundance of species in the forest control plots. The 10 most abundant species are listed in Table 3.

Table 3 Most abundant species in Forest Plots

Species	Numbers Present Plots 29,30,31	Mined Plots
* *Lomandra hermaphrodita*	156	5
* *Lepidosperma tenue*	141	90
* *Lomandra sonderi*	136	7
* *Cyathochaete avenacea*	105	9
Loxocarya flexuosa	94	-
* *Conostylis setosa*	82	143
* *Lasiopetalum floribundum*	66	118
Lomandra micrantha	52	-
* *Hibbertia montana*	50	31
Trymalium ledifolium	47	304

* Present in all 3 forest plots

The majority of these 10 species are grass-like of the ground cover. Those species marked with an asterisk were the most 'frequent' being present in all 3 plots. If plot frequency only is considered then the other three species would be replaced by *Xanthosia peltigera*, *Eucalyptus marginata* and *Hibbertia amplexicaulis* with 42, 33 and 26 individuals respectively on the forest plots and 4, 9 and 19 in the mined plots.

E.marginata is the dominant species of the unmined forest, giving its name (Jarrah) to the formation. In the mined plots it was only represented in 2 of the 30 sites. Only *Trymalium ledifolium* (23 sites) *Conostylis setosa* (19 sites), *Lasiopetalum floribundum* (19 sites) and *Hibbertia amplexicaulis* (12 sites) can be considered as reasonably abundant in both forest and mine sites. The fact that *T. ledifolium* was present in only two of the three forest sites is of some interest.

A total of 15 species is listed in Table 4. The first 10 were the most abundant, with highest numbers of individual plants recorded in the mined plots. Of these, three species of Asteraceae (daisies) viz *Helipterum cotula*, *Gnaphalium candidissimum*, and *Waitzia paniculata*, were present in nine or fewer plots. Together with the exotic grass *Aira caryophyllea* they were not represented in the forest controls. These four annuals contribute little cover and cannot be considered as important species in terms of biomass. *A.caryophyllea* and *G.candidissimum* showed greater abundance sooner following post-mining rehabilitation than the other two (see Fig.2). Numbers of *A.caryophyllea* showed a tendency to decline with time from treatment, suggesting that it behaves as a seral species in relation to shade.

The only other species listed in Table 4 and not represented in the forest controls was the legume *Mirbelia dilatata*. It is a woody shrub of the understorey in the Jarrah forest. It is particularly abundant in more open areas. It has 455 seeds g^{-1}[1] with 74 per cent germination after 63 days[5]. This species was most abundant in plot 11, perhaps a fortuitous event of little significance. We now consider the more important species recorded after mining.

Brief notes on the species of greatest abundance are given below.

Trymalium ledifolium in the family Rhamnaceae must be considered the most important coloniser. It was present in more mined plots than the other species of perennial, it was more abundant, and was of greater size than most of the species of Table 4. It is a well known fireweed shrub growing to about 1 m, and producing abundant seed. It is self pollinating. Seeds will germinate within 38 days[3] and there is evidence that ants assist in seed dispersal. This species was found in all of the plots >8 year from treatment ex-

Table 4 Most abundant species in Mined Plots, with most frequent species also considered.

	Mined Plots		Forest Control	
	Plot frequency	Total number of plants	Plot frequency	Total number of plants
Most abundant species				
*Helipterum cotula**	6	1713	-	-
Aira caryophyllea	14	877	-	-
*Gnaphalium candidissimum**	3	480	-	-
Trymalium ledifolium	23	304	2	47
Stylidium hispidum	16	265	2	15
*Waitzia paniculata**	9	245	-	-
Conostylis setosa	19	143	3	82
Boronia spathulata	19	125	2	20
Lasiopetalum floribundum	19	118	3	66
Opercularia echinocephala	20	104	1	3
Other species in >8 mined plots				
Xanthosia candida	18	56	1	8
Bossiaea ornata	14	58	2	3
Hibbertia amplexicaulis	12	19	3	26
Mirbelia dilatata	12	51	-	-
Platysace compressa	10	77	2	39

* These species drop out of the top ten if frequency is considered most important

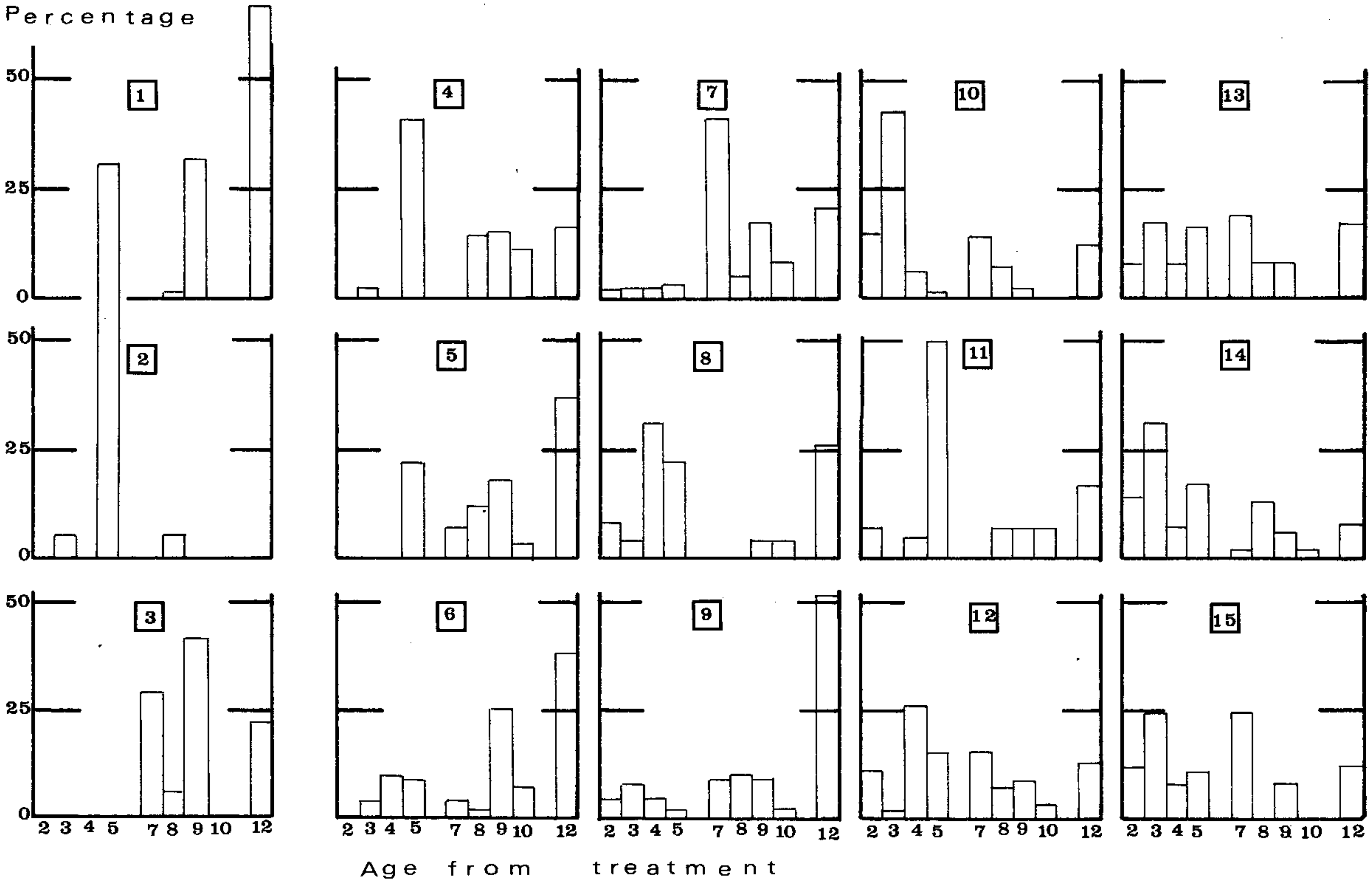

Figure 2 Percentage representation of 15 abundant species by age from post-mining treatment. (Calculated by summation of mean numbers per plot by one year age groups, using only those plots in a set for which the species was recorded). 1 *Helipterum cotula*, 2 *Gnaphalium candidissimum*, 3 *Waitzia paniculata*, 4 *Aira caryophyllea*, 5 *Stylidium hispidum*, 6 *Boronia spathulata*, 7 *Conostylis setosa*, 8 *Bossiaea ornata*, 9 *Lasiopetalum floribundum*, 10 *Platysace compressa*, 11 *Mirbelia dilatata*, 12 *Trymalium ledifolium*, 13 *Xanthosia candida*, 14 *Opercularia echinocephala*, 15 *Hibbertia amplexicaulis*.

cept for the 1970 *Pinus pinaster* plantation (plot 2) which had very few species recorded (Fig.1). It was particularly abundant with the older *E.saligna* (plot 7) and in the *E.resinifera* plots at Del Park (plots 13, 28). It was also frequent in the cleared but unmined sample (plot 19). Of the more recent plots it was not recorded in plot 22 but was well represented in plots 6 and 24, treated two years earlier. The plant will persist upto 10 years. *T.ledifolium* is killed by fire.

Stylidium hispidum is a rosette-form trigger plant (Stylidiaceae) with a flowering stalk to about 30 cm. Apart from the seeded plot 20 where one individual was recorded, it was not recorded from plots where treatment was more recent than 5 years before sampling. It was most abundant in the 1966 plots (1, 3 and 7). The species produces abundant seed and germination takes 51 days.[3] *S.hispidum* must be considered a late coloniser in comparison with *T.ledifolium*. Greatest density occurred in the unmined plot (19). It is a perennial herb, persisting for five years or more.

Conostylis setosa is a low clump-form perennial of rhizomatous stock in the family Haemodoraceae, growing to about 30 cm. Unlike the previous species discussed it is somewhat fire resistant and will sprout after burning. Seed will germinate in 45 days.[3] This species was more abundant on sites >7 years from treatment though it was present in six of the twelve plots sampled at 2.5 to 5.5 years from post-mining treatment. It was most frequently recorded in the unmined site (plot 19).

Boronia spathulata is a low perennial shrub which tends to favour moister sites. It is a member of the Rutaceae and produces few comparatively large seed. *B.spathulata* was most frequent on sites >9 years from treatment where 96 were recorded from 8 sites, compared with sites >3 years and <9 years in which 31 plants were recorded from 11 sites. Of the more recently treated sites it was most abundant in plots 15 and 13 both at Del Park. It was present in the unmined site and absent from areas less than 3 years from treatment.

Lasiopetalum floribundum was present throughout, in greatest abundance in plots 1 and 3. This species is a member of the family Sterculiaceae. It is a soft, hairy, undershrub which may grow quite fast. Seeds germinate in 51 days[3], but viable seed production is low. The limited evidence suggests that it increases in importance with time from disturbance-of the abundant species it was second in frequency to *Conostylis setosa* in the forest controls (Table 4).

Opercularia echinocephala in the Rubiaceae is a herbaceous perennial of low stature. It produces abundant seed which probably germinates readily. It is self pollinated. It was recorded over the range of times from treatment following mining, but tended to be most abundant in the past five years (Fig.2). This species may be considered an early pioneer, it was scarce in the undisturbed forest controls (Table 4) and was not recorded from plot 19.

Xanthosia candida is another herbaceous species which persists for several years. It is a member of the family Apiaceae and species in this genus have a comparatively lengthy germination period of about 90 days[3]. It produces a lot of seed. It was equally distributed over the range of sites examined following mining, though not well represented in the forest controls.

Bossiaea ornata and *M.dilatata* are the only legumes (Fabaceae) noted in Table 4. *B.ornata* produces abundant seed, with 450 g^{-1}[1]. It is a fireweed species, with seed stimulated by fire. The seed are taken by ants. Germination will occur within 28 days[3]. *B.ornata* is a low shrub to about 70 cm tall. It was well represented in the older plots, but in the plots more recently treated it was much commoner at Del Park than at Jarrahdale. It was particularly common with Eucalyptus resinifera (plots 13 and 28).

Hibbertia amplexicaulis is a low scarcely erect sub-shrub of the Dilleniaceae. It was nowhere as abundant in mined plots as in the forest controls. There was no discernable pattern of frequency in relation to time from treatment. This species produces few seed, and the germination is long at 56 days,[3] regeneration is lignotuberous following fire. *H.montana*, a frequent species of the unmined forest (Table 3), was present in 8 mined plots with a total of 31 records, 13 from plot 23.

Platysace compressa is another small plant of the family Apiaceae. There was a tendency for this plant to be more frequent in the earlier years (Fig.2). However the distribution of numbers was skewed with 36 per cent of all recorded individuals in plot 23. It was also well repsented in the seeded plot 20.

Of the species so far described none are of the Proteaceae. Five species of this family were recorded in mined plots. Of these *Adenanthos barbigerus* was most frequent, present in seven plots, and *Dryandra sessilis* most numerous with all individuals recorded in the unmined site, plot 19. The latter species is a fast growing pioneer on cleared gravel pit sites within the jarrah forest, and is often abundant following fire. It sets prolific seed but does not regenerate from root stock, growing as a tall single stemmed shrub to 5 m. *A.barbigerus* is a low shrub <1 m which readily re-grows from lignotuber material after fire, probably producing less seed. This species was most numerous in areas treated >9 years earlier. *Persoonia longifolia*, a small tree of the understorey, was present in four plots. *Banksia grandis* a larger understorey species was present in plots 7 and 19 only and *Grevillea wilsonii* a sprawling low shrub <2 m was only recorded from plot 19.

By contrast leguminous species were well represented in the samples. In addition to *Bossiaea ornata* and *Mirbelia delatata* (Table 4) six species of *Acacia*, two of *Daviesia*, two *Gompholobium* species, another *Bossiaea* and one species each of *Hovea*, *Kennedia*, *Oxylobium* and *Albizia lophantha* were recorded. A number of these species show high germination rates after the seed is heated[5] and all are prolific seeders. Of the more frequently recorded *Acacia* species *A.urophylla* was most frequent in sites >9 years from treatment. This species is a low (to 2-3 m) undershrub able to tolerate shade. *A.pulchella* (170 seeds g^{-1}) and *A.extensa* (80 seeds g^{-1}) are pioneers, prolific after fire[5], but tend to die out as shade develops. These were recorded on 7 and 8 plots respectively, mainly <5 years from post-mining treatment at much greater density than *A.urophylla*. *Kennedia coccinea*, a twiner, was present at 8 sites, all <6 years from treatment.

Other species of interest include *Phyllanthus calycinus* a small perennial shrub of the Euphorbiaceae which sets abundant seed and is often seen as a pioneer. This was present at 8 sites >4 and <10 years from treatment. The understorey tree *Casuarina fraserana* was scarce, with single recordings only in plots 7, 19 and 28,

Discussion

The present account must be considered of a preliminary nature. However some areas of interest may be noted in relation to forest development and future studies.

The use of mixed eucalypts as against pure plantings[1] is now preferred[4]. The limited data available from the present study do not allow a rigorous analysis of how mixtures may affect species diversity. We note that amongst the earlier plantings plot 18 was a mixed planting. This had a mean of 14 species recorded compared with 7, 14 and 17 (mean 13) from plots 2, 4 and 10 treated at the same time. At five years from treatment plot 33 had only 7 species compared with 17, 16, 20 and 16 in plots 11, 15, 28 and 32. The major and irregular contributions to numbers of individual plants recorded, from the annual grass *Aira caryophyllea* and the three common daisies, suggest that these should be discounted in examining biomass development of shrub or understorey layers.

Of equal interest is a consideration of balance between the low herbaceous layer and the shrub component. Excluding *Trymalium ledifolium, Hibbertia montana, Lasiopetalum floribundum* and *Conostylis setosa* from the list given in Table 3, we find the remainder are monocotyledons.

Two of the six species were entirely unrecorded from mined sites (viz *Loxocarya flexuosa* and *Lomandra micrantha*). The other four were found only on 3 to 5 sites, generally in low numbers apart from *Lepidosperma tenue* in the unmined cleared plot (19) and in plot 7 one of the older set of treated areas. Plot 19 accounted for 70 per cent of the records of this group of species, and 80 per cent of the records were due to *L.tenue* in plots 7 and 19. Ninety per cent of all occurrences of the group were in plots treated nine or more years prior to sampling. No combination of treatments post-mining has resulted in regeneration of numbers of these species so abundant in the low herbaceous layer of the jarrah forest.

The presence and abundance of a number of species (particularly legumes; *Trymalium ledifolium* and *Phyllanthus calycinus*), often referred to as fire-weeds, indicate that these species readily colonise the new sites, provided seed is available. Double-stripping of topsoil enhances species numbers early on (plot 23, Fig.1) but whether further increases in diversity are more likely than, for example, with the type of treatment rendered to plot 7, must await further development. Successional theory suggests that as the stands thicken up some intolerant species will decline and a number of shade bearers will increase. Some of these trends are already evident as shown in Fig.2.

Members of the Proteaceae have not returned to the mined areas in any significant numbers. This reflects poor dispersal and relatively heavy seed. There is some evidence that replacement of proteaceous understorey, particularly by legumes, may be beneficial in restricting the spread of *Phytophthora cinnamomi*[5]. The new stands produced all tend to be unique with patterns affected by species planted, the local topography and chance invasion.

Acknowledgements

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PHYLLODE PROFILE FOR 'CHARLEVILLE' ACACIA ANEURA GROWN IN WESTERN AUSTRALIA

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Introduction

In a previous account attention was drawn to differences in phyllode length and area between individual trees of *Acacia aneura* in a particular locality.[1] An analysis of within tree variation was also given.

At WAIT a collection of sets of progeny from seed batches is being built up. Where possible these come from seed taken from an individual tree. In general terms the progeny from individual trees exhibit a surprising degree of similarity in view of the often wide range of phyllode shape and size in trees found in nature in the vicinity of the parents.

The first major seed collection which became available to the programme was from the Charleville area (∿ 26°25'S, 146°13'E) of Queensland. This was supplied by the Queensland Department of Primary Industry, courtesy of Bill Burrows. Material from this collection has been utilised in a number of experiments.[2,3] A set of plants ex germination in the summer of 1977-78 was potted on and transplanted to the field in July, 1978. Twenty-four seedlings averaging 7.5 cm in height were planted out in mixture with smaller numbers of progeny from trees in the Meekatharra area of Western Australia.

Of the 24 Charleville plants 20 survived and attained mean heights of 0.60 m after one year, 1.80 m after two years and 2.40 m after 3 years (i.e. July, 1981). The soil was Bassendean grey sand, with liberal amounts of organic matter added to the surface. The plants have been watered through each summer, and several trees flowered in the 1981-82 summer.

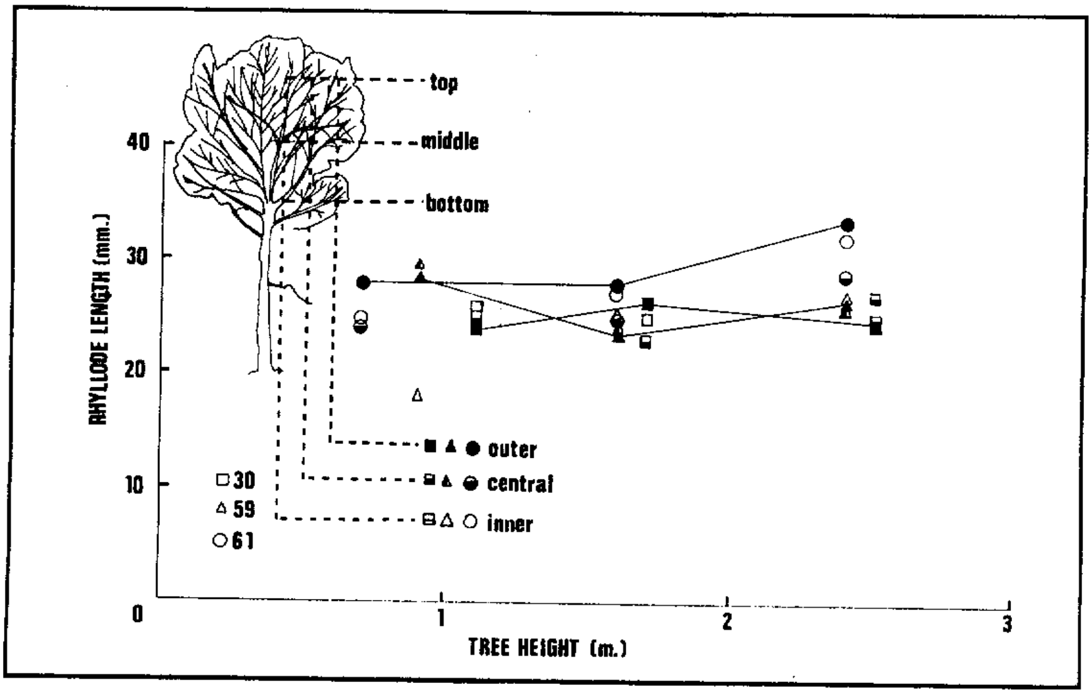
Despite the fact that the seed batch was a mixed collection, the progeny were all similar, in at least a superficial sense. The common mulga of the Charleville region tends to have broader phyllodes than many Western Australian forms[1,4] and the similarity may reflect a degree of uniformity in the stand from which the seed was collected.

The present account describes the extent of variation within 3 individuals of the set of 20 plants, utilising the same sampling procedure adopted in the earlier study. The objectives of the study were to contrast the progeny of one batch of *A. aneura* and to determine the suitability of the method for comparing other more recently planted sets.

Sampling Technique

Three well grown individuals were selected from the set of 20 plants. Tree heights were measured and crown shapes and widths determined in order to derive three appropriate sampling heights and distances from the bole within each tree. Vertical sampling positions were designated 'top', 'middle' and 'bottom'. The three equi-horizontal points at each level were designated 'outer', 'central' and 'inner' in relation to the bole (Fig. 1).

Figure 1. Mean phyllode length at different crown positions. *Three 'Charleville' mulga at 3 yrs from planting, grown at Bentley, Western Australia. Solid lines join 'outer' samples for each tree.*



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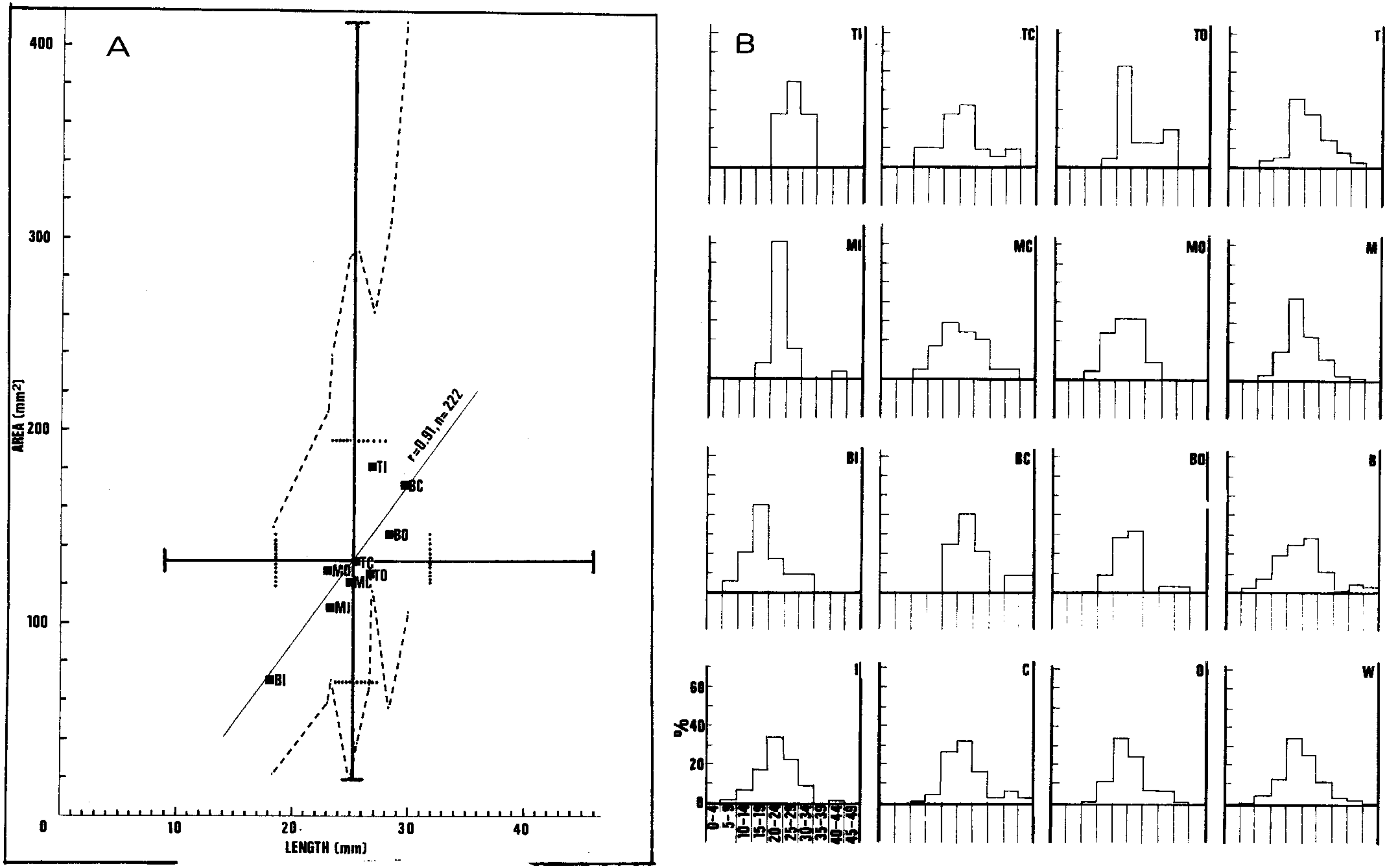

Figure 2. Phyllode Profile, Tree No. 30.

A - *Summary of phyllode profile for whole tree. Letters refer to sampling positions as in Fig. 1 viz. T top, M middle, O outer, C central, I inner. Diagonal line is whole tree regression line. Dotted inner bars refer to standard deviation of mean. Solid outer bars are extreme values recorded. Irregular dashed line joins extreme values for leaf area at each crown position.*

B - *Phyllode length percentage frequency histograms. Letters as in A, note W is whole tree.*

On August 1st 1981 twenty-five phyllodes (when available) were stripped from each of the nine sample positions, labelled and pressed. All phyllodes were measured in the laboratory for length to the completed millimetre (mm) and then passed through a leaf area planimeter for area to the completed square millimetre (mm^2). The proportions of phyllodes that were healthy, unhealthy (signs of necrosis) and those that had been grazed by insects (margin interrupted) were determined.

Each tree is discussed separately below. A summary of mean phyllode length and area is given for each sampling position, with overall means for vertical and horizontal foliage layers.

Results

Tree 30 Profile

This tree is located in the centre of the planted block, perhaps because of its location it was taller (3.1 m) than the other two, both of which were edge trees. Tree 30 had a narrow crown, distances between outer, central and inner sampling positions were 0.15 m at the bottom position, rising to 0.2 m at the middle and to 0.25 m at the top. Samples were taken at 2.5 m (top), 1.72 m (middle) and 1.1 m (bottom) from the ground.

A total of 222 phyllodes were measured from Tree 30. The following 'Profile' summarises the mean values for length and area at the nine sampled positions and for these grouped vertically and horizontally, as illustrated in Fig. 1.

Longest phyllodes occurred at bottom central and bottom outer positions, but the bottom inner position had shortest phyllodes. On average phyllodes in the top layer were longest and shortest phyllodes were found in the middle. Greatest range in length was in the bottom layer, and, in the vertical dimensions, in the inner core.

PROFILE
TREE 30

n = $\bar{x}$ length $\bar{y}$ area position	25 26.9 mm 182.8 mm^2 TI	22 25.8 132.2 TC	25 26.7 126.1 TO	72 26.4 147.7 T *top*
	25 23.4 109.2 MI	25 25.2 122.3 MC	25 23.2 127.8 MO	75 23.9 119.8 M *middle*
	25 18.2 75.4 BI	25 29.6 171.6 BC	25 28.5 147.0 BO	75 25.4 131.3 B *bottom*
	75 22.8 122.5 I *inner*	72 26.9 142.4 C *central*	75 26.1 133.6 O *outer*	222 25.2 132.7 W TREE 30

The complete phyllode profile is given in Fig. 2B, in the form of percentage histograms for numbers of phyllodes in the range of 5mm length classes.

Greatest mean phyllode area was found at the top inner position and smallest area at the bottom inner position. For all phyllodes the relationship between length and area expressed as a linear regression was:

Area = −74.49 + 8.21 length, r = 0.91

This line is illustrated in Fig. 2A together with the mean points for each sampling position. Vertical and horizontal bars denote extreme values for phyllode area and length, and the dotted lines give standard deviations. The dashed irregular lines join extreme values for phyllode area at each crown position.

Table 1 gives linear regression constants (a) coefficients (b) and correlation coefficients calculated for each sample position, and for horizontal layer and vertical division of the crown.

Table 1. Linear regression values for Tree 30

Position	Constant a	Coefficient b	Correlation Coefficient r
Top inner	-86.72	10.02	0.90
Top central	-73.23	7.97	0.96
Top outer	-88.95	8.08	0.94
Middle inner	-60.04	7.24	0.90
Middle central	-75.15	7.85	0.92
Middle outer	-88.52	9.32	0.95
Bottom inner	-25.30	5.54	0.96
Bottom central	-112.08	9.58	0.91
Bottom outer	-100.92	8.71	0.94
Top	-75.00	8.42	0.87
Middle	-69.88	7.93	0.90
Bottom	-74.90	8.12	0.94
Inner	-78.95	8.83	0.89
Central	-88.77	8.60	0.93
Outer	-76.73	8.06	0.92

The equations given in Table 1 were used to estimate the mean phyllode area of the whole tree. The percentage errors are illustrated in Fig. 5. Lowest errors for position were given with bottom and middle central locations, both underestimating the mean. The top inner position gave the largest overestimate (>20 per cent). For grouped data least errors were given with middle, bottom and inner sets; all gave about the same error (∿ 2.5 per cent).

Phyllode health is summarised for all trees in Fig. 6. Tree 30 had a slightly higher proportion of phyllodes damaged by insects than the other two trees and considerably more necrotic/chlorotic phyllodes than did Tree 61. Most grazing damage was noted at bottom positions, with a consistent level of about 20 per cent. At the

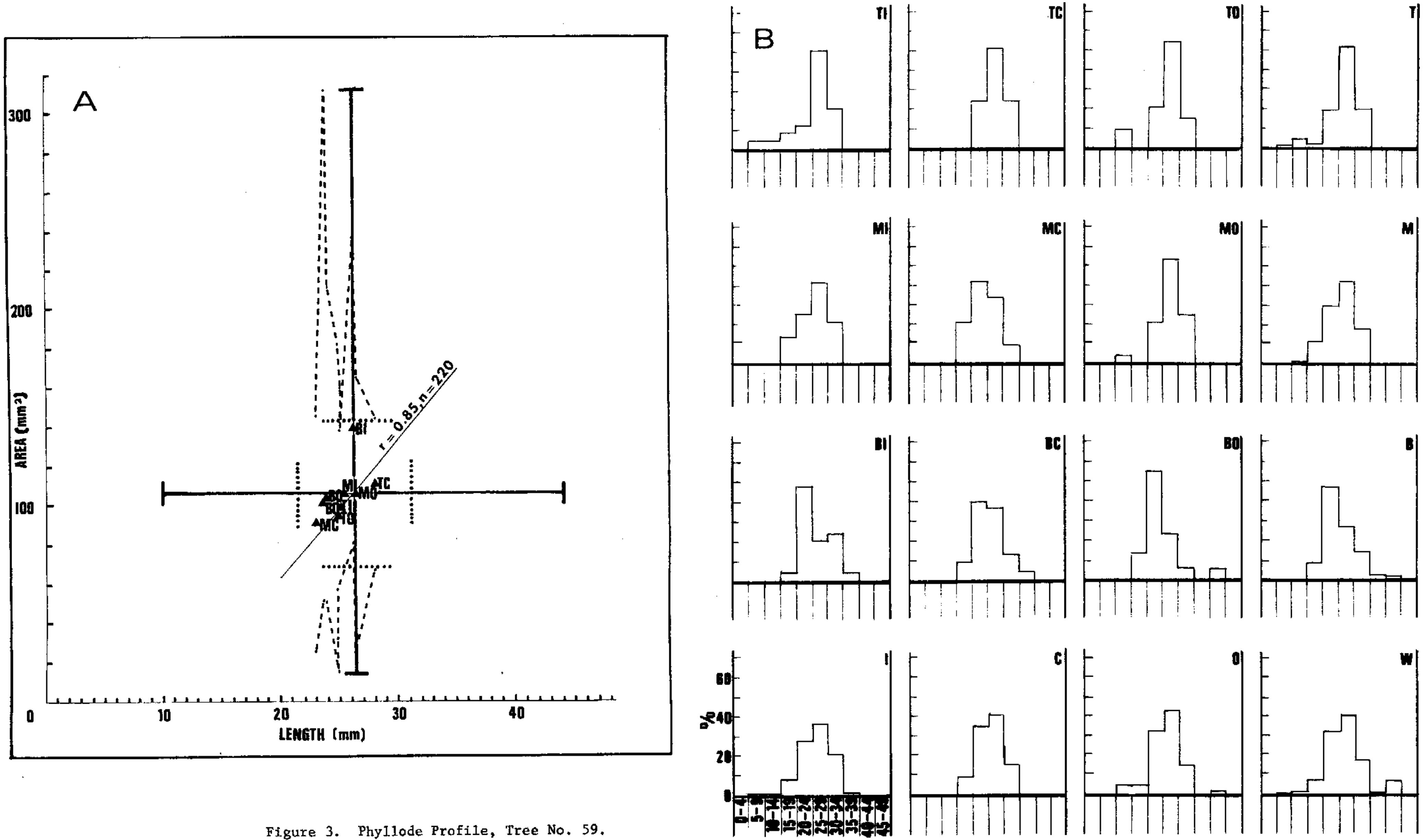

Figure 3. Phyllode Profile, Tree No. 59.
Details as in Fig. 2.

middle level the outer position suffered most and at the top the outer level was least affected. Necrotic/chloritic phyllodes were more frequent at the middle level with 50 per cent or more at each position. At the top level the outer set were most affected, whilst necrosis was more consistent at the bottom level.

The top part of Tree 30 had the highest proportion of healthy phyllodes.

Tree 59 Profile

This tree was 2.8 m tall at the time of sampling. The crown was more or less uniformly foliaged and rather broader than Tree 30. Distances between outer, central and inner sampling positions were 0.4 m for all three vertical layers. Samples were taken at 2.4 m (top), 1.6 m (middle) and 0.9 m (bottom) from the ground (see Fig. 1).

A total of 220 phyllodes were collected and measured. Mean values for length and area are given in the following 'Profile' for the nine sample positions and for vertical and horizontal sets. Mean values are illustrated graphically in Fig. 3.

PROFILE
TREE 59

n =	25	25	20	70
$\bar{x}$ length	25.1 mm	27.0	24.8	25.7
$\bar{y}$ area	98.2 mm^2	111.4	94.4	101.8
position	TI	TC	TO	T *top*
	25	25	25	75
	25.2	23.2	26.4	24.9
	107.1	90.4	107.6	101.7
	MI	MC	MO	M *middle*
	25	25	25	75
	26.0	24.8	24.0	25.0
	139.5	103.2	102.7	115.1
	BI	BC	BO	B *bottom*
	75	75	70	220
	25.4	25.0	25.1	25.2
	114.9	101.7	102.1	106.6
	I *inner*	C *central*	O *outer*	W TREE 59

The sampling position with greatest mean phyllode length was top central, followed by middle outer. Phyllodes in the top layer averaged out at greatest length, while middle and bottom layer mean lengths were very close. Shortest mean phyllode length was at the middle central position. Greatest range in length was in the inner core (Fig. 3B)

Of some interest is the less normal distribution by length classes than with Tree 30. The whole tree histogram (W of Fig. 3B) shows a bulge at 40-44 mm length, reflecting presence of this class in the bottom outer position, but none in the preceeding class 35-39 mm.

Mean phyllode area was greatest at the bottom inner sample position with smallest mean area from the middle central point. Both weighted the respective means for layers and cores.

The relationship between length and area expressed as a linear regression was:

$$\text{Area} = -56.35 + 6.46 \text{ length}, \; r = 0.85$$

While there was a similar extreme range in phyllode length to that with Tree 30, the range for phyllode area was much less (Fig. 3A). Position points for area/length were closely aligned, and standard deviations were lower.

Table 2 gives linear regression data for all positions and for layers and vertical divisions.

Table 2. Linear regression values for Tree 59

Position	Constant a	Coefficient b	Correlation Coefficient r
Top inner	-29.08	5.04	0.93
Top central	-100.06	7.83	0.83
Top outer	-24.25	4.79	0.89
Middle inner	-50.23	6.25	0.89
Middle central	-36.96	5.45	0.74
Middle outer	-52.36	6.05	0.87
Bottom inner	-55.55	7.50	0.94
Bottom central	-66.70	6.84	0.89
Bottom outer	-96.28	8.31	0.93
Top	-38.07	5.45	0.87
Middle	-46.95	5.93	0.84
Bottom	-82.32	7.91	0.89
Inner	-46.74	6.36	0.84
Central	-60.95	6.51	0.83
Outer	-59.27	6.44	0.88

Regression equations for the middle inner and bottom central positions were most efficient in predicting mean phyllode error for the whole tree (Fig. 5). The top outer and top inner positions were least efficient. For grouped data the middle set gave the best overall estimate.

Slightly more phyllodes were healthy than in Tree 30 (Fig. 6). Foliage in the lower part of Tree 59 was most healthy. Grazing damage due to herbivorous insects was generally low and uniformly spread through the tree. Middle level samples and top outer showed the most necrosis/chlorosis ($\sim$ >40 per cent at each position).

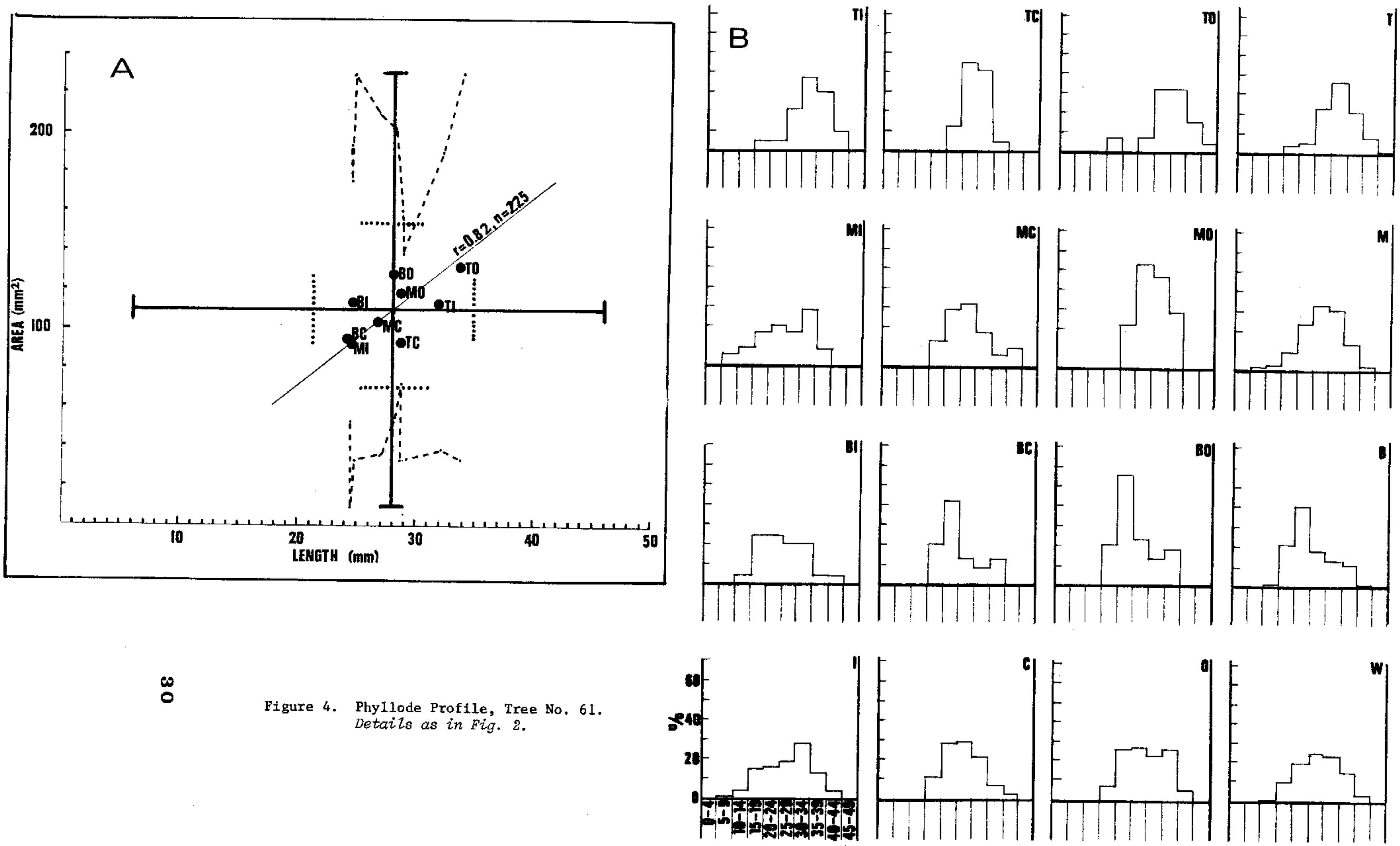

Figure 4. Phyllode Profile, Tree No. 61.
Details as in Fig. 2.

Tree 61 Profile

The shape of Tree 61 was very similar to that of Tree 59. The height was 2.7 m at sampling and distances between outer, central and inner samples were 0.4 m for the middle and bottom layers, and 0.3 m at the top. Samples were taken at 2.4 m (top), 1.6 m (middle) and 0.7 m (bottom) from the ground level (see Fig. 1).

Twenty-five phyllodes were taken from each sampling position, to give a total sample of 225. Mean values for phyllode length and area are given in the following 'Profile' and are also illustrated graphically in Fig. 4.

PROFILE
TREE 61

n =	25	25	25	75
$\bar{x}$ length	32.1 mm	28.8	34.0	31.6
$\bar{y}$ area	112.6 mm^2	93.8	131.7	112.7
position	TI	TC	TO	T *top*
	25	25	25	75
	24.5	27.0	28.2	26.5
	93.1	103.3	119.6	105.3
	MI	MC	MO	M *middle*
	25	25	25	75
	24.8	24.3	28.2	25.7
	114.2	94.4	128.8	112.5
	BI	BC	BO	B *bottom*
	75	75	75	225
	27.1	27.9	30.1	28.0
	106.6	97.2	126.7	110.2
	I *inner*	C *central*	O *outer*	W TREE 61

Mean phyllode length of the three trees examined was greatest in Tree 61. The longest mean position-length was at top outer, followed by top inner. Shortest lengths were at bottom central and middle inner. Phyllodes in the top layer were longer than those in the middle layer, and the latter, in turn, were longer than those in the bottom layer. Similarly phyllodes in the inner core were shorter than those in the central division, which in turn were shorter than those in the outer zone. The greatest ranges in length were in the middle layer and in the inner core (Fig. 4B).

Mean phyllode area did not follow the apparent symmetry noted with length. This was greatest in the top outer position, followed by bottom outer. Phyllode area was least at the middle inner position with top and bottom central positions close. Of the layers and cores the outer zone had greatest mean phyllode area followed by the top layer, which was little more than the bottom layer.

The linear regression fitted for all phyllodes was less significant than for Trees 30 and 59, viz:

Area = -27.35 + 4.91 length, r = 0.82

The total range of phyllode area was much less than for the other two trees (Fig. 4A). Although the overall mean phyllode area was similar to that of Tree 59, the position points were less clustered.

Table 3 gives linear regression data for all positions and for layers and vertical divisions.

Table 3. Linear regression values for Tree 61

Position	Constant a	Coefficient b	Correlation Coefficient r
Top inner	-71.78	5.75	0.90
Top central	-52.64	5.07	0.75
Top outer	-78.10	6.18	0.91
Middle inner	-39.23	5.41	0.89
Middle central	-37.99	5.24	0.91
Middle outer	2.99	4.14	0.73
Bottom inner	-46.85	6.50	0.90
Bottom central	-50.94	5.98	0.88
Bottom outer	-40.53	5.91	0.85
Top	-80.31	6.10	0.90
Middle	-35.91	5.32	0.89
Bottom	-35.92	6.21	0.88
Inner	-18.83	4.63	0.80
Central	-34.87	4.95	0.82
Outer	-22.91	4.94	0.82

Of the equations summarised in Table 3 lowest errors in predicting overall mean tree phyllode area were given by top outer, middle inner and middle central positions. The bottom inner position was least efficient in predicting mean phyllode area. The inner set gave the best results for grouped data (Fig. 5).

Phyllode health is summarised in Fig. 6. Tree 61 had a higher proportion of healthy phyllodes than the other two trees sampled. This was particularly so at the top outer, middle central and bottom inner, bottom central positions. Only at top central and bottom outer positions was a lower proportion of healthy phyllodes recorded. Insect damage was most prevalent at the upper part of the tree, with the top central set scoring the highest proportion damaged by herbivores. Necrotic/chlorotic phyllodes were most frequent in the middle inner set, where above average damage was also present on foliage of the two other trees sampled.

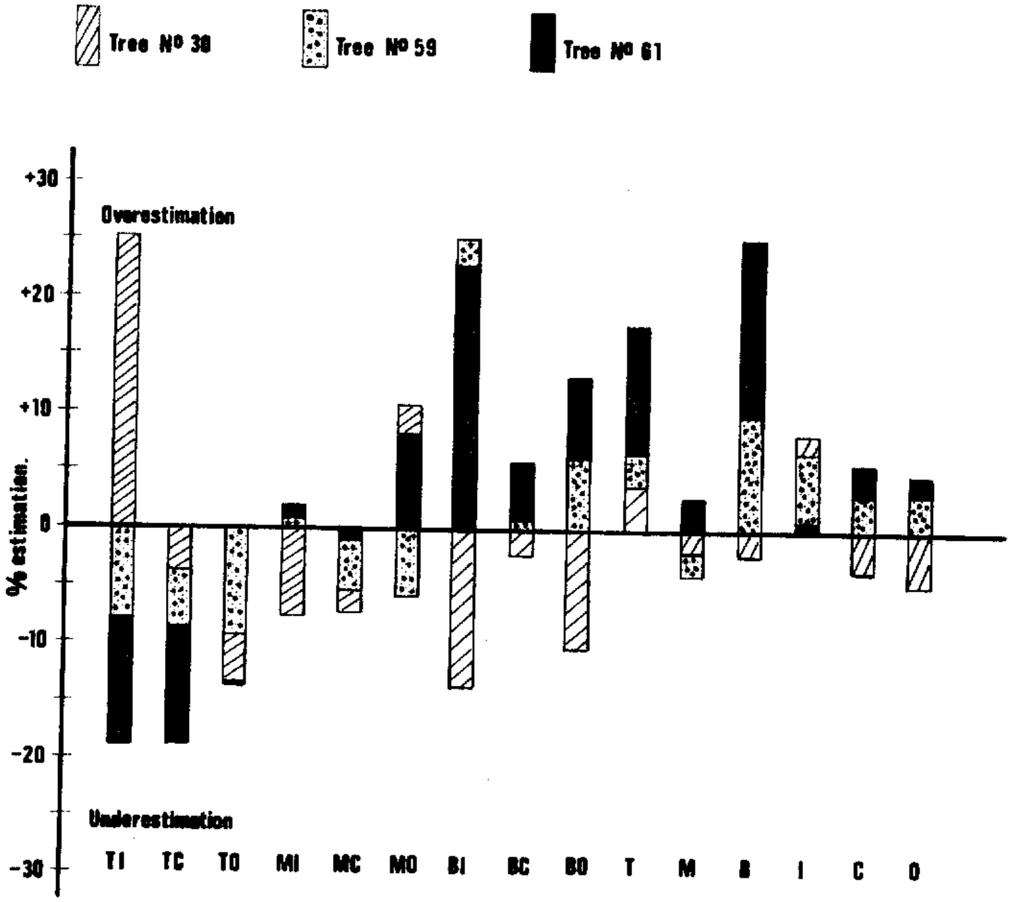

Figure 5. Percentage error of Whole Tree Mean Phyllode Area. *Bars represent positive or negative errors for each tree using regression equations as in Tables 1, 2, 3, for each sampling point.*

Discussion and Conclusions

Phyllodes of the Charleville 'variety' of *Acacia aneura* taken from three year old trees at Bentley Western Australia were narrowly oblong to lanceolate with rounded apices, entire margins and attenuate bases. These phyllodes were greyish-blue in colour and thus far have not been matched by any Western Australian collections. In size the phyllodes averaged 25-28 mm length, 3.9-5.3 mm across and 107-133 mm^2 in surface area.

Each of the three trees sampled had differing phyllode profiles but these may best be viewed as segments of a population profile. There was no consistent trend between phyllode length and tree height (Fig. 1), but at some positions there was an observable tendency for phyllodes in the inner core (closest to the trunk) to increase in length with tree height e.g. inner sets of Trees 30 and 61. This may be related to the branchlet subtending phyllode often being larger than subsequently formed foliage. Longest phyllodes were found in the top layer of each tree. Mean phyllode length was greatest in Tree 61 and least in Tree 59. Ranges in mean length between the 9 sampling positions were also greatest in Tree 61 and least in Tree 59. Mean area of phyllode was greatest in Tree 30 and least in Tree 59 with Tree 61 intermediate. In the case of phyllode area the greatest range between position means was with Tree 30, with Tree 61 showing the least range. The range in phyllode area in Tree 30 was 20-411 mm^2 and consequently this tree had greatest standard deviation (Fig. 2).

Tree 59 had a range in phyllode area of 280 mm^2 (32-312) and Tree 61, 220 mm^2 (10-230). The upper extreme values of phyllode area plotted against mean length for each sampling position showed a consistent increase with phyllode length in Tree 30 (Fig. 2) but responses were generally irregular.

Phyllode length of the 3 study trees tended towards a normal distribution. The model class for Tree 30 was 20-24 mm but for the other two trees it was 25-29 mm. No phyllodes were found in the 0-4 mm class on any tree and no phyllodes under 10 mm were recorded in the centre and outer positions. At all positions a single modal group was recorded.

Summing sampling position means for the three trees in sets of three suggests that certain positions may be more efficient than others in predicting overall means. For phyllode length greatest variation (measured by highest standard deviation) was at the top outer position, viz:

Position	Top outer >	Bottom inner >	Top inner
Mean	28.46	22.99	28.01
SD	4.86	4.23	3.64
Deviation*	+2.34	-3.13	+1.89

By contrast least variation occurred at the middle inner position:

Position	Middle inner <	Top centre <	Middle centre
Mean	24.35	27.20	25.09
SD	0.89	1.55	1.90
Deviation*	-1.77	+1.08	-1.03

(* where whole tree mean length is 26.12±1.59)

Similarly with phyllode area, highest standard deviation occurred at the top inner positions,

Position	Top inner >	Bottom central >	Bottom inner
Mean	131.21	123.08	109.68
SD	45.29	42.25	32.30
Deviation*	+14.71	+6.58	-6.88

and lowest standard deviation was found in the

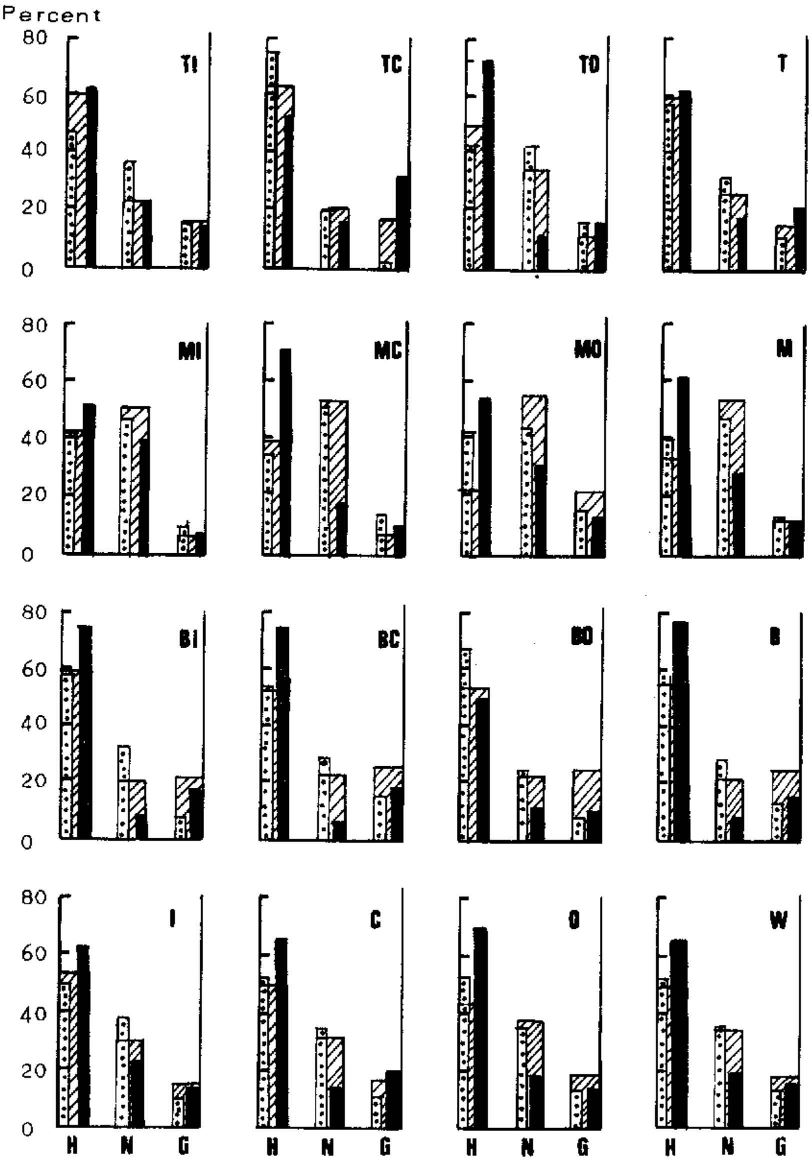

Figure 6. Percentage Distribution of Phyllodes by Health Classes. *Phyllodes are classed as healthy (H) if entire and green; necrotic/chloritic (N) if with brown or yellow patches; or grazed (G) if partially eaten.*

middle inner position,

Position	Middle inner <	Middle outer <	Middle centre
Mean	103.14	118.31	105.33
SD	8.74	10.14	16.02
Deviation*	-13.36	+1.81	-11.17

(* where whole tree mean phyllode area is 116.50 ± 14.15).

Sample correlation coefficients for whole tree phyllode area and length were 0.91, 0.85 and 0.82 for Trees 30, 59 and 61 respectively. Tree 30 had the greater degree of linear association. Linear regression equations for each position were used to estimate overall mean phyllode area for the whole tree. Percentage errors are given in Figure 5. Greatest errors came from top and bottom positions with middle positions generally giving the most efficient predictions. Errors tended to range from under-estimates at the top to overestimates at the bottom. Lowest errors were 2.3 per cent for Tree 30 at the bottom, central position; 0.7 per cent for Tree 59 at middle, inner; and 1.5 per cent for Tree 61 at the middle central position.

When the 27 position means were analysed by linear regression the equation derived was

$$\text{Area} = 14.82 + 3.88 \text{ length}, \ r = 0.49$$

This equation underestimated the mean phyllode area of Tree 30 by 15 per cent, and overestimated the values for Trees 59 and 61 by 5 and 11 per cent respectively. Of the three whole tree regressions applied to derive mean phyllode area from mean phyllode length, that pertaining to Tree 59 was most efficient giving an under-estimate for Tree 30 of 20 per cent and an over-estimate for Tree 61 of 13 per cent. Thus the linear relation for Tree 59 best fits the set of three tree data.

The degree of leaf damage (grazing, chlorosis/necrosis) was measured (Fig. 6). In all trees chlorosis and necrosis was predominant in the middle positions and in Trees 30 and 59 the number of damaged leaves exceeded the number of healthy appearing phyllodes at these positions. Herbivory was greatest at the bottom positions in Tree 30 although it was not much more than the total for the whole tree. Tree 59 had uniform grazing and the top positions were more susceptible to insect attack in Tree 61.

The variety of *A. aneura* under study showed distinct differences regarding the phyllode profile. Trends were irregular and varied from tree to tree. Variations occurred within individual trees but not to a great extent.

This study should provide a useful background for examining the progeny of single parent tree seed collections for phyllode variation. It is anticipated that smaller numbers of phyllodes should prove adequate, provided consistency of sampling position is adopted. Age of phyllodes has been ignored in the present account but the extent of variation suggests that phyllode age may well be an important criterion to be taken into consideration in further studies.

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GLASSHOUSE TRIALS WITH LEGUME SPECIES ON NAKINA FORMATION OVERBURDEN MATERIAL

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Introduction

The Collie coalfield lies 150 km south-east of Perth on an infilling of Permian sedimentary strata in a small basin of pre-Cambrian basement rock.[2] Old unconsolidated overburden dumps are prone to wind and water erosion. Natural recolonization of overburden dumps may occur with time but the process is slow, and species composition is limited.[1]

It has been estimated that an additional ∿500 ha of land will be directly disturbed by mining in the last quarter of the present century.[4] Some are convinced that this is likely to be an underestimate.[2]

Field screening of a wide range of plant species on a variety of spoil types suggests that planted individuals all fail on materials of pH less than 4.0.[2] *Eucalyptus patens* Benth. showed the greatest acid tolerance of volunteer local species. This species was able to invade areas with surface pH as low as 4.5. Some colonization of sedge species was found at a pH as low as 4.0.[2]

Planted species which showed some acid tolerance at pH 4.0 to 4.5 were: *Lolium rigidum* Gaud. (rye grass) and three legumes: *Vicia sativa* L. (vetch) and two native wattles *Acacia extensa* Lindl. and *A. pulchella* R. Br.[2] These latter two were not inoculated with root nodule-forming *Rhizobium* bacteria. Despite tolerance they exhibited poor nodulation, slow early growth and high mortality.

The relationship between pH and growth is indirect. When the soil pH is raised, root growth can increase due to the increased availability of both the major and minor nutrients and the decrease of toxic elements such as aluminium and manganese. Nodulation and hence nitrogen fixing also increase. In the case of some legumes, at least, soil acidity affects not only nutrient availability but also growth and survival of *Rhizobia*. Low acidity will inevitably give lower growth than when plants are grown in soils of their optimum pH range.[5] There is some indication that fertilization reduces *Rhizobia* activity in *Acacia*.[7] Legumes generally vary considerably in their sensitivity to aluminium ions and *Rhizobia* strains differ in their response to low pH. It is not known if this is a pure calcium response.[6] Lime pelleting, where finely ground calcium carbonate is made to adhere to legume seeds, improves nodule formation with sensitive species in acid soils.[8]

Soil pH can be increased by the addition of lime (calcium carbonate) but too much lime reduces the availability of iron, magnesium, boron and potassium, and may affect the availability of phosphorous. Overliming some acid soils will result in loss of growth due to induced trace-element deficiencies. These can be serious in acid sands, particularly if an attempt is made to increase pH by too much in a single step. In addition to the elements noted above manganese deficiency can be induced by a light dressing of lime.[6]

One of the materials present in overburden dumps is Nakina Formation sand, which was deposited over the Collie Basin as lake sediment in the Tertiary Period.[4] Nakina Formation sand is composed of weakly lithified claystone, sandstone, and conglomerate. It is moderately to strongly acidic, poor in nutrients, and generally non toxic. For rehabilitation to be successful on this material, acid tolerant species must be used or, alternatively, an economical method of increasing pH to a range suitable for optimal plant growth needs to be devised.

Soil amendment by the addition of lime seems to be the most promising technique of rehabilitation. If the soil pH can be increased it may widen the selection of plant species which may be useful for rehabilitation. The dense ground cover of low shrubs and herbaceous plants, resulting from a successful rehabilitation programme will reduce erosion and may change the rate of formation of acid.

The aim of this project was to examine survival and growth of several species in unamended soil material and to compare these results with the same species grown in pots which had received sufficient lime to increase the pH by 1 or 2 units.

Materials and Methods

A quantity of Nakina formation sand was provided by The Griffin Coal Mining Company Limited. Bulk density was determined and then the material was mixed thoroughly with a spade so that a fairly homogenous 'soil' was obtained.

Random samples were taken from the soil and pH measurements were read 1 hr after saturation. Fine powdered calcium carbonate was added to the samples until the quantities required to raise soil pH by ∿ 1 unit and then by ∿ 2 units were known.

A set of 120 black plastic pots 14.3 cm d and 14.5 cm deep, together with a set of 6 plastic seed trays each containing 30 compressed peat jiffy pots were filled with the soil. One third recieved unamended soil, one third received pH + 1 and one third pH + 2. Calcium carbonate was mixed in by hand. A layer of polyalkathene beads was placed in the bottom of each pot.

Seed of a number of legume species had been subjected to hot water treatment and placed in germination trays filled with coarse sand on June 10th. As seedlings germinated these were transplanted to jiffy pots.

Jiffy Pots

Swollen or recently germinated seeds taken from germination trays were planted into the top of jiffy pots on August 8th. The following species were used:

Acacia extensa Lindl. (5)
Acacia pulchella R.Br. (15)
Acacia rhodoxylon Maiden (25)
Cytisus proliferus L.(5)
Hardenbergia comptoniana Benth.(5)
Kennedia prostrata R.Br. (5)

The number in brackets refers to the number of seeds placed in each of the three soil types.

The trays with jiffy pots in them were placed inside clear plastic bags. Deionised water was introduced into the bags at intervals sufficient to keep the pots moist. Some supplementary surface watering was applied when the upper parts of the jiffy pots appeared to have died out.

The surviving plants were harvested on October 23rd after 76 days growth in the jiffy pots. Length of tops and roots were measured, numbers of nodules and leaves were counted and the mean fresh weight per species by soil treatment was obtained. The plants were then dried for 48 h at 80°C and dry weight taken.

Pot Trial

Seedlings from jiffy pots were transplanted to black plastic pots on August 7th. The following five species were planted into a total of 24 pots each, 8 pots for each of the three soil treatments:

Acacia extensa
Acacia pulchella
Cytisus proliferus
Hardenbergia comptoniana
Kennedia coccinia Vent.

In most cases one seedling per pot was used, but with *H. comptoniana* where germination had been slower and seedlings were smaller a total of 37 seedlings was planted.

Four pots of each treatment were stood in plastic trays lined with transparent plastic bags. The plants were watered from above with deionised water to field capacity daily for three weeks and then at 2-3 day intervals. At weekly intervals plant height and leaf number were recorded.

Harvests were taken on September 9th, October 6th and October 21st i.e. after 33, 60 and 75 days growth from potting. Pots for harvests 1 and 2 were selected randomly. At each harvest the plants from 8 pots of each species, 2 or 3 pots per soil treatment, were carefully removed from the soil. Length of top and roots were measured, number of root nodules and leaves were counted and fresh weights of tops and roots were taken. The plants were dried at 80°C for 48 h and then dry weights were taken.

Dried material of each species, from each soil treatment, was ground and placed into individual 150 ml conical flasks. 10 ml of concentrated sulphuric acid, followed by 5 ml of 100 vol. hydrogen peroxide were then added to the flasks and mixed well. The flasks were heated to 200°C on a hot plate until the solution was clear of organic matter. This took 2-3 h. The cool solution was then made up to 50 ml with deionised water.

A 40 ml aliquot of each solution was then used for total nitrogen analysis by the Kjeldahl technique, and the remaining 10 ml aliquot was analysed for sodium, potassium and calcium with a flame photometer.

Results

The pH of unamended Nakina sand material was 4.6. The level of calcium carbonate required to attain ∿ 5.6 was calculated to be 1g/1000g, and to attain pH ∿ 6.6 5g/1000g was required. Soil bulk density was 1.44 and the weight of soil per pot was 1.86 kg.

During the course of the experiment the measured pH levels drifted upwards, such that 39 days after potting the recorded mean values for 0, 1 and 5 g of calcium carbonate pots were 5.2, 6.9 and 7.5 respectively.

Jiffy Pots

Plants survived the 76 d in jiffy pots in 138 of the 160 planted (Table 1) with the three *Acacia* species showing greatest survival percentages. There was no significant difference in survival between treatments. Plants of *Kennedia prostrata* produced greatest dry weight in all 3 soils, and also had substantial root lengths. If dry matter production is taken as the most appropriate index of success then, for this species, the addition of calcium carbonate depressed growth with poorest growth in the soil of highest, amended pH. A similar pattern was also shown in *Acacia extensa, A. rhodoxylon* and *Cytisus proliferus*. On the other hand *Hardenbergia comptoniana* showed increased growth with higher pH and *Acacia pulchella* showed equally good growth in unamended soil and at the lower level of calcium carbonate.

In most cases plant fresh weight fell off at higher pH levels, with only *H. comptoniana* showing the reverse trend. The mean number of nodules produced was low with none at all on *Cytisus proliferus* and very few on *Acacia rhodoxylon*. However there was a trend of increasing numbers of nodules with higher pH. Rank correlation coefficients of nodule numbers with both dry weight and shoot length were not significant, rs 0.28 and 0.26 respectively.

The rank correlation coefficient for dry weight and shoot length was significant (rs = 0.53, p 0.05 = 0.48).

TABLE 1. Dimensions of plants grown for 76 days in jiffy pots with standard deviations*

Species	Lime Level	Shoot length (mm)	Root length (mm)	No. of leaves/ phyllodes	Fresh weight (g)	Dry weight (g)	Fresh/dry weight ratio	No. of nodules (mean)
Kennedia prostrata	0	42.5 ± 10.6	367.5 ± 215.7	14.5 ± 0.7	1.50	0.43	3.49	3
	1	50	174	15	1.73	0.40	4.33	2
	2	45	170	12	1.16	0.29	4.00	5
Acacia rhodoxylon	0	23.7 ± 4.6	168.4 ± 57.2	14.9 ± 3.9	0.25	0.06	4.17	1
	1	25.9 ± 7.2	136.5 ± 66.8	13.5 ± 3.9	0.16	0.04	4.00	1
	2	21.7 ± 5.2	87.4 ± 29.1	10.4 ± 3.6	0.07	0.02	3.50	0
Acacia extensa	0	64.0 ± 14.8	153.4 ± 63.0	18.2 ± 5.6	0.56	0.12	4.67	2
	1	74.6 ± 4.6	137.0 ± 63.8	22.6 ± 9.0	0.47	0.11	4.27	2
	2	51.8 ± 22.0	111.6 ± 35.2	19.4 ± 4.2	0.27	0.06	4.50	1
Cytisus proliferus	0	90	210	13	1.07	0.23	4.65	0
	1	-	-	-	-	-	-	-
	2	33	105	18	0.49	0.14	3.50	0
Hardenbergia comptoniana	0	35.0 ± 5.0	140.3 ± 45.3	5.7 ± 2.1	0.53	0.12	4.42	1
	1	50	185	8	0.74	0.14	5.29	1
	2	47.5 ± 17.7	119.0 ± 1.4	10.0 ± 1.4	0.84	0.18	4.67	4
Acacia pulchella	0	33.4 ± 8.1	107.3 ± 16.7	50.0 ± 20.2	0.18	0.04	4.50	1
	1	36.9 ± 5.7	75.4 ± 17.1	44.9 ± 10.3	0.10	0.04	2.50	3
	2	33.4 ± 5.3	87.3 ± 31.9	51.8 ± 18.1	0.09	0.03	3.00	3

* No standard deviation denotes only one survivor.

Pot Trial

All plants survived. Mean dry weights are presented in Table 2. Three entries are given for each harvest to distinguish between the effect of more than one plant in a pot. The first line refers to the mean dryweight of all plants of a species harvested from a treatment. The second line refers to the mean weight per pot and the third line gives the weight separately for the pot with greatest dry weight harvested. We refer to the treatments as T0, T1, T2 as for the lime levels of Table 2.

At the 33 and 60 day harvests *Cytisus proliferus* generally produced highest yields but at the third harvest *Kennedia coccinea* had highest mean for all plants and for largest pot weight. The progress of mean plant weights is illustrated in Fig. 1. Differences between dry weight yields within a species for the three different soils at any one harvest were not significant. When yields at all harvests were summed for the three soils as treatments only *Acacia extensa* showed significance at p0.10 where

T1 > T0 > T2

In this species growth was markedly better in the lower level of lime, but differences between T0 and T2 were not great at the first two harvests. The overall mean (all species, all harvests, Table 2) is similar to this.

Analysis of variance for all harvested plants, all pots and largest pots, resulted in no significant differences between soil effects at a harvest. However, species were significantly different at second and third harvests, viz

Second Harvest, All Plants

T0 $C.p. > A.e. > H.c. > \begin{matrix} K.c. \\ A.p. \end{matrix}$

T1 $C.p. > \begin{matrix} A.e. \\ A.p. \end{matrix} > K.c. > H.c.$

T2 $H.c. > C.p. > K.c. > A.e. > A.p.$

(F 5.45, p0.05)

Second Harvest, Largest Pot

T0 $C.p. > H.c. > A.e. > A.p. > K.c.$

T1 $C.p. > H.c. > A.e. > A.p. > K.c.$

T2 $C.p. > A.p. > H.c. > A.e. > K.c.$

(F 13.55, p0.01)

TABLE 2. Summary of mean dry weights (g) for pot trial.

SPECIES SAMPLE	HARVEST 1 33 DAYS				HARVEST 2 60 DAYS				HARVEST 3 75 DAYS				ALL 3 HARVESTS			
LIME LEVEL	0	1	2	ALL	0	1	2	ALL	0	1	2	ALL	0	1	2	ALL
Kennedia coccinea																
All plants	0.17	0.15	0.31	0.21	0.39	0.52	0.58	0.49	0.66	1.17	1.31	1.01	0.44	0.62	0.66	0.57
Plants by pots	0.17	0.15	0.31	0.21	0.39	0.52	0.58	0.49	0.66	1.17	1.31	1.01	0.44	0.62	0.66	0.57
Largest pot weight	0.23	0.26	0.46	0.32	0.55	0.54	0.74	0.61	1.38	2.19	1.62	1.73	0.72	1.00	0.94	0.89
Cytisus proliferus																
All plants	0.41	0.43	0.33	0.40	1.27	1.26	0.92	1.15	0.97	1.11	0.80	0.94	0.85	0.88	0.75	0.83
Plants by pots	0.55	0.57	0.33	0.50	1.27	1.89	1.22	1.44	0.97	1.11	1.06	1.06	0.96	1.10	0.94	1.00
Largest pot weight	0.66	0.73	0.40	0.60	1.96	1.90	1.64	1.83	1.12	1.39	1.26	1.26	1.25	1.34	1.10	1.23
Hardenbergia comptoniana																
All plants	0.09	0.16	0.19	0.16	0.42	0.41	0.94	0.49	0.38	0.65	0.59	0.51	0.34	0.43	0.42	0.40
Plants by pots	0.14	0.24	0.28	0.23	0.85	0.82	0.94	0.86	0.63	0.86	0.59	0.71	0.59	0.76	0.52	0.62
Largest pot weight	0.19	0.30	0.32	0.27	0.99	1.12	1.05	1.05	1.03	1.42	0.75	1.07	0.74	0.95	0.71	0.80
Acacia extensa																
All plants	0.13	0.31	0.17	0.18	0.54	0.71	0.55	0.61	0.65	0.84	0.53	0.67	0.38	0.66	0.37	0.46
Plants by pots	0.17	0.31	0.22	0.23	0.54	0.71	0.55	0.61	0.65	0.84	0.53	0.67	0.43	0.66	0.42	0.50
Largest pot weight	0.30	0.32	0.37	0.33	0.77	0.88	0.76	0.80	0.84	0.91	0.72	0.82	0.64	0.70	0.62	0.65
Acacia pulchella																
All plants	0.33	0.10	0.04	0.15	0.39	0.71	0.49	0.49	0.66	0.25	0.43	0.42	0.43	0.31	0.35	0.36
Plants by pots	0.33	0.10	0.06	0.17	0.51	0.71	0.81	0.67	0.66	0.25	0.43	0.42	0.48	0.31	0.48	0.42
Largest pot weight	0.57	0.14	0.06	0.26	0.69	0.79	1.44	0.97	0.87	0.33	0.56	0.59	0.71	0.42	0.69	0.61
Overall means																
All plants	0.23	0.24	0.19	0.22	0.58	0.68	0.67	0.64	0.60	0.79	0.70	0.70	0.47	0.58	0.50	0.52
Plants by pots	0.29	0.27	0.25	0.27	0.73	0.90	0.83	0.81	0.70	0.85	0.76	0.77	0.58	0.68	0.60	0.62
Largest pot weight	0.39	0.35	0.32	0.35	0.99	1.05	1.13	1.05	1.05	1.25	0.98	1.09	0.81	0.88	0.81	0.83

Third Harvest, All Plants

T0 *C.p.* > $\begin{smallmatrix}A.p.\\K.c.\end{smallmatrix}$ > *A.e.* > *H.c.*

T1 *K.c.* > *C.p.* > *A.e.* > *H.c.* > *A.p.*

T2 *K.c.* > *C.p.* > *H.c.* > *A.e.* > *A.p.*

(F 4.02, p0.05)

Third Harvest, Largest Pot

T0 *K.c.* > *C.p.* > *H.c.* > *A.p.* > *A.e.*

T1 *K.c.* > *H.c.* > *C.p.* > *A.e.* > *A.p.*

T2 *K.c.* > *C.p.* > *H.c.* > *A.e.* > *A.p.*

(F 7.85, p0.01)

Differences between species at each harvest were significant, and the interaction species/lime level was significant at p0.05 for individual plants and pots at first harvest. The following shows Scheffé contrasts at each harvest:

Individual Harvested Plants

H1 *C.p.* > *K.c.* > *A.e.* > *H.c.* > *A.p.*

Relative weights 100 53 45 39 38

(F 9.35, p 0.001; Interaction F 2.83)

H2 *C.p.* > *A.e.* > *K.c.* > *H.c.* > *A.p.*

Relative weights 100 53 43 43 42

(F 6.93, p0.001)

H3 *K.c.* > *C.p.* > *A.e.* > *H.c.* > *A.p.*

Relative weights 100 92 66 51 41

(F 3.82, p0.05)

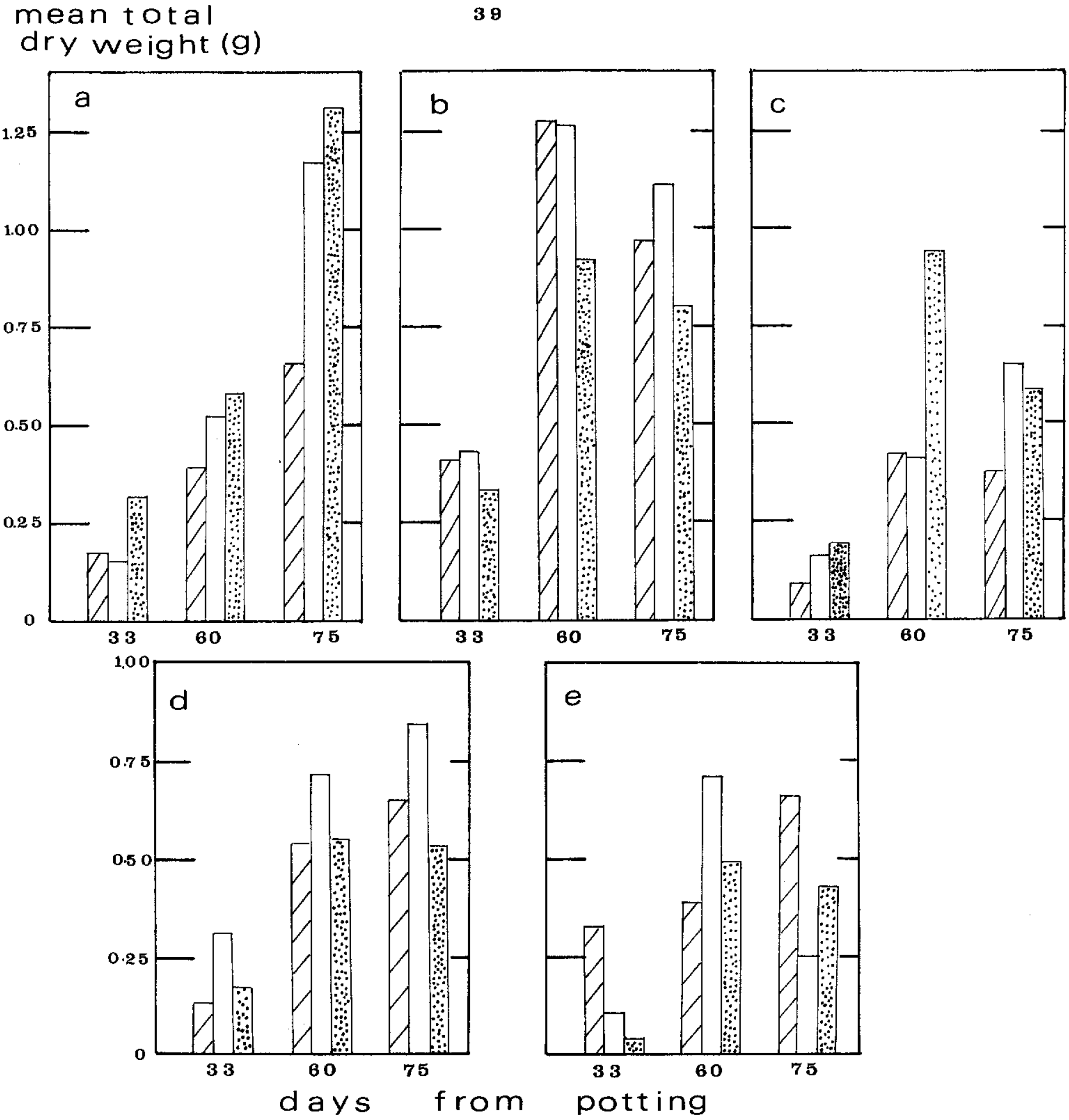
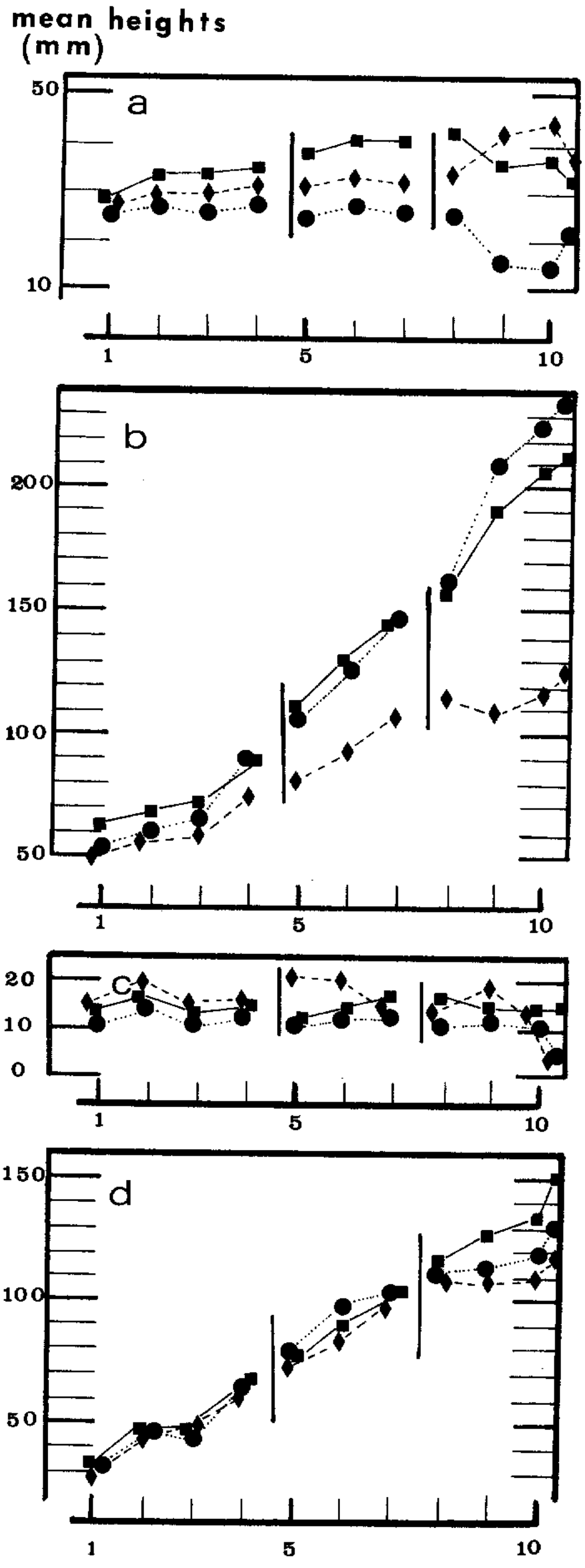


Figure 1. Mean total plant dry weights at harvests.
a *Kennedia coccinea*; b *Cytisus proliferus*; c *Hardenbergia comptoniana*; d *Acacia extensa*; e *Acacia pulchella*. Dashed bars represent treatment with no lime (control T0); open bars with lower level of lime (T1); stippled bars upper level of lime (T2).



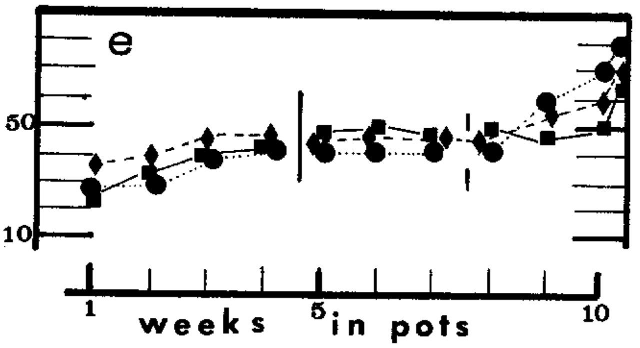


Figure 2. Mean heights at weekly intervals from potting.

a *Kennedia coccinea*; b *Cytisus proliferus*; c *Hardenbergia comptoniana*; d *Acacia extensa*; e *Acacia pulchella*. Vertical bars represent harvest times. No lime control (T0) circles; lower lime (T1) squares; upper lime (T2) diamonds.

Individual Pots

H1 *C.p.* > *H.c.* > *A.e.* > *K.c.* > *A.p.*

Relative weights 100 47 45 42 34

(F 10.51, p0.001; Interaction F 2.74)

H2 *C.p.* > *H.c.* > *A.p.* > *A.e.* > *K.c.*

Relative weights 100 60 47 42 34

(F 11.47, p0.001)

H3 *C.p.* > *K.c.* > *H.c.* > *A.e.* > *A.p.*

Relative weights 100 96 70 64 40

(F 3.41, p0.05)

Largest Pots

H1 *C.p.* > *A.e.* > *K.c.* > *H.c.* > *A.p.*

Relative weights 100 55 53 45 43

(F 2.28, p0.2 N.S.)

H2 *C.p.* > *H.c.* > *A.p.* > *A.e.* > *K.c.*

Relative weights 100 57 53 44 33

(F 15.17, p0.001)

H3 *K.c.* > *C.p.* > *H.c.* > *A.e.* > *A.p.*

Relative weights 100 73 62 48 34

(F 7.39, p0.01)

The following harvest means within a treatment level were significantly different:

Kennedia coccinea	T2	H3 > H2 > H1 (p0.05)
Cytisus proliferus	T1	H2 > H3 > H1 (p0.05)
Hardenbergia comptoniana	T2	H2 > H3 > H1 (p0.001)
Acacia extensa	T1	H3 > H2 > H1 (p0.05)
Acacia pulchella	T1	H2 > H3 > H1 (p0.01)

Height growth is illustrated in Fig. 2 and leaf numbers in Fig. 3. Both *Kennedia coccinea* and *Hardenbergia comptoniana* are climbers, but over the first few weeks from germination stems are mainly erect. In *K. coccinea* a marked ranking in heights T1 > T2 > T0 was apparent for the first 7 weeks. By week 9 T2 plants had become the tallest and heights in both T0 and T1 declined due to stems dying back or falling over. This was coupled with some leaf loss in T0 (Fig. 3).

Cytisus proliferus heights in T2 were consistently lower than in T0, T1 which were similar over much of the experiment. By 9 weeks T0 plants were growing taller faster than T1 plants whereas height growth increased very little over weeks 8-11 in T2. This pattern was repeated for leaf numbers over weeks 5-7. There was little change in leaf numbers for all treatments over the final three weeks.

Height growth in *H. comptoniana* was rather erratic with T2 plants generally taller throughout, except towards the end of the experiment. At most assessments the pattern was T2 > T1 > T0. Leaf numbers in this species declined after the second harvest becoming closer in number in T0 and T1.

Acacia extensa was the second tallest species to *C. proliferus*. Mean heights in all three treatments were similar to the first harvest. Between first and second harvest heights were T0 > T1 > T2, and after the second harvest T1 > T0 > T2. Phyllodes appeared about 3-5 weeks from sowing. By the seventh week phyllode numbers were highest in T1 followed by T0 then T2.

Height rankings changed considerably in *Acacia pulchella* from T2 > T1 > T0 in the first five weeks to T1 > T2 > T0 between first and second harvests and then T0 > T2 > T1 in the final three weeks (Fig. 2). Leaflet numbers tended to follow the same trends (Fig. 3).

Harvest ratios by treatments for shoot/root (S/R) and fresh/dry (F/D) weight ratios are given in Table 3. S/R varied from around 0.1 to 0.7 with the greatest range in *Cytisus proliferus* at third harvest. In *Kennedia coccinea* and *Hardenbergia comptoniana* ratios tended to run in the sequence T0 > T1 > T2, whereas in *A. extensa* the reverse was the case with T2 > T1 > T0.

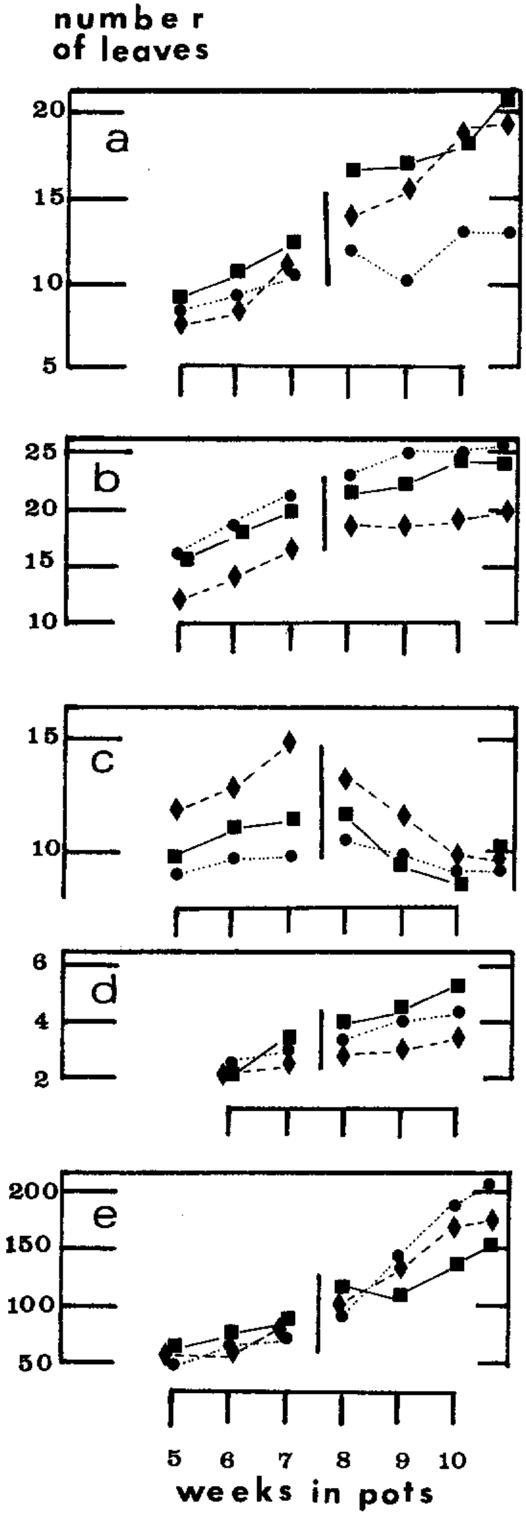


Figure 3. Number of leaves at intervals from potting.

a *Kennedia coccinea*; b *Cytisus proliferus*; c *Hardenbergia comptoniana*; d *Acacia extensa*; e *Acacia pulchella*. Vertical bars represent second harvest. Symbols as in Figure 2. Note for d - phyllodes only; e - leaflets.

TABLE 3. Shoot/Root and Fresh/Dry weight ratios of harvested plants.

SPECIES/RATIO	HARVEST 1 33 DAYS			HARVEST 2 60 DAYS			HARVEST 3 75 DAYS		
LIME LEVEL	0	1	2	0	1	2	0	1	2
Kennedia coccinea									
Shoot/Root	0.42	0.40	0.25	0.38	0.37	0.14	0.25	0.16	0.10
Fresh/Dry	2.71	4.20	2.52	2.56	3.42	2.38	2.41	2.53	2.34
Cytisus proliferus									
Shoot/Root	0.37	0.23	0.36	0.17	0.21	0.28	0.67	0.46	0.21
Fresh/Dry	3.98	3.49	3.82	2.07	2.87	2.62	4.27	3.79	2.90
Hardenbergia comptoniana									
Shoot/Root	0.50	0.45	0.46	0.35	0.28	0.24	0.23	0.25	0.31
Fresh/Dry	4.89	4.81	3.74	2.79	3.10	2.64	3.37	3.00	3.75
Acacia extensa									
Shoot/Root	0.18	0.28	0.31	0.38	0.42	0.45	0.55	0.58	0.58
Fresh/Dry	3.54	3.81	3.47	2.89	3.46	2.98	3.03	3.65	3.30
Acacia pulchella									
Shoot/Root	0.18	0.29	0.50	0.18	0.18	0.63	0.29	0.56	0.34
Fresh/Dry	2.70	4.00	7.50	2.33	2.55	2.18	3.30	4.80	3.95

S/R ratios were highest in *K. coccinea* and *Hardenbergia comptoniana* in TO for the first harvest, and in *C. proliferus* and *Acacia extensa* for the final harvest. At TI S/R was highest at first harvest in *H. comptoniana*, and in *A.pulchella* at first and second harvests and in *A. extensa* at the final harvest.

The F/D ratios ranged from 2.1 in *Cytisus proliferus* at TO at the second harvest to an extreme of 7.5 in *Acacia pulchella* in T2 at the first harvest. In *K. coccinea* F/D ratios ran consistently T1>TO>T2 at each harvest but there was little pattern amongst the other species, although both *Acacias* at final harvest showed T1>T2>TO (Table 3).

Relative growth rates (R.G.R.) between harvests are shown for each species in Fig 4. In general R.G.R. showed a decline across species and treatments. The exceptions were *Kennedia coccinea* where all treatments showed a rise with the greatest rise in T2. In *A. pulchella* RGR in the unaltered material of TO rose from a low initial level over the period of the experiment.

Percentage nutrient contents of harvested plants are given for each species at each harvest by treatments in Table 4. As the plants became larger the percentage nutrient contents declined between harvests. At first harvest the sodium percentage varied from 0.12 for *C. proliferus* in T1 to 1.15 in *A. pulchella* at T2. By final harvest the sodium percentages were lowest in *K. coccinea* at 0.03 for T2 and highest in *A. pulchella* for T1. A similar pattern occurred with potassium. The percentage potassium at first harvest fell between 0.11 in TO for *A. pulchella* and 0.47 in T2 for the same species. The range at final harvest was from 0.03 in *K. coccinea* at both T1, T2 to 0.16 in *A. pulchella* at T1.

Calcium levels were fairly consistent at first harvest with some plants similar at each lime level, and others showing differences between treatments. However, by final harvest all TO values were lower than T1,T2, and only *A. pulchella* was T1 not less than T2 (these were the same). The range in percentage calcium was from 0.001 in several species at TO or T1 to 0.05 in T2 of *A. pulchella* at first harvest. From the second harvest all species at TO had the same level at 0.001. The highest percentage at third harvest was in T2 in both *H. comptoniana* and *A. extensa* at .03.

Levels of nitrogen ranged from 0.25 percent in *K. coccinea* T2 to 1.34 in T1 of the same species at first harvest. By final harvest *A. pulchella* T1 had the highest percentage nitrogen at 0.84 and *H. comptoniana*, also in T1, had the lowest at 0.20.

Discussion

The comparatively low pH of 4.6 for Nakina sand from the sample used suggests the material came from the lower levels of the overburden. In the Muja area some 10 to 40m of Nakina formation sands overlie the Ate Coal Seam (E. McDonald, private communication 1980). A sample taken at depth with a pH of 4.6 had conductivity of ~600 µmhos cm and bases (in meq 100g $^{-1}$) as follows sodium .31, potassium .13, calcium .71, magnesium 1.27.

Each of the tested species is discussed in turn in this section.

As nutrient contents *per se* are likely to fall with increasing woodiness we consider the question of absolute nutrient content changes in this discussion. That is a conbination of the 'all plants' dry weight values of Table 2 with the percentage nutrient contents of Table 4.

a) *Kennedia coccinea* showed a straight forward growth relationship to added lime (Fig. 1) with increased dry weight at successive harvests, though T0 and T1 yields at 33 days were close. This species produced greatest dry matter yields of the five species tested, at 75 days from potting.

The course of shoot length increases did not mirror dry matter production until 9 weeks from planting when heights were ranked T2>T1>T0. Prior to that T1 plants had longest shoots. These also carried more leaves (Fig. 3) over most of the experiment, with T1>T2>T0 for 7 - 11 weeks from planting.

At each harvest the shoot/root ratio was always highest in the unlimed treatment, and always lowest in the higher lime treatment. The ratio S/R fell off at each successive harvest in each treatment. That is as the plants became older a higher proportion of harvested material was in the root portion. At final harvest the mean root weights of *Kennedia coccinea* were greater than for all other species at T1 and T2, and second only to *C. proliferus* in T0. Root weights more than doubled between successive harvests, in contrast to shoot weights which increased much more slowly.

The F/D ratio in *K.coccinea* was generally lower than in other species suggesting more material accumulation into woody tissues. By the final harvest the ratio was lowest in all three treatments within the range of 2.34 to 2.53 (Table 3). At

TABLE 4. Percentage nutrient contents of harvested plants.

SPECIES/NUTRIENT		HARVEST 1 33 DAYS			HARVEST 2 60 DAYS			HARVEST 3 75 DAYS		
	LIME LEVEL	0	1	2	0	1	2	0	1	2
Kennedia coccinea										
Percentage	Sodium	0.74	0.54	0.29	0.07	0.24	0.05	0.04	0.04	0.03
	Potassium	0.26	0.25	0.13	0.04	0.11	0.01	0.04	0.03	0.03
	Calcium	0.03	0.03	0.02	0.001	0.02	0.01	0.001	0.003	0.007
	Nitrogen	0.75	1.34	0.25	0.58	0.64	0.24	0.31	0.28	0.22
Cytisus proliferus										
Percentage	Sodium	0.13	0.12	0.33	0.03	0.05	0.06	0.08	0.04	0.05
	Potassium	0.18	0.14	0.22	0.05	0.06	0.08	0.15	0.06	0.05
	Calcium	0.001	0.001	0.02	0.001	0.01	0.05	0.001	0.002	0.003
	Nitrogen	0.52	0.41	0.50	0.28	0.20	0.31	0.61	0.43	0.28
Hardenbergia comptoniana										
Percentage	Sodium	0.45	0.33	0.19	0.07	0.08	0.07	0.05	0.05	0.14
	Potassium	0.30	0.25	0.22	0.08	0.09	0.08	0.06	0.08	0.14
	Calcium	0.03	0.03	0.03	0.001	0.02	0.02	0.001	0.005	0.03
	Nitrogen	0.94	0.92	0.65	0.41	0.32	0.37	0.67	0.20	0.54
Acacia extensa										
Percentage	Sodium	0.31	0.29	0.24	0.10	0.08	0.12	0.12	0.07	0.12
	Potassium	0.23	0.16	0.16	0.12	0.09	0.10	0.13	0.15	0.13
	Calcium	0.001	0.001	0.01	0.001	0.01	0.02	0.001	0.01	0.03
	Nitrogen	0.73	0.72	0.54	0.54	0.51	0.42	0.55	0.62	0.59
Acacia pulchella										
Percentage	Sodium	0.16	0.50	1.15	0.04	0.06	0.01	0.08	0.16	0.12
	Potassium	0.11	0.32	0.47	0.05	0.07	0.001	0.10	0.16	0.11
	Calcium	0.001	0.04	0.05	0.001	0.01	0.001	0.001	0.02	0.02
	Nitrogen	0.32	0.92	1.06	0.29	0.32	0.23	0.40	0.84	0.47

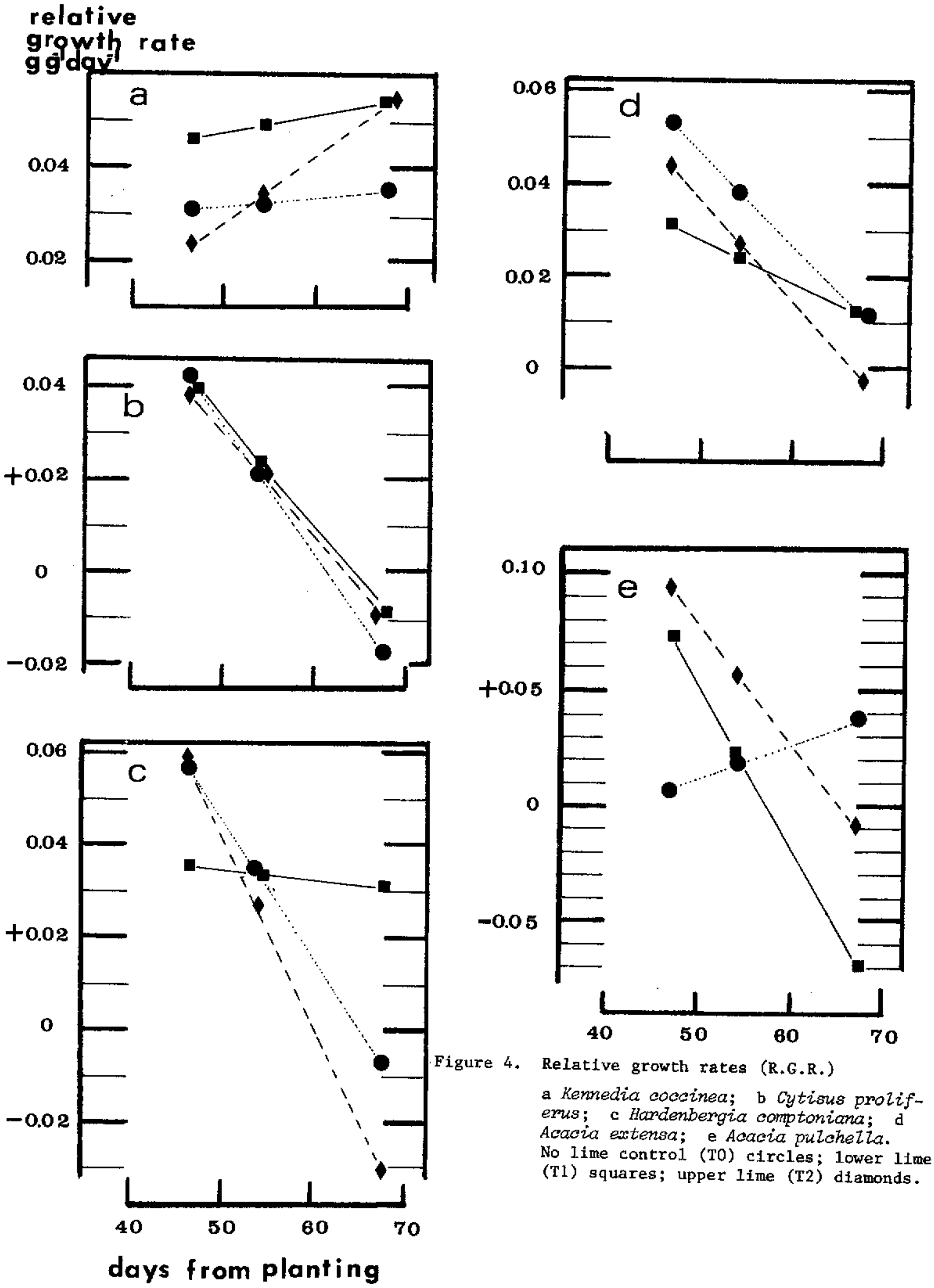


Figure 4. Relative growth rates (R.G.R.)

a *Kennedia coccinea*; b *Cytisus proliferus*; c *Hardenbergia comptoniana*; d *Acacia extensa*; e *Acacia pulchella*. No lime control (T0) circles; lower lime (T1) squares; upper lime (T2) diamonds.

the two earlier harvests the F/D ratios in T1 were second greatest of all species. As noted earlier this species showed a consistent pattern of F/D ratios T1>T0>T2 at each harvest.

R.G.R. rose continuously through the duration of the experiment at all lime levels. Both T1 and T2 had higher R.G.R. than the control towards the end of the experiment, at >0.05 g g^{-1} day^{-1} compared with 0.035 (Fig. 4). The trends were similar in T0, T1 but R.G.R. increased more steeply in T2 from 0.023 to 0.054 g g^{-1} day between harvests. This was the only species in which T2 showed a rise between harvests.

Nutrient contents for plants at T1 were highest in this species at the first two harvests (Table 4), but were generally lowest at all treatments for final harvests. In only two cases did absolute nutrient content show an increase between harvests. These were: calcium in T2 where H1 0.06, H2 0.06 and H3 0.09 mg; and nitrogen also in T2, H1 0.78, H2 1.39, H3 2.88 mg. Sodium exceeded potasium at the first two harvests by the the third these elements were of the same order in each treatment.

Kennedia coccinea was not used in the jiffy pot experiment. However, the related *K. prostrata* was the most productive species of those used. Its pattern of growth did not follow *K. coccinea*, and best growth was in the unlimed soil.

b) *Cytisus proliferus* dry matter yields tended to be rather erratic. Initially this species produced highest dry matter yeilds, but at the final harvest all mean yields were lower than at second harvest, suggesting that conditions were not conducive to extended growth in the media. In most comparisons plants in unamended soil differed least from those in T1. Dry matter production in T2 was always lowest of the three soils (Table 2), as also in the jiffy pot experiment (Table 1). The species outperformed all the others in dry matter yields at first and second harvest, except for *K. coccinea* which had the largest pot in T2 at first harvest, and *H. comptoniana* which had a 2 percent greater mean plant weight in T2 at second harvest. By the third harvest *K. coccinea* had displaced *C. prolierus* except for unamended soil, but even here it had the largest pot. In the jiffy pot trial *C. proliferus* ranked second to *K. prostrata*. *Cytisus proliferus* grew taller than the other plants used in the experiment. T2 plants were consistently shorter than T0 and T1, where mean heights were much closer. Most leaf numbers were produced in T0 plants with T2 plants carrying fewest leaves.

At the first harvest S/R was in the order T0>T2>T1 but at the final harvest the order was T0>T1>T2. This ratio declined steadily in T2 at successive harvests, but increased from 0.23 to 0.46 in T1. Final ratio in T0 was much greater than that at first harvest. While shoot weights increased between successive harvests in T0 and T1, T2 reached a peak at second harvest. Root weights were highest in all three treatments at second harvest.

There was a considerable range in F/D ratios in *C. proliferus* during the growing period. At first harvest all three treatments fell between 3.5 and 4.0 with T0>T2>T1. By the second harvest the range was 2.1 - 2.9 with T1>T2>T0 and at the final harvest the range was 2.9 to 4.3 with T0>T1>T2.

R.G.R. was very similar for all treatments over each period for which it was calculated. There was a general decline from around 0.04 g g^{-1} day^{-1} between the first two harvests, leading to negative values, (due to final harvest being lighter) for all three treatments between second and third harvests. The decline was marginally steeper in T0.

Although nitrogen content in percentage terms was generally lower than the other species, the absolute quantities of nitrogen were high. Nitrogen was the only analysed nutrient which showed consistent increases (except T2 H2 → H3) in absolute quantities:

T0 H1 2.13 < H2 3.56 < H3 5.92 mg

T1 H1 1.76 < H2 2.52 < H3 4.77 mg

T2 H1 1.65 < H2 2.85 > H3 2.24 mg

These data suggest that at increasing lime levels there is a decrease in nitrogen uptake in this species.

c) *Hardenbergia comptoniana.*

This species shared a marked response to liming by the first harvest, but by the second individual plant mean weight in T2 was much greater than T0, T1 which were close. At the final harvest best yield was at T1 and both T0 and T2 were less than at the second harvest. In the jiffy pots ranking was T2>T1>T0 after 76 days.

This climber is a common plant on coastal limestone areas e.g. in the tuart forest. It is difficult to assess in pot trials as the twining nature of the leading shoot causes difficulties in measurement. Plants leaf out basally to different degrees also. There was very little difference in mean plant height over the period of the experiment (Fig. 2) and leaf number declined after the second harvest (Fig. 3). However, leaf numbers were fairly consistently T2>T1>T0. Lower leaf numbers in jiffy pots (Table 1) suggests some loss of performance due to constriction. Shoot/root ratio was much the same at each of the three harvests being 0.45 to 0.50 at first harvest, 0.24 to 0.35 at second harvest, and 0.23 to 0.31 at the final harvest. The ratio was highest in T0 at the first harvests, lowest in the final harvest. Both root and shoot weights increased between harvest 1 and 2 for each treatment. Thereafter root and shoot weights were both lower for T2, and root weight was the same in T0 where shoot weight declined. In T1 both increased between second and third harvest.

The F/D ratio varied between 4.9 in T0 at first harvest to 2.6 in T2 at second harvest. There was no consistent pattern other than that T0 and T1 were closer than T2. At the first two harvests T0 and T1 were > T2, but at final harvest T2 >T0>T1 was the pattern. This ratio tended to be amongst the higher of the species considered for *H. comptoniana*. Ratios were also highest at T1, T2 in jiffy pots (Table 1).

R.G.R. in *H. comptoniana* was initially high in T0 and T2 at > 0.05 g g-1 day -1 but declined steeply in these two treatments to negative values between the final two harvests. T1 showed little change, declining slightly from 0.035 to 0.032 g g^{-1} day $^{-1}$ over the period of measurement.

Percentage nutrient composition was high in T0 at first harvest and lower at T1 and T2 (Table 4), consistently for all nutrients analysed. This pattern did not persist, and was reversed such that by third harvest ranking was T2>T1>T0 for sodium, potassium and calcium. Nutrients tended to increase in absolute terms in T2 between harvests, except for nitrogen which was lower at H3 than at H2 these values are as follows.

Sodium H1 0.36 < H2 0.66 < H3 0.83 mg

Potassium H1 0.42 < H2 0.75 < H3 0.83 mg

calcium H1 0.06 < H2 0.19 > H3 0.18 mg

and for nitrogen, values for treatment were:

T0 H1 0.85 < H2 1.72 < H3 2.55

T1 H1 1.47 > H2 1.31 > H3 1.30

T2 H1 1.24 < H2 3.48 > H3 3.19

There is a strong suggestion here that higher lime levels are associated with increased nitrogen uptake as well as potassium and sodium.

d) *Acacia extensa*

Except for largest pot weight at first harvest all sets (Table 2) showed best response to the lower lime level. This produced plants of consistently greater mean weight than no lime and the higher level of lime. The same was true of the more limited jiffy pot trial (Table 1). Heights increased steadily through the experiment with the pattern T1>T0>T2 well established by 8 weeks, phyllode number followed the same pattern.

Shoot/root ratios were similar within successive harvests. In each case the pattern was T2>T1>T0. Ranges were 0.18 to 0.55 for T0, 0.28 to 0.58 for T1 and 0.31 to 0.58 in T2, with lower values for each treatment at first harvest, and higher values at third harvest. Shoot weights increased steadily through the growing period, as did root weights except for T2 between second and third harvests where there was a small decline. Both weights were consistently higher in T1 at each harvest.

The F/D ratio was characterised by a comparatively low spread in values between treatments at each harvest. At each harvest this ratio was always higher in T1 than in T0 or T2, which were closer together. The values were highest for all species at second harvest (Table 3) but at the lower end of the range at the other harvests. The total range in F/D was from a high of 3.8 in T1 at first harvest to a low of 2.9 in T0 at second harvest. Values in the jiffy pot experiment were much higher, reflecting the much lower dry weight yields there, probably due to constriction.

The R.G.R. for *A. extensa* showed continuous decline. Unaltered soil material (T0) had highest values throughout and T1 declined less steeply than T0, T2. Only T2 reached a negative value towards the end of the experiment. Initially only *Hardenberia comptoniana* performed better in T0 but only in T2 did *A. extensa* show a higher R.G.R. than other species except for *K.coccinea* towards the end of the experiment.

This species showed better nutrient uptake in absolute terms than the other species, with 9 cases of increases across harvests within a treatment out of a possible 12 (4 nutrients analysed x 3 treatments). These were as follows:-

Sodium T0 H1 0.40 < H2 0.54 < H3 0.85

Potassium T0 H1 0.30 < H2 0.65 < H3 0.85
T1 H1 0.50 < H2 0.64 < H3 1.26
T2 H1 0.27 < H2 0.55 < H3 0.69

Calcium T1 H1 0.003< H2 0.07 < H3 0.08
T2 H1 0.02 < H2 0.11 < H3 0.16

Nitrogen T0 H1 0.95 < H2 2.92 < H3 3.58
T1 H1 2.23 < H2 3.62 < H3 5.21
T2 H1 0.92 < H2 2.31 < H3 3.13

(all values in mg)

Percentage nutrient contents were generally low at first harvest in comparison with the other species, but were generally highest at the second two harvests. The data suggest that T1 provided best conditions for nitrogen and potassium uptake.

e) *Acacia pulchella*

Apart from *Cytisus proliferus* this species produced greatest mean weights by first harvest in untreated soil. Growth in the untreated material was steady and consistent. In treated soil lower weights were producedat the third harvest than at the second suggesting that amended soil was not producing optimum growth. Growth in jiffy pots was very poor through all treatments. Height growth of *A. pulchella* was poorer than *C. proliferus* and *A. extensa* the other shrubs used in this experiment. Only after the second harvest did a burst in height growth take place. This established the pattern T0>T2>T1 and coincided with a doubling of foliage in T0 (Fig. 3).

Root dry weights increased through successive harvests in T0, as did shoot weights, and the S/R ratio rose from 0.18 at first and second harvests to 0.29 at the third. The pattern was not clear in the other treatments. In T1 S/R was highest at third harvest, and in T2 it was highest at second harvest. Root weight in T1 was highest at second harvest as was shoot weight. In T2 root weight was highest at third harvest, but shoot weight was highest at second harvest.

The F/D weight ratio for *A. pulchella* showed the greatest range in values from 7.5 in T2 at first harvest to 2.2 in T2 at second harvest. The only consistent pattern in this ratio was that the values for all three treatments declined from first to second harvests, and then rose again at the final harvest. The ratios for T1 and T2 were greatest of all species at the third harvest, suggesting addition of lime was coincident with less woody development generally.

R.G.R. in *A. pulchella* showed greatest change over the experimental period. Initially, both T1 and T2 had higher values than the other species, whereas T0 had the lowest value recorded between the first two harvests. While T1 and T2 declined steeply with T1 showing the steepest decline, T0 increased to give a final R.G.R. of 0.035 g g^{-1} day^{-1} the same as that for *K. coccinea.*

In percentage terms nutrient uptake was highest in *Acacia pulchella* (compared with the other species) at higher lime levels in first harvest and at T1 at the final harvest (Table 4). Nitrogen contents increased in absolute terms (mg) as follows

T0 H1 1.06 < H2 1.13 < H3 2.64

T1 H1 0.92 < H2 2.27 > H3 2.10

T2 H1 0.42 < H2 1.13 < H3 2.02

suggesting that nitrogen uptake was not inproved at higher lime levels. The only other nutrient to increase in absolute terms through the course of the experiment was calcium in T0, to be treated with some caution.

f) *Acacia rhodoxylon*

This species has been found useful on coal wastes at Collinsville (A. Hay, personal communication, 1978). Unfortunately its generally poor growth in the jiffy pot trial (Table 1) provides little information for discussion.

The more general rehabilitation programmes for coal wastes involve creation of pastures. For example in Queensland Rhodes and Buffel grass are used to re-establish low grazing intensity pastures. [3] There lime has some beneficial effect on soil conditions at rates > 1.5 t ha $^{-1}$. Soils of low pH will inevitably give lower growth[5] than less acid soils. It has been estimated that lime needed to bring the pH of spoils from 4.1 to 6.5 would be of the order of 12.5 t ha^{-1} depending on depth.[2]

At present the types of rehabilitation preferred in the Collie area are open. If pastures are to be grown then it must be noted that legume based pastures while improving soil fertility by increasing soil nitrogen and organic matter also build up soil acidity. [5] While many legumes have an appreciable calcium demand there is no evidence that calcium plays any role in nitrogen fixation. It is probable that pH tolerances in legumes depends partly on their tolerance to aluminium ions and partly on calcium requirements. Some clovers can fix nitrogen in soils of pH 4.2 to 4.5 although these generally respond to liming; many tropical legumes can fix nitrogen actively at these low levels of soil acidity provided they can extract calcium from the soil. [5]

The option of conversion of waste areas to native shrubs, and possibly trees, is the one explored here. The introduced *Cytisus proliferus,* though found on many areas of waste land, seems not to benefit from reduced acidity and could well be used as a stabilising pioneer species in association with *Acacia pulchella* on unimproved spoils. Of the ground cover species, *Kennedia prostrata* may be the most useful but further work is required to confirm acid tolerance in this species.

Conclusions

Overall dry matter production was rather more at the intermediate lime level than without any amendment. The higher lime level and unamended soil gave about the same level of production.

The greatest difference in species ranking was for the second harvest at the higher lime level, here mean plant dry weights were as follows

H.c. > *C.p.* > *K.c* > *A.e.* > *A.p.*

plants by pots

C.p. > *H.c.* > *A.p.*> *K.c.* > *A.e.*

and

largest pots

C.p. > *A.p.* > *H.c.*> *A.e.* > *K.c.*

Kennedia coccinea showed best dry matter production with the heavier lime treatment, and for harvests at 60 and 75 days, lowest dry weights with zero lime. In *Cytisus proliferus* heavier lime consistently lowered dry weights. *Hardenbergia comptoniana* showed greater early growth at heavier lime, but final harvest was better at the low lime level. *Acacia extensa* showed best growth in low lime throughout. In *Acacia pulchella* early growth was best with no lime, as was the final harvest. At the middle harvest no lime gave the poorest weights.

The results confirm acid tolerance in *A. pulchella* and suggest that *C. proliferus* may behave similarly. Both *Hardenbergia comptoniana* and *Kennedia coccinea* (the latter more so) perform best on non-acid soil, and *A. extensa* responds to a slight change in pH.

Acknowledgements

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GERMINATION OF SANDALWOOD SEED

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Introduction

The re-establishment of Sandalwood, *Santalum spicatum*, in the field requires the growth of large numbers of seedlings, and this in turn means the germination of many seeds. It was considered advantageous to develop a simple method for the germination of sandalwood seeds. Several methods had been tried previously[1] including the method used for germinating quandong seed[2]. All these methods involved complex preparation of the seed and controlled conditions for germination. The method described in this paper was devised by Ms Mara Bergs and provides a very simple method for the germination of sandalwood seeds.

Method

The method for germination of sandalwood seed currently used in the School of Biology, WAIT is outlined in Figure 1.

Results and Discussion

The position of the incision in the hard endocarp is not critical as it merely allows the entry of water and oxygen to start the germination process. The incision is not always the point of exit of the radicle as the force of germination tends to split the endocarp in several places (Fig. 1-3).

Contrary to the findings of Grant and Buttrose[2] the most successful germination rates of sandalwood seed have been with fresh seed. Germination rates of 75%-80% are achieved with seed that is germinated one to four months after collection from the tree. This rate decreases to 40%-45% for seed that has been stored for twelve months or longer.

The use of fungicide powder and solutions, controls most of the fungal growth. Any fungi that grow during the germination time can be killed by a further dusting of powder or spraying with a weak solution of benlate. This does not effect the seeds that have germinated.

Acknowledgements

This work has been financially supported by the Sandalwood Research Institute. Thanks are expressed to the W.A. Forests Department for providing sandalwood seeds, and to Ms Mara Bergs for invaluable help in developing the method.

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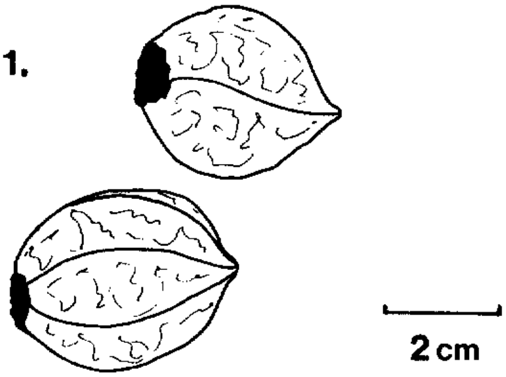

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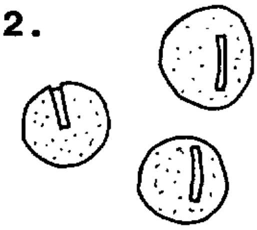

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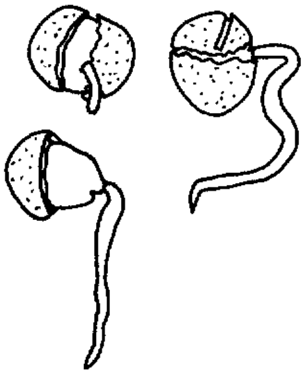

1. The brown, dry outer flesh of the seed is removed.

2. A 5-8mm split is made in the smooth, hard endocarp using a band saw. The seeds are held in wooden tongs for safety and ease of handling.

   The seeds are then dusted with a fungicide powder (e.g. Thiram).

   The seeds are placed between hessian sacks that have been soaked in a fungicide solution (e.g. 5% benlate).

   The bags are kept moist in a glasshouse with a mist watering system.

3. The seeds are ready for planting when the radicle is 4-5cm. long.

GERMINATION AND EARLY GROWTH OF *Banksia attenuata* R.Br. WITH DIFFERENT FERTILIZER TREATMENTS

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Introduction

Banksia attenuata is a constituent of the natural vegetation on sand plain heath at Eneabba, the site of mineral sands mining enterprises to the north of Perth.[1]

The vegetation of the area has aroused a certain amount of interest in recent years[8,10,15,17,19] and the term 'kwongan' has been used to describe it.[17] Some ten species of *Banksia* occur in the area of which 7 are of limited distribution with *B. attenuata, B. menziesii* and *B. sphaerocarpa* being more widespread.[17] While the latter is often of low bushy stature the former two are tree-like and *B. attenuata* distribution is readily mappable from aerial photography.[17] Both *B. attenuata* and *B. menziesii* reach the norther limits of their distribution near Eneabba.[15] *B. attenuata* avoids lateritic ridges found in the Eneabba area[19], and is generally found near to or on sand ridges.[15] Through much of their distribution these two species (*B. attenuata* and *B. menziesii*) show a wide tolerance of sites, with maximum development on dry sites.[13]

B. attenuata flowers between November and March, with a peak in January. In common with a number of *Banksia* species the proportion of flowers which develop seeds is low.[34]

Two major environmental perturbations need to be considered in relation to future management of rehabilitated areas. These are fire and drought. Both occur in the Eneabba area with major effects on the natural vegetation[15,19].

Banksia attenuata as a sapling may be burnt back to ground level by fire. Sprouts arise from lignotubers and from the upper branches of larger trees.[2] As in many species of *Banksia*[9,26,27] the seeds are held on the tree and follicles open with fire. Seed used in the present study was extracted from cones with the aid of a blow-torch.

In an analysis of the long term effects of drought in the Perth area, Heddle[13] noted a tendency for *B. attenuata* to increase in numbers of stems in runs of dry seasons. In the Eneabba area[15] most drought deaths reported were in the Proteaceae and *Banksia attenuata* was recorded 8 times more frequently as dead than as present as a seedling.

Both *Banksia aspleniifolia* and *B. serratifolia* regenerate from underground rootstocks as well as seed in central New South Wales. These may dominate areas frequently burnt at the expense of *B. ericifolia* which does not have this capacity.

Soils are generally sandy and have been referred to the Bassendean Dune System[17] described by McArthur and Bettenay.[22] Soil samples analysed by Allied Eneabba have yielded 82 to 562 parts per million of phosphorus in the surface 25 cm, with 2-8 p.p.m. of available phosphorus.[17] For the Bassendean sands as a whole figures of <10 p.p.m. P, <100 p.p.m. K and 300-400 p.p.m. N have been reported.[22]

The extraction of mineral sands severely disturbs the native vegetation[27] and restoration of native species to disturbed areas is a difficult problem.

A typical schedule of recommendations for revegetation of mined sites by native species has been described by Specht[30]. A variety of methods has been utilised in the Eneabba area[1,10] In seeking a multiple species mixture, the complications of differential response to various treatments, including fertilizers, suggests that combinations of treatments will give best results. At least small amounts of fertilizer are necessary to compensate for losses due to mining and to maintain the nutrient capital until the newly constituted system attains sufficient maturity.[20]

The objective of the investigation reported herein was to examine the effects of standard fertiliser treatments, contrasted with no treatment on *Banksia attenuata* seedlings. Seedlings in the nursery at Eneabba had been observed to respond well to light urea treatments but little was known concerning its mineral nutrition. In the field *B. attenuata* has not featured greatly in rehabilitation sites[10] and there is a suggestion that early top growth of heath species, stimulated by fertilizer treatment, may not be beneficial for the long-term stability of such vegetation.[33] This view is held despite the fact that seeds released after fire fall onto ground often enriched with ash.[26]

The use of potted, nursery raised plants is favoured at Eneabba in contrast with the practices used in some eastern Australian localities.[27]

The problem of "phosphorus toxicity" has appeared in fertiliser experiments in heathlands at levels as low as 100-200 kg ha^{-1} of superphosphate[31] and 125 kg ha^{-1} (elemental P at 12.0 kg ha^{-1}).[14] Grundon[11] was able to show correlation between high tissue P and the presence of toxicity symptoms. It appears that *Banksias* tend to be unable to avoid luxury consumption of phosphorus.[11]

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Growth problems associated with phosphorus are considered to be due to an imbalance of P and N.[31] Both sodium nitrate and superphosphate alone at 250 kg ha^{-1} reduced the survival of *Banksia ornata*[28], with the effects of superphosphate being more severe. The depressant effect on growth of higher levels of P may be lessened when the supply of other nutrients is also increased.[11],[26] Proteoid roots may increase the efficiency of phosphorus ion uptake.[32]

Initial increased growth on fertilized plots does not continue indefinitely. However life cycles of the constituent species may be accelerated[31] with larger plants produced.[30]

Methods

Grey Bassendean sand was dug from under *Banksia* trees at Bentley. This was left in a vertical electrical plate heat-sterilizing unit for 40 minutes. It was then passed through a 5 mm mesh sieve to remove root fragments and other organic debris.

Batches of sand sufficient to fill 20 12.5 cm diameter horticultural pots per treatment were isolated for fertilizer addition. There were seven treatments as follows:

1. 2P, N, K, Cu, Zn, Mo
2. 2P, K, Cu, Zn, Mo
3. P, N, K, Cu, Zn, Mo
4. 2P, N, Cu, Zn, Mo
5. P, N, K
6. N
7. Nil (control).

A total of 40 pots was assigned to treatment 7. Nitrogen (N) was supplied in the form of ammonium nitrate ('agran') at an equivalent to field application of 50 kg ha^{-1} of the fertiliser. Trace elements, copper (Cu), zinc (Zn) and molybdenum (Mo) were provided in a superphosphate mixture at 90 kg ha^{-1} field equivalent. Phosphorus (P) was also supplied to treatments 1, 2, 4 and 5 as single superphosphate at 90 kg ha^{-1}. Potassium (K) was supplied in muriate of potash at 10 kg ha^{-1}.

Active ingredients in kg ha^{-1} were as follows:

P	15.75	in T 1,2,4
	8.19	in T 5
	7.56	in T 3
N	17.5	
K	5.0	
Cu	0.3	
Zn	0.27	
Mo	0.036	

A layer of inert polystyrene beads was placed in the bottom of the pots and the soil mixtures added. The soil was moistened and two seeds of *Banksia attenuata* (mean seed weight 24 mg) were placed just under the soil surface in early August. Distilled water was used throughout. Initially each pot received 100 ml water three times a week. This regime continued for 4 weeks. By then algal growth was evident on the surface of the pots, so a layer of polystyrene beads was placed over the soil surface. Water was reduced to 40 ml per application, and after a further week, the frequency of watering was reduced to twice a week. After 90 days, in early November, surviving plants were placed under automatic overhead irrigation. The progress of germination was recorded.

Five plants from each treatment were randomly selected for harvest 38 days after sowing. Further harvests were taken at 59, 80, 118 and 150 days from sowing. At harvest each plant was divided into root and stem (i.e. leaves and shoot) sections which were then weighed separately. Plant material was dried in an oven at 80°C for 24 hr and reweighed.

Stem material from the first three harvests was ground up by treatment set. These samples were analysed for nitrogen content using the Kjeldahl technique, phosphorus by the Lovibond method and potassium by flame photometry.

Results

Germination

The first seedlings had germinated 10 days after sowing, 87 per cent of the total germinants had emerged after 14 days and germination was complete by 17 days when 89.1 per cent (overall) of seed sown had germinated. The time course of germination is illustrated by treatment in Fig. 1.

A number of germination values are presented in Table 1 to contrast the progress of germination between treatment sets. Treatments 4 and 5 had the highest percentage germination with treatment 1 giving the lowest. Mean days is a measure calculated by summing the products of numbers of germinants and days from sowing, divided by the total number of germinants. Treatments 5 and 7 gave highest values for this character. The coefficient of velocity is the reciprocal of mean days multiplied by 100.

Peak value is a measure of the steepness of the germination gradient. The cumulative germination is taken at the point where the germination rate slows down and this is divided by the time taken to reach that germination percentage. Peak value was least in treatments 1 and 3 and greatest in treatment 4.

Mean daily germination is obtained by division of the final percentage germination by the number of days from sowing for the last recorded seedling to emerge. This value was greatest for treatment 4 and least for treatment 2. Germination value combines rate of germination and viability, it is obtained as a product of peak value and mean daily germination. Treatment 4 gave the highest and treatment 1 the lowest value for this measure.

Germinative energy is a measure of the strength of the seed. In Table 1 the percentage of total germination attained at 14 days from sowing is given. Treatment 7 had the lowest value and treatment 2 the highest for this measure. Vigour combines energy and germinative capacity and is obtained by division of percentage germinated (at a specific time from sowing, here 18 days) into the value for germinative energy. This may be used as an objective measure for fitness. Seed in treatments 1 and 2 had the highest values for vigour while treatment 5 had the lowest.

Table 1: Germination values for *Banksia attenuata* seed sown in Bassendean sand with fertilisers added.

Value	Fertilizer treatment (see text for details) 1	2	3	4	5	6	7	All/ Mean
First germination (days)	10	11	10	11	11	11	11	10
Last germination (days)	16	17	16	16	17	17	17	17
Percentage germinated	82.5	85.0	85.0	95.0	97.5	90.0	88.8	89.1
Mean days	12.8	12.8	12.8	12.9	13.5	12.9	13.4	13.1
Coefficient of velocity	7.8	7.8	7.8	7.8	7.4	7.7	7.5	7.7
Peak Value	5.5	5.9	5.5	6.1	6.0	5.9	5.7	5.7
Mean daily germination	5.2	5.0	5.3	5.9	5.7	5.3	5.2	5.2
Germination value	28.6	29.5	29.2	36.1	34.4	31.2	29.6	29.8
Germinative energy (14 days)	94	97	88	90	82	92	79	87
Vigour	1.14	1.14	1.04	0.94	0.84	1.02	0.89	0.98

Mean days as defined in Hartmann and Kester[12] the coefficient of velocity of Kotowski[18] peak value, mean daily germination and germination value after Czabator[6] germinative energy and vigour after Loneragan[21].

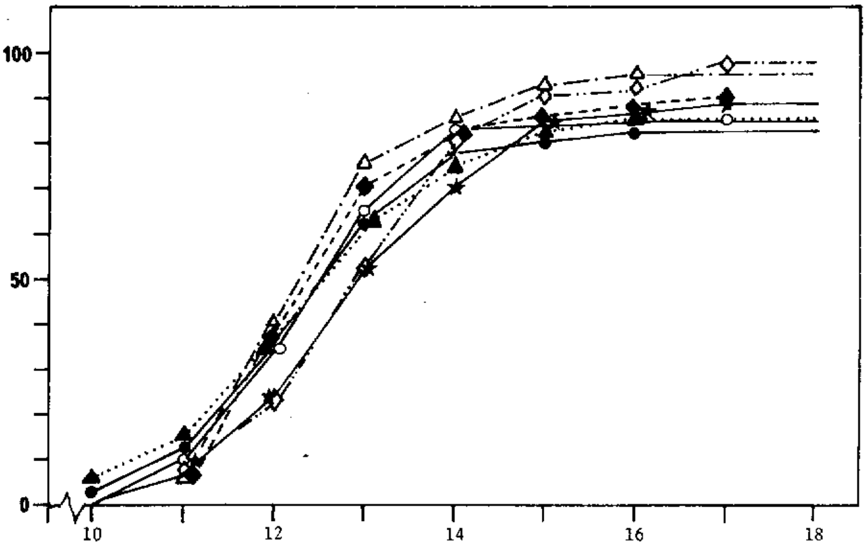

Fig 1 Percentage germination and time from sowing *Banksia attenuata* fertiliser trial. Treatments as follows

T7★——★zero fertiliser . T1 ——● T2 ——○

T3 ……….▲ T4 —.— △ T6- - - - -◆

T5 —..—..—◇

Survivals

Of the 285 plants which had germinated by 17 days from sowing a total of 181 plants were harvested and 104 plants died during the course of the experiment. Harvests took the following numbers: at day 38, 35 plants; at day 59, 40 plants; at day 80, 60 plants; at day 118, 19 plants and at day 150, 27 plants (all remaining).

Fifty seedlings died between days 17 and 38 from sowing. Losses in this period were greatest in treatment 1 with 12 deaths (see Fig. 2 for percentage changes with time). Treatment 6 lost 8 seedlings in the same three week period and survivals were best in treatments 2 (30 of 34 survivals) and 7 (63 of 71 survivals). Altogether 235 plants survived this three week period, a mean percentage survival of 82.5. Treatments 7, 2, 5 and 4 survived better than the overall mean. Survivals in treatment order from best to worst were as follows:

T7 > T2 > T5 > T4 > T3 > T6 > T1

During the period 38 and 78 days from sowing a further 20 plants died leaving 140 alive at day 78. Losses were greatest in treatment 5 where 5 seedlings died, and least in treatment 3 where only 1 of 17 seedlings died. Over this 40 day period the mean percentage survival (excluding the harvested plants at day 59) was 87.5 per cent. Treatments 3, 1, 4 and 7 survived better than the overall mean. Survivals in treatments from best to worst were as follows:

T3 > T1 > T4 > T7 > T2 > T6 > T5

October 24th was a very hot day. The plants were dried out very rapidly and a number of deaths occurred over the period 78 to 80 days from sowing (Fig. 2). A total of 32 plants died of the 140 which were alive

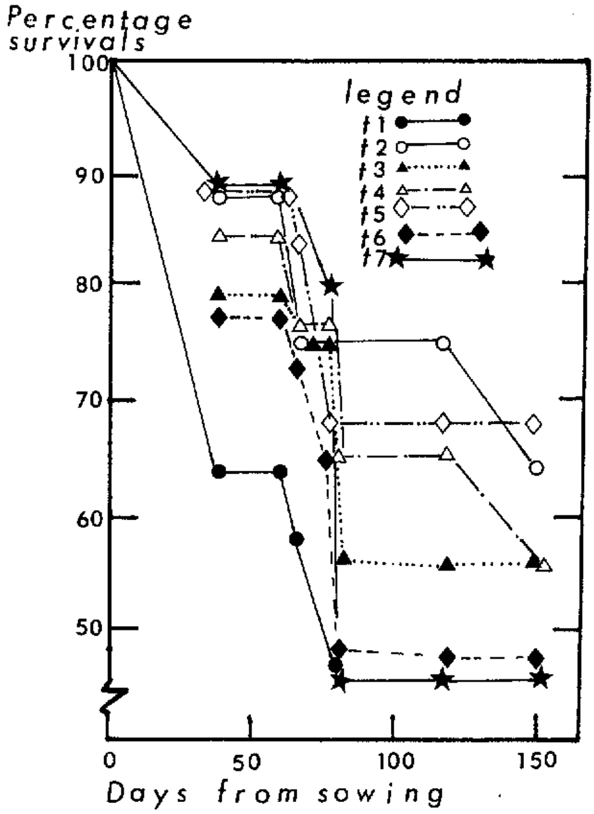

Fig. 2 Survivals as a percentage of germinated plants, with allowance made for harvests.

Table 2: Plants harvested by treatments during the course of the experiment.

Days from Sowing		Fertiliser Treatment 1	2	3	4	5	6	7	Total Plants	Percentage
Harvest 1	38	5	5	5	5	5	5	5	35	12.3
Died before day 38		12	4	7	6	5	8	8	50	17.5
Harvest 2	59	5	5	5	5	6	5	9	40	14.0
Died	39-66	1	3	1	2	1	1	1	10	3.5
Harvest 3	80	7	7	7	7	7	7	18	60	21.1
Died	66-80	2	0	4	3	4	6	23	42	14.7
Harvest 4	118	1	3	3	3	3	3	3	19	6.7
Harvest 5	150	-	6	2	6	8	1	4	27	9.5
Died	118-150	-	1	0	1	0	0	0	2	0.7
Total Plants		33	34	34	38	39	36	71	285	
Per cent harvested		54.6	76.5	64.7	68.4	74.4	58.3	54.9	63.5	
Per cent died		45.4	23.5	35.3	31.6	25.6	41.7	45.1	36.5	

Table 3. Harvest weights of *Banksia attenuata* plants, means by treatment (weights in g).

Days from Sowing		Fertilizer Treatment						
		1	2	3	4	5	6	7
38	Fresh weight (F)	0.27	0.38	0.30	0.37	0.34	0.36	0.32
	Dry weight (D)	0.10	0.11	0.09	0.12	0.10	0.10	0.10
	F/D weight ratio	2.7	3.4	3.3	3.2	3.5	3.7	3.2
59	Fresh weight (F)	0.87	0.76	0.86	0.85	0.94	1.02	1.08
	Dry weight (D)	0.21	0.22	0.20	0.23	0.26	0.26	0.28
	F/D weight ratio	4.1	3.4	4.3	3.7	3.6	3.9	3.9
80	Fresh weight (F)	2.16	2.14	2.40	1.51	1.60	1.87	1.42
	Dry weight (D)	0.72	0.71	0.78	0.61	0.52	0.56	0.46
	F/D weight ratio	3.0	3.0	3.1	2.5	3.1	3.3	3.1
118	Fresh weight (F)	2.35+	3.89	7.39	4.08	3.92	3.58	4.27
	Dry weight (D)	0.96	1.28	2.29	1.40	1.67	1.43	1.23
	F/D weight ratio	2.5	3.0	3.2	2.9	2.4	2.5	3.5
150	Fresh weight (F)	*	5.74	7.09	7.70	10.36	11.79+	8.27
	Dry weight (D)		1.87	2.24	2.25	3.05	3.40	2.50
	F/D weight ratio		3.1	3.2	3.4	3.4	3.5	3.3

\+ one plant only; * no plants left.

at day 78. Of these a disproportionate number died from treatment 7. There were 44 plants alive in this set compared with 96 in treatments 1-6 inclusive from which 13 plants died. The χ^2 of this contrast is 13.39, highly significant.

By this stage a mass of surface rootlets were present near the surface in a number of pots of treatment 7.

The harvest at day 80 took 7 plants each from treatments 1-6 and 18 from treatment 7. The experiment had been planned to finish after this third harvest, but it was then considered useful to continue on with surviving plants rather longer. After the day 80 harvest 48 plants remained, with only 1 in treatment 1 and 4 in treatment 6.

The surviving individual of treatment 1 was harvested at 118 days from sowing, at which time 3 plants from each of the other treatments were also harvested. Between 118 and 150 days from sowing two further plants died, 1 from each of treatments 2 and 4, leaving a total of 27 plants for harvest at 150 days. Of these treatment 6 had 1 individual and treatment 3 had 2. Table 2 summarises numbers harvested and dead by treatment.

Best survivals to final harvest were in treatments 5 (8 plants) and treatments 2 and 4 with 6 plants each. All the plants of treatment 2 were pale yellowish-green in colour at final harvest in contrast with the other treatment plants.

The overall percentage of plants harvested during the course of the experiment was 63.5 (i.e. 181 of 285 germinated). Less than 60 per cent of plants from T6, T7 and T1 were harvested. The best overall survival was in treatment 2 with 76.5 per cent and treatment 5 with 74.4 per cent of plants taken at the harvests (Table 2). Survivals to harvest in order from best to worst were as follows:

T2 > T5 > T4 > T3 > T6 > T7 > T1

Harvest Yields

Fresh and Dry Weights

Table 3 summarises fresh and dry weight means for the seven treatments by five harvests. At 38 days from sowing mean dry weights were very close. Levels ranged from 0.09 g in treatment 3 to 0.12 g in treatment 4, while fresh weight was least in treatment 1 at 0.27 g and greatest in treatment 2 at 0.38 g. Treatment 7, control was intermediate in dry weight. The question of significance with respect to dry weights is discussed below.

The progress of dry weight with days from sowing is illustrated in Fig. 3 where a logarithmic scale is used to accentuate differences. Treatment 3 dry weight remained lowest at the 59 day harvest, but this set then had the highest fresh/dry (F/D) weight ratio at 4.3 - the highest recorded during the course of observations. At the following two harvests treatment 3 had highest mean dry weight. Mean dry weights at least doubled between 38 and 59 days from sowing, with control plants (treatment 7) showing the greatest gain. This was not continued to day 80 when control showed the poorest net gain in dry weight, presumably a reflection of the severe loss of plants in this treatment just previously. Harvested plants of treatments 2, 3 and 4 had lowest dry weights at the final harvest.

Fresh weights increased at a faster rate between 38 and 59 days than did dry weight, in all treatments.

Subsequently, the rate declined and while fresh weight in treatment 7 was highest at day 59, by day 80 this treatment had the lowest mean fresh weight. At day 80 treatments 3, 1 and 2 had greatest fresh weight. Treatment 3 remained highest at 118 days but both 1 and 2 had fallen

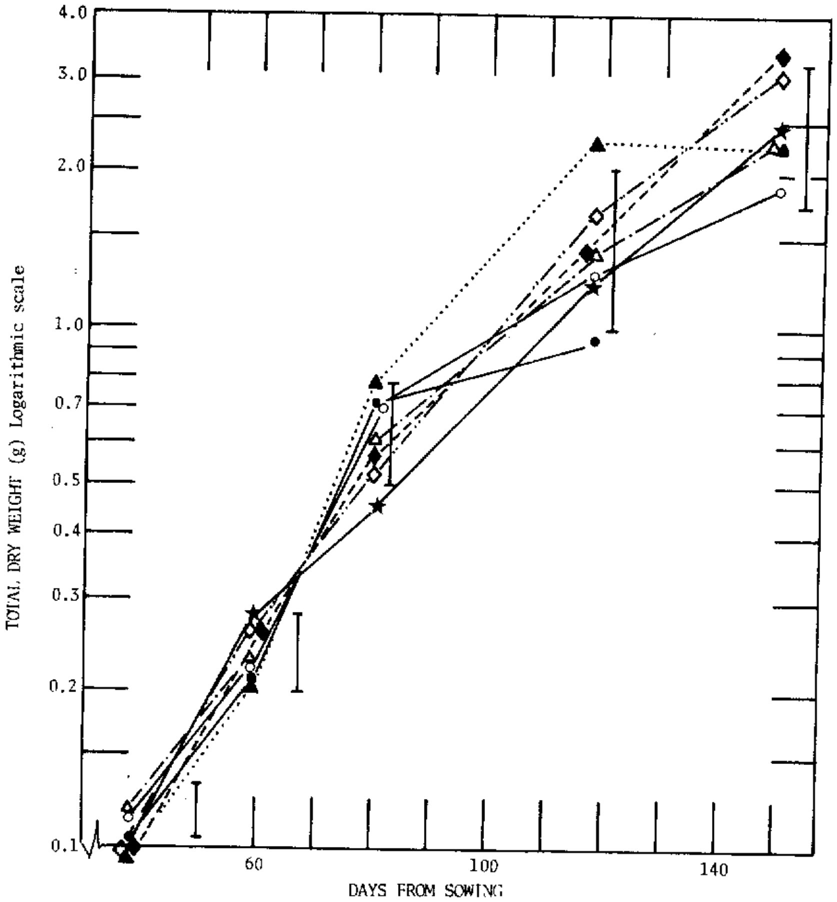

Fig 3 Total dry weight means, values by treatment. Vertical bars represent LSD at p0.05

Treatments ——● 1,
——○ 2, ...▲ 3,
—·—△ 4, —··—◇ 5,
-----◆ 6,
★——★ 7 (zero fertiliser)

behind treatment 7. At termination treatment 6 (1 plant only) had highest fresh weight followed by treatments 5 and 7 with treatments 2 and 3 the lowest.

Fresh/Dry Weight Ratios

F/D weight ratios are illustrated in Fig. 4. The total range in mean ratio was between 4.3 and 2.4. Values tended to be higher earlier on and to decline after the second harvest with a final range of 3.1 to 3.5 compared with 2.7 to 3.7 at the start. Treatments 1 and 3 were erratic over the first few harvests, rather more so than treatment 7. Treatment 7 had an initial ratio of 3.2, this was exceeded in all treatments except 1 and 4; its final ratio was 3.3 with treatments 2 and 3 the only ones lower than this.

Weighted mean F/D ratios for each harvest were 3.3, 3.8, 3.0, 2.9, and 3.3 from first to fifth harvest respectively.

Analysis of Variance and Significance

Each harvest set of dry weights was subjected to an analysis of variance (Table 4). Only at the third harvest was the level of significance normally acceptable in biological investigations approached (0.05). At all other harvests the variance ratio was less than the tabulated value for significance at p 0.20. That is there was a 1 in 5 chance of the results attained occurring in any set of similar trials irrespective of treatments.

Table 4. Analysis of variance on total dry weights of *Banksia attenuata* plants by treatments.

Days from Sowing	Treatment ranking mean dry weight Greatest ---➤ Least Grouping by L.S.D. test p 0.10	LSD (F0.10)	Variance Ratio	
			F	Significance level
38	T4 > T2 > T1 > T7 > T5 > T6 > T3	0.021	1.184	< p 0.20
59	T7 > T5 > T6 > T4 > T2 > T1 > T3	0.069	1.214	< p 0.20
80	T3 > T1 > T2 > T4 > T6 > T5 > T7	0.237	1.956	> p 0.1 < 0.05
118	T3 > T5 > T6 > T4 > T2 > T7 > T1	0.861	1.326	< p 0.20
150	T6 > T5 > T7 > T4 > T3 > T2 > T1	1.277	1.179	< p 0.20

Tukey D test at 5% all differences between means not significant.

The closeness of the dry weight means for the first harvest has been alluded to. The percentage difference between least and greatest was 31 for the first harvest, then 37, 71, 39 and 82 for the subsequent harvests. As the fertiliser treatments are not linear in that they are not additional dosages of the same materials, but differ in their constituents we see some justification here for the use of tests to determine critical differences between means (note the arguments against such tests[7]). However the main effects to be distinguished are the ranking and grouping of responses in respect of dry weight. Critical differences were exceeded at all harvests with Tukey's test, and for most with the L.S.D. test at p 0.05. The body of Table 4 shows grouping derived from the L.S.D. test at p 0.10, a level that may be more appropriate in a pot trial of this nature than the conventional p 0.05. At the first harvest, treatments 4 and 2 gave significantly greater dry weight yields than treatment 3. Treatments 4, 2, 1, 7, 5 and 6 were not significantly different, as also treatments 1, 7, 5, 6 and 3 were not.

By the second harvest only treatments 7 and 3, the heaviest and lightest dry weight yields respectively, were significantly different. At the third harvest, 80 days from sowing, treatments 3, 1 and 2 were significantly different from treatment 7. At the fourth harvest only one replicate of treatment 1 (Table 2) was available, if this were to be included then treatment 1 was significantly different from all other treatments. However the main result, with most credence at this harvest is the difference between treatment 3 and all others. By the last harvest with no treatment 1 and only one plant of treatment 6 (much heavier than the rest) the only significance of note is that treatment 5 was greater than treatment 2.

Fertiliser Component Effects

Each treatment (with its replicates) received a fertilizer mix different from every other treatment. Despite the inherent structural design of the experiment we consider it useful to divide the replicates harvested according to the constituent fertilisers. Thus treatments 1, 2, 3, 4, 5 received phosphorus whilst 6 and 7 did not. Treatments 1, 3, 4, 5, 6 received nitrogen, whilst 2 and 7 did not. Similarly 1, 2, 3, 5 had potassium, and 4, 6, 7 did not; treatments 1, 2, 3, 4 received trace elements and 5, 6, 7 did not.

Mean harvest weights examined in this way differ less than individual treatments as all replicates harvested at one time are assigned to one of only two sets. Table 5 gives mean dry weights for harvested replicates from each of the four pairs of fertiliser presence/absence, with the overall mean dry weight of all plants harvested at each date. The difference in mean weight between replicates with and without each element(s) is given with this value also expressed as a percentage of the overall mean.

As a comparison note that (ex Table 3) the maximum difference at the second harvest between treatments (T7 and T3) was 30.9 per cent of the overall mean, the least difference from the heaviest treatment (T7 and T6) was 5.4 per cent of the overall mean. For the fourth harvest (also ex Table 3) the maximum difference (T3, T1) was 87.7 per cent of the overall mean and the least difference from greatest mean dry weight (T3, T5) was 40.9 per cent of the overall mean.

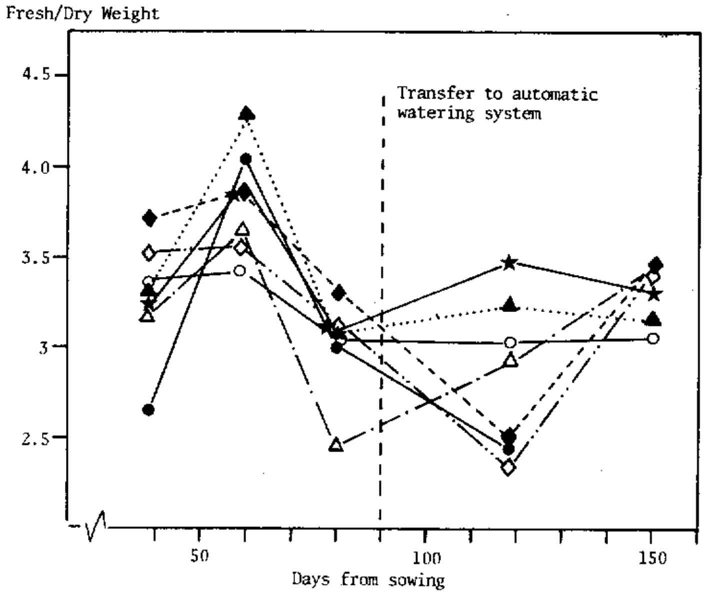

Fig 4 Fresh/dry weight ratios at each of five harvests Banksia attenuata seedlings.

Treatments ——● 1, ——○2, ...▲ 3, —.—△ 4,

—··—◇5, -----◆6,★——★7 zero fertiliser

Table 5. Fertilizer component effects on mean dry weights (g). *Mean values based on replicates containing the element as fertilizer or not* (+ or -)

Days from Sowing		Fertilizer Component								Overall mean dry weight
		+P	-P	+N	-N	+K	-K	+ Traces	- Traces	
38	Mean dry weight	0.103	0.098	0.100	0.106	0.100	0.105	0.105	0.098	0.102
	Number of replicates	25	10	25	10	20	15	20	15	35
	Difference	.005		.006		.005		.007		
	Percentage of overall mean	4.9		6.0		4.8		6.9		
59	Mean dry weight	0.228	0.271	0.236	0.257	0.227	0.261	0.218	0.269	0.243
	Number of replicates	26	14	26	14	21	19	20	20	40
	Difference	.043		0.021		0.034		0.052		
	Percentage of overall mean	17.8		8.8		14.0		21.2		
80	Mean dry weight	0.666	0.488	0.638	0.528	0.681	0.515	0.704	0.494	0.592
	Number of replicates	35	25	35	25	28	32	28	32	60
	Difference	0.178		0.109		0.166		0.209		
	Percentage of overall mean	30.0		18.5		28.0		35.4		
118	Mean dry weight	1.606	1.325	1.639	1.254	1.667	1.351	1.587	1.439	1.517
	Number of replicates	13	6	13	6	10	9	10	9	19
	Difference	0.281		0.385		0.317		0.148		
	Percentage of overall mean	18.5		25.4		20.9		9.7		
150	Mean dry weight	2.433	2.677	2.689	2.121	2.504	2.442	2.084	2.903	2.478
	Number of replicates	22	5	17	10	16	11	14	13	27
	Difference	0.244		0.567		0.062		0.820		
	Percentage of overall mean	9.9		22.9		2.5		33.1		

Table 5 suggests that for phosphorus added initial growth was better, but lower at the second harvest and again greater at third and fourth harvests but lower at the final harvest. The difference was greatest at the third harvest. For nitrogen and potassium added Table 5 suggests that growth was lower for harvests one and two but that thereafter the addition of nitrogen or potassium coincided with increased dry weight. Trace elements followed the pattern for phosphorus, but the difference at the final harvest was almost as great as that at the third.

At the 80 day harvest the Scheffe contrast test showed that P vs no P sets (treatments 1, 2, 3, 4, 5 vs 6, 7) and traces vs no traces sets (treatments 1, 2, 3, 4 vs 5, 6, 7) were significantly different at p 0.05.

Overall greatest differences, as a percentage of the mean dry weight, were associated with trace elements. Presence of nitrogen added showed greatest percentage difference at the fourth and fifth harvests while the other three were most different at the third harvest.

Table 6. Comparison of replicates from treatment sets 1,2,4 (excess phosphorus) and 3,5,6,7 (little or no phosphorus) for mean dry weight (g).

Harvest (days)	Treatment Set 1,2,4 Mean	No.	Treatment Set 3,5,6,7 Mean	No.	Percentage difference from overall mean
38	0.110	15	0.096	20	14.1
59	0.223	15	0.256	25	13.5
80	0.678	21	0.546	39	22.2
118	1.287	7	1.651	12	24.0
150	2.058	12	2.815	15	30.5

* Of overall mean, as in Table 5.

Further analysis specifically related to phosphorus is presented in Table 6 where treatments with the higher level of phosphorus (15.75 kg ha^{-1}) are contrasted with treatments with little or no phosphorus. The first three harvests parallelled the trend of Table 5 but with a greater percentage difference at first harvest and a lower difference at second and third harvests. At the fourth harvest the replicates in the set 'excess phosphorus' had a lower mean dry weight than all other sets and this continued at the final harvest. Both these latter showed a greater difference as a percentage of the mean than the differences between with and without phosphorus.

Shoot/Root Ratio

Successful establishment requires a well developed root system and some balance between shoot and root growth. In a pot trial pot size must constrain root growth to some extent, however provision of equal soil volumes and uniform water application suggests that differences in allocation of resources to shoots or roots would be due to treatment differences.

Shoot dry weight

Shoot and root dry weights from the second harvest onwards are illustrated by treatment in Fig. 5. The pattern of shoot dry weight closely follows that for total dry weight (Fig. 3) reflecting the greater contribution, in this study, of shoots to dry weight accummulation. At the second harvest shoot weight varied from 0.13 g in treatment 2 to 0.19 g in treatments 5, 6 and 7. Thereafter shoot weight increases in treatment 7 were least but followed a consistent, steady trend. At the third harvest shoot weights ranked from greatest to least by treatments were as follows:

T3 > T1 > T2 > T6 > T4 > T5 > T7

We note that treatments 4 and 6 are reversed for total dry weight (Table 4). By the fourth harvest the ranking became

T3 > T5 > T6 > T4 > T2 > T7 > T1

which exactly mirrored that for total plant dry weight. At the final harvest the ranking was

T6 > T5 > T4 > T3 > T7 > T2

which again differed from total dry weight where treatment 7 was greater than treatments 4 and 3.

Final shoot weight for treatment 6, based on only one harvested replicate, was much greater than all other treatments. Generally the rate of increase between fourth and fifth harvests was less (note that in treatment 3 final shoot weight was lower than the preceeding value - Fig. 5) than between the third and fourth harvests.

Root dry weights

By 59 days from sowing mean root weights ranged from 0.05 g in treatment 1 to 0.09 g in treatment 2. Treatments 5, 6 and 7 all averaged 0.08 g. At this harvest all plants had a greater shoot weight than root weight. Increases in mean root weight from second to third harvest ranged from a doubling in treatments 5, 6 and 7 to an increase of >4 times in treatments 1 and 3. By the third harvest root weights ranked from greatest to least by treatments were:

T3 > T2 > T1 > T4 > T5 > T6 > T7

This pattern more or less follows that for total dry rate (Table 4) except that treatments 1 and 2 and treatments 5 and 6 are reversed. At the third harvest one replicate of treatment 2 had root and shoot weight more or less equal, and one of treatment 3 had root weight more than shoot weight.

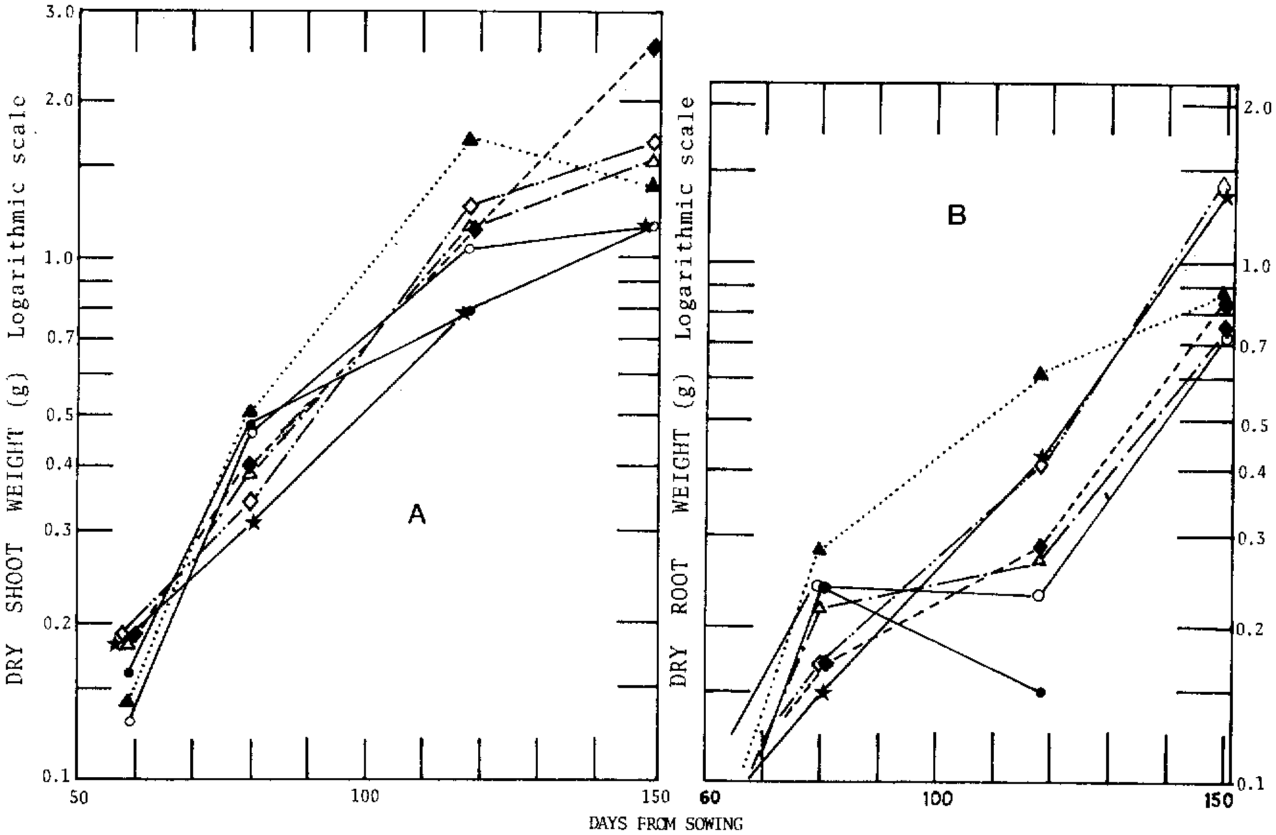

Fig 5 Shoot (a) and root (b) dry weights of Banksia attenuata seedlings
Treatments as follows

——● 1; ——○ 2; ·······▲3; —·—△4;

—··—◇5; — — —◆6; ★——★zero fertiliser(7);

By the fourth harvest root weight ranking was as follows:

T3 > T7 > T5 > T6 > T4 > T2 > T1

Here we note that treatment 7 improved its position considerably, increasing in root weight at a faster rate than all other treatments (Fig. 5). The remaining plant of treatment 1 had a lower root weight than at the third harvest, and the mean weight of roots in treatment 2 declined. Root weight increased less, proportionately than shoot weight, in treatments 4 and 6. At the fourth harvest there were no plants with greater root weight than shoot weight.

At the final harvest root weight ranking was

T5 > T7 > T3 > T6 > T4 > T2

Here the biggest discrepancy between root and shoot weight was with the individual from treatment 6. Of particular note was the fact that two of the four plants of treatment 7 (control) had greater root than shoot weight, and this was sufficient to render the mean root weight greater than the mean shoot weight. Whereas most plants continued to put on good root weights between the fourth and fifth harvests, increasing weight by a factor of 3, the rate of increase in treatment 3 declined.

Shoot/Root Dry Weight Ratios

The ratio of dry weight of shoots (above ground parts - leaves and stem) to roots varied across the experiment from a high of 5.2 in treatment 1 at the fourth harvest (the last remaining individual replicate in this treatment) to a low of 0.86 for treatment 7 at the final harvest. Shoot/root ratios (S/R) are plotted in Fig. 6. At 59 days from sowing S/R ranged from 1.5 for treatment 2 to 3.1 in treatment 4. The spread at 80 days was much less, with all values between 1.8 (treatments 3 and 4) and 2.4 (treatment 6). At 118 and 150 days all treatments with fertilisers had higher S/R than did the control (treatment 7). Treatment 6 continued high to the end and treatment 2 showed most range, if the final value for treatment 1 is ignored. Least range was shown in treatment 3 and treatment 7. Treatments 3 and 5 were most consistently similar to treatment 7 with treatments 6 and 4 most often dissimilar.

Weighted means for S/R were 2.4, 2.9, 3.5 and 1.5 for harvests 2 to 5 respectively.

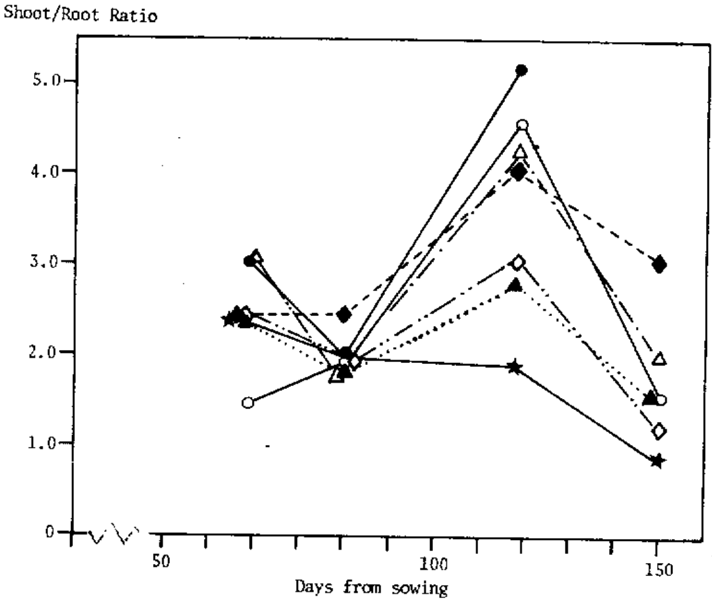

Fig 6 Shoot/root ratio Banksia attenuata seedlings

Treatments ——● 1, ——○ 2, ……▲ 3, —·—△ 4,
—··—◇ 5, ----◆ 6, ★——★ 7 zero fertiliser

Relative Growth Rate

All plants started initial growth from seedling resources. Subsequent growth may be expressed in relative terms as well as absolute terms. The relative growth rate takes account of starting dry matter at a given time point and relates production over unit time to the increase relative to the start of the time period:

$$R.G.R. = \frac{\ln W_2 - \ln W_1}{t_2 - t_1}$$

where W_2 is dry weight at time $2(t_2)$,
W_1 is dry weight at time 1,
$t_2 - t_1$ is time between harvests, so that RGR is expressed in gg^{-1} day^{-1}.

Using mean dry seed weight (24 mg) and data from the successive harvests 5 different time points were used for R.G.R. calculations illustrated in Fig. 7. It should be noted that intermediate R.G.R. points are also plotted (e.g. between fifth and third harvest etc.) for treatment 7. Growth became comparatively constant in treatment 7 at between 0.02 and 0.03 gg^{-1} day^{-1} after about 70 days. By contrast most other treatments showed a decline from then or earlier in R.G.R. values.

At the first station of Fig. 7, 19 days from sowing, (being the mid point for 0 to first harvest at 38 days) the range in R.G.R. was small, from 0.035 to 0.042 gg^{-1} day^{-1}. At the second station two groups became evident, treatments 5, 6, 7 at >0.04 and treatments 1, 2, 3, 4 at <0.04 gg^{-1} day^{-1}. These groups reversed at the third station and treatment 6 steadily declined in R.G.R. from about 50 days onwards. Treatment 5 did not decline in productivity until after 100 days. Treatments 1, 2, 3 and 4 all exhibited sharp increases in R.G.R. at the third station and three of them, treatments 1, 2 and 3 showed a steep decline from the 70 day level.

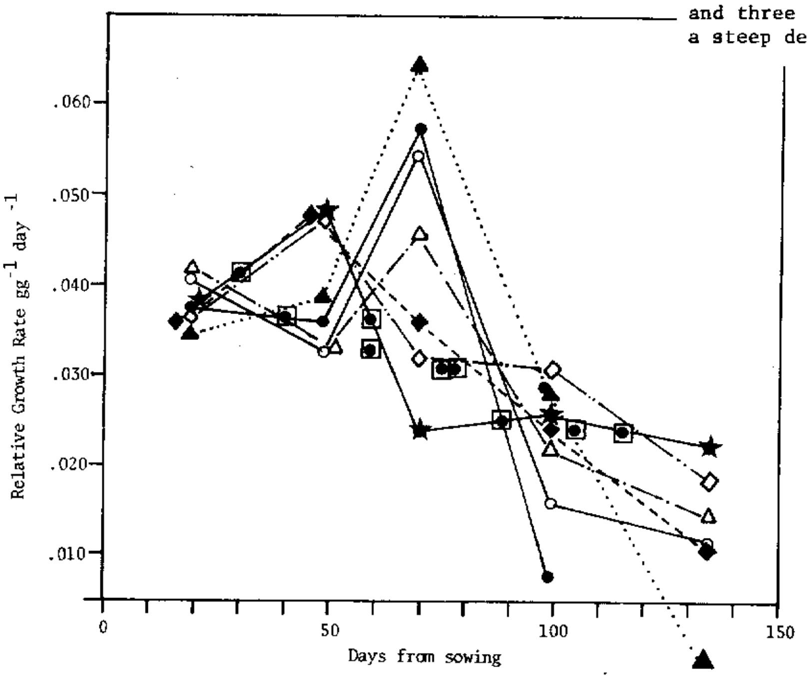

Fig 7 Relative growth rate between harvests, Banksia attenuata seedlings. Intermediate rates ▣ are guides for treatment 7 (zero fertiliser). All lines join rates between successive harvests.

Treatments ——● 1, ——○ 2, ……▲ 3, —·—△ 4,
—··—◇ 5, ----◆ 6, ★——★ 7.

Leaf Area

Leaf area of harvested plants was recorded, after drying, with a planimeter for the final three harvests. Mean plant leaf areas by treatment expressed relative to control (treatment 7) are illustrated in Fig. 8. By 80 days from sowing control plants harvested had mean leaf area of 13.1 cm^2. In treatment 3 leaf area was 18.7 cm^2 and in treatments 1 and 5, 8.6 cm^2. At this harvest only treatments 3 and 4 exceeded control.

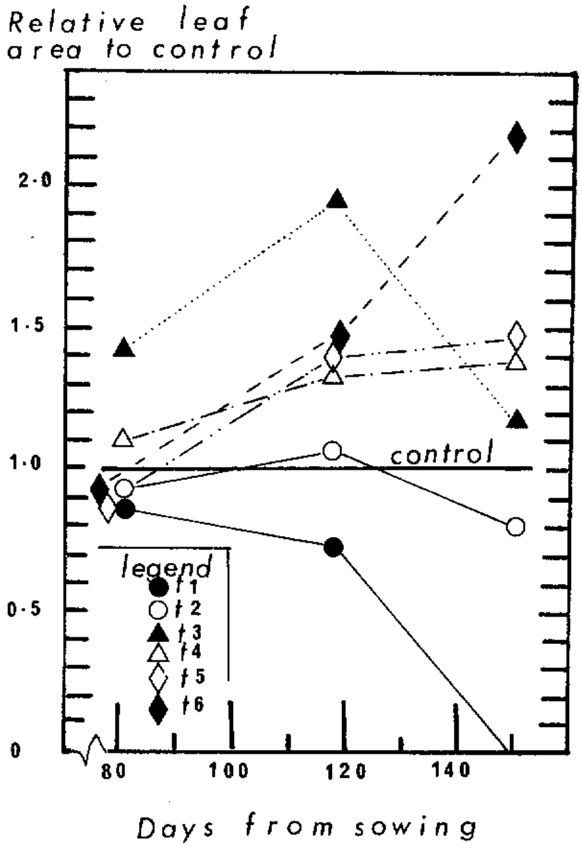

Fig.8 Mean leaf area by treatments expressed relative to control.

At 118 days from sowing control plant leaf area was 34.3 cm^2 and only treatment 1 was less. Treatment 3 showed greatest apparent increase between 80 and 118 days in mean leaf area, however mean leaf area of the two plants left for the final harvest in this treatment was lower. The individual plant of treatment 6 taken at final harvest had leaf area of 111.6 cm^2.

Shoot Heights

Mean heights of survivors by treatment, relative to control, are illustrated for 38, 59, 66, 80, 118 and 150 days from sowing in Fig. 9.

At 38 days from sowing mean heights ranged from 1.5 cm in treatment 1 to 6.4 cm in treatment 7. All fertilizer treatment means were lower than control. The range in mean shoot height decreased at subsequent measurement dates and by 80 days from sowing all treatment means were marginally taller than that of control. Thereafter most treatments were marginally less than control. Treatment 3 plants showed the greatest deviation in height over control for the period 66 to 118 days from sowing.

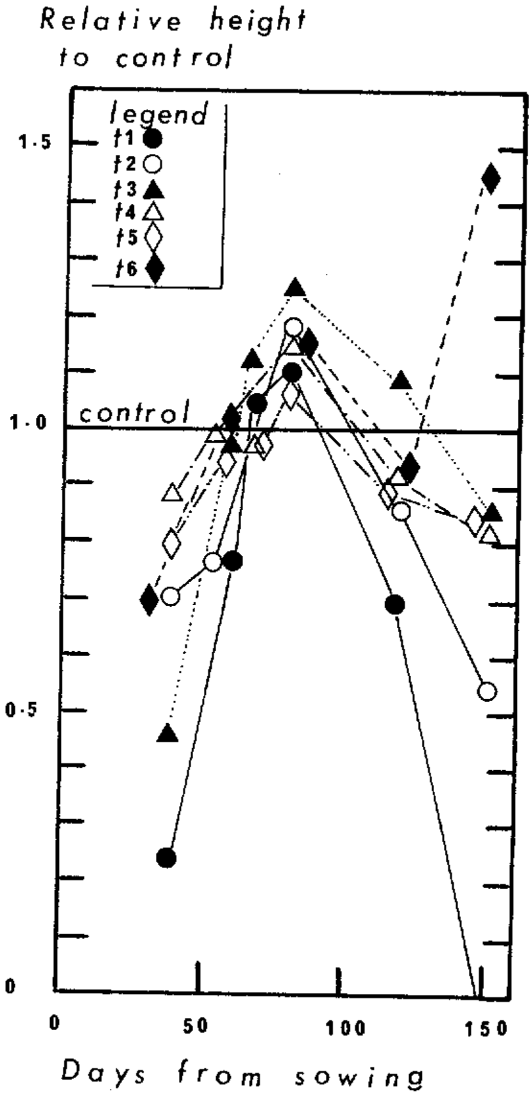

Fig.9 Mean shoot heights of harvested plants of *Banksia attenuata* expressed relative to control.

Table 7. Nutrient contents of *Banksia attenuata* stem and foliage.

Days from sowing		Fertilizer Treatment						
		1	2	3	4	5	6	7
38	Percent nitrogen	2.2	6.5	5.8	4.5	3.9	6.2	6.9
	Potassium (ppm)	5.8	10.0	7.3	12.0	11.0	7.5	8.5
	Phosphorus (ppm)★	10	10	10	2	20	10	10
59	Percent nitrogen	3.2	5.1	3.6	4.4	4.6	4.3	3.6
	Potassium (ppm)	30.0	20.8	27.4	23.0	29.0	23.5	23.0
	Phosphorus (ppm)★	100	20	20	100	100	80	20
80	Percent nitrogen	1.6	1.7	0.6	1.0	1.7	2.0	3.4
	Potassium (ppm)	37.2	34.5	25.0	23.5	34.0	22.8	18.3
	Phosphorus (ppm)★	120	80	60	100	120	80	40

★As P_2O_5

Chemical Analysis

Analysis for N, P, K was restricted to the first three harvests and utilized the shoot material (stem and foliage) only. The results are given in Table 7 in the form of parts per unit of dry matter by treatment. Percentage nitrogen showed a steady decline over the first three harvests in treatments 2, 3, 4, 6 and 7 while the levels of potassium and phosphorus generally increased. Highest phosphorus levels were recorded at the third harvest, and also for potassium except in treatments 3, 6 and 7.

Discussion

The species of *Banksia* clearly differ in their response to phosphate fertilisers.[14] *Banksia oblongifolia* (coastal Queensland heath) showed little or no response to 1250 kg ha^{-1} equivalent in pot trials and 1600 kg ha^{-1} equivalent in a bush trial.[5]

In South Australian studies[28] *B.ornata* 12 yr from fire decreased in numbers and showed chlorosis with 1400 kg ha^{-1} of superphosphate, but in another experiment on 5 yr old regeneration from fire there was a marked growth response by this species to phosphorus applied as $NH_4H_2PO_4$ equivalent to 1000 kg ha^{-1} of superphosphate.

After 22 years the 1400 kg ha^{-1} P plots density figures showed *B.ornata* absent. On the other hand *B.marginata* had about the same numbers, but both cover and mean heights for this species were significantly greater on P plots, *B.ornata* declined in cover and height compared with unfertilised controls.[14]

Biological variability imposes a number of constraints in considering the usefulness of the results presented here. This problem is not confined to pot trials and much of the field work which forms the basis of the accepted theory of "phosphorus toxicity" in relation to *Banksia* has involved difficult problems of interpretation. For example observations on longevity and growth involving *B.ornata* in relation to superphosphate application have involved interpretation of bushfire effects on regenerative potential.[14] Similarly some pot trials have involved losses[32] which have removed certainty, in a statistical sense, from the results.

Natural soil levels of phosphorus were not calculated but are believed to be <10ppm.[22] In the present case the levels of fertilizer used (maximum P to 180 kg ha^{-1}) were generally lower than those reported in the literature, reflecting the concern shown for avoiding excessive weedy growth in rehabilitated sites. Some blurring of effects and indecisive results would not therefore be unexpected.

Germination

Germination was entirely unaffected by treatment. Other workers have found similar results with a range of species e.g. *B. aspleniifolia, B. ericifolia* and *B. serratifolia* using solution culture.[26] In addition to a lack of response to substrate in *B. aemula, B. integrifolia* and *B. serrata* (Sonia and Heslehurst[27]), no improvement in germination was obtained with light or with seedcoat treatments. In the field no effect of fertilizers on germination of *B. ornata* has been evident.[28]

Nevertheless, the usual precautions require to be followed, should seeding be used instead of transplants, to avoid fertilizer contact.[23] We note the suggestion that phosphate drilled into the soil may affect plants differently from phosphate dropped onto the soil surface.[4]

Mobility of P may be related to rainfall and depth of sand remaining after mining.[20]

Sonia and Heslehurst showed a marked sensitivity of germination to temperature.[27] In their three species germination occurred in much shorter times at optimal temperatures than that taken with *B. attenuata*. We assume that warmer temperatures would result in faster germination of this species. For outplanting of potted plants a later start to germination would be usual, with the plants kept in the nursery through one summer and planted with the first rains (May) of the following autumn.

Survival

Field out planting of transplants will inevitably lead to losses. Field losses may be associated with poor handling, unbalanced shoot/root development, or differential access to moisture. In the greenhouse trial losses are believed to have been due to two main causes, the direct effect of fertilisers and losses due to excessive drying out.

Internal water characteristics of *B. serrata* have been examined.[33] Additional water increased growth rates but fertilizer alone had no effect; it was suggested that stress conditioning may assist seedlings to withstand subsequent additional stress.[33]

The effect of water supply on growth in different sand/loam mixtures has been investigated in *B. asplenifolia*, *B. ericifolia* and *B. serratifolia*.[24] Dry matter production at about 17 weeks from sowing for *B. asplenifolia* was greatest in 60 per cent sand with daily watering. In all sand this species produced greatest weight with a one day interval between watering; proteoid root development was much greater in this treatment than in the sand loam mixture. *B. ericifolia* produced greatest dry matter in all sand with daily watering, this treatment had greatest proteoid root development. In *B. serratifolia* 40 per cent sand produced greatest dry weight (with no proteoid root formation) at daily watering; in all sand greatest dry matter production was achieved with a 4 day interval between watering, and this treatment had greatest weight of proteoid roots.[24] *B. serratifolia* grows naturally on similar substrates[24] to *B. attenuata* and our initial watering regime would have been not dissimilar to that producing maximum dry weight in all sand by *B. serratifolia*.

In the present experiment with *B. attenuata* the watering regime was uniform for all plants in all treatments. Most fatalities around October 24th were from treatment 7, zero fertilizer. Here proteoid root development was greatest with a mass of roots near the soil surface in a number of pots.

There is a strong indication then that with no added fertilizers *B. attenuata* will produce more proteoid roots and in the pot/glasshouse environment such plants are more susceptible to heat induced drought. Under field conditions we would not necessarily expect the same degree of loss as some roots would be quite deep. The change in water supply imposed at 90 days from sowing may have affected survival rates (as well as overall growth) but as all treatments were affected we cannot assess any fertilizer/water interaction.

Survival has been shown to be adversely affected by large supplements of phosphorus and by potassium in *B. serratifolia*.[26] In *B. ornata* increased growth may occur with nitrogen or phosphorus but the combination may reduce chances of survival.[28]

B. attenuata showed 57 deaths in treatments with phosphorus against 121 harvests, compared with 47 deaths without phosphorus and 60 harvests. The χ^2 for this contrast is 3.58 ($> p0.10 < p0.05$) suggesting that survival was better in the phosphorus added treatments. Other fertilizer component contrasts differed much less. This overall summary masks some other differences. If all plants which survived the first three weeks after germination are considered, during which time losses were particularly high in treatment 1, the following percentage survivals are obtained:

XSP 79	+ N79	+ K80	+ Tr79	Control 89
+P 84	- N93	- K85	- Tr86	Overall mean 83
-P 85				

These early results suggest then that each of the fertilizer components added was associated with more plants lost than without it. In particular we note highest survivals in treatment 7 (control) and treatment 2 (XS P, no N) and lowest survivals in treatment 1 (XS P + N) and treatment 6 (+ N). Thus nitrogen alone or nitrogen with high phosphorus gave most deaths to 38 days from sowing.

The three treatments discussed here in terms of effects viz droughting treatment 7; and treatments 1 and 6 highest early deaths, were those which provided fewest plants (of those germinated) for harvest during the course of the experiment.

Dry Matter Production

The utilization quotient (UQ) where

$$UQ = \frac{\text{g dry matter produced}}{\text{mg content of element}}$$

was calculated for shoot material (Grundon[11] used the whole plant). For nitrogen these values ranged from

0.045 in T1 to 0.014 in T7 at 38 days
0.031 in T1 to 0.020 in T2 at 59 days
0.167 in T3 to 0.029 in T7 at 80 days

and compare with Grundon's levels of 0.04 to 0.06.

There was an exact pattern of consistently higher values with lower percentage nutrient contents such that ranked values for Table 7 would be reversed. Dry matter production was inversely proportional to the proportion of nutrients in the shoots.

Initial yields and R.G.R. were similar suggesting that in the short term the different nutrient combinations had exerted little effect on growth of survivors.

Seed reserves of phosphorus in *Banksia grandis* (seed weight 79 mg) are sufficient to allow 22 weeks of growth with no phosphorus deficiency[3]. For a number of heathland Proteaceae with largish seeds around one percent of the dry weight of seeds is phosphorus.[11,16]

The following seed weights have been recorded:

B. aemula	113.2 mg[11]
B. asplenifolia	17.7 mg[26]
B. attenuata	24.0 mg (present report)
B. ericifolia	22.5 mg[26]
B. grandis	79.0 mg[3]
B. oblongifolia	21.2 mg[11]
B. ornata	33.0 mg[32]
B. serratifolia	153.3 mg[26]

It may take longer for P to reach "toxic" levels in tissues of species with larger seedlings from larger seeds.[26] For example *B. serratifolia* took longer to develop "toxic" symptoms than *B. asplenifolia* and *B. serratifolia*. Grundon found P at harvest similar to that in the seed when *Banksia* plants were grown at low P levels.[11]

The 3 species of *Banksia* reported by Siddiqi et al[26] produced plants with dry matter content of 20-35 times original seed weight over 22 weeks from sowing. In *Banksia grandis* Barrow noted a 30 fold increase over seed weight of 79 mg in a similar period.[3] In our case the 150 day yield for control plants was 104 times seed weight.

The best long term survivals were in treatments 5, 2 and 4. Chloritic symptoms were evident in plants of treatment 2 by final harvest. Grundon observed an interaction with nitrogen or potassium and high phosphorus level reduced the uptake of P and decreased toxicity symptoms.[11] We presume that the absence of nitrogen from treatment 2 may have influenced the chlorosis in this treatment.

Grundon recorded toxicity symptoms with levels of P in shoot material > 1.03 per cent.[11] These levels were not reached in material analyzed from the first three *B. attenuata* harvests but it is possible that high tissue P (not analyzed) may have been reached. The time may be critical, as the growing season was well advanced. In the case of *B. ornata*, which produced chloritic spots in high P levels in water culture, more P as orthophosphate was found in plant tissues at low levels of P substrate coincident with the period of active field growth.[32]

Between 59 and 80 days from sowing treatments 3, 2 and 1 produced greatest fresh weights and highest increases in fresh weight. These treatments also showed greatest gains in dry weight. The general fall in F/D weight ratios from 59 to 80 days may have been associated with the drying effects of the hot spell just prior to the third harvest. A subsequent increase in F/D ratios for treatments 7, 3 and 4 may have been due to increased water availability after the 90th day (Fig. 4). However, there seems to be no straightforward explanation as to why the F/D ratio should have been at its highest in all treatments at the 59 day harvest.

Treatments 1 and 3 (presence of potassium and traces, with phosphorus and nitrogen) exhibited the most erratic F/D weight ratios over the first three harvests.

Dry weight production is likely to provide the best index as to behaviour in terms of field establishment, providing that root weight is satisfactory.

In Grundon's experiment dry matter production tended to rise with increased nutrient levels, over a narrow part of the range of N or P used by him. Depression of yield at low N or P was less than the severe depression recorded at high levels of P.[11]

In the case of *B. ornata* total dry weight 46 weeks after sowing ranged from 2.2 g for low phosphorus levels to 8 g at high levels.[32] The shoot/root ratio for these plants was between 1.5 and 2.0 for low phosphorus levels and rose steeply at the highest level. In *B. grandis* the shoot/root ratio was around 4.0.[3]

At 118 days the three high P treatments: 1, 2, 4, had highest shoot/root ratios (Fig. 6). These treatments also had lowest root weights at both 118 and 150 days from sowing (Fig. 5). This is similar to the New South Wales *Banksia* species[26] where root development under all regimes of added phosphorus was curtailed.

Banksia grandis had a low relative growth rate (compared with other species tested[3]) at $0.026\ g\ g^{-1}\ day^{-1}$. Low relative growth rates were noted by Grundon, who suggested that these may be of survival value in poor soils. His *Banksia* plants grew within the range 0.03 to $0.06\ g\ g^{-1}\ day^{-1}$.[11]

Treatments 1 and 3 achieved the highest R.G.R. between days 59 and 80, but R.G.R. in these subsequently declined dramatically (Fig. 7). It may be presumed that treatments 1, 2, 3 and 6, which all showed steep declines in R.G.R. after about 60 days, carried more fertilizer than the plants could tolerate in the medium-term establishment phase. Although R.G.R. in treatment 5 declined, its pattern of change was similar to that for treatment 7.

Longer-term Considerations

Watering regimes in pot trials rarely show any relation to natural rainfall levels. This experiment is no exception. The fate of transplants often depends on the first few weeks' soil moisture conditions. Greatest effort requires to be put into the more dominant species in developing a suitable matrix. It has been noted that only dominant native species from mined sites will achieve long term stability without later treatment (long term meaning through 1 or more fire cycles).[30]

Assuming adequate P (and other major nutrients) content in the seed combined with the added fertilizer in the nursery soil, how well could the plants do in the field? The soil concentration ex planting will be much less than a uniform field dressing of fertilizer, even though it would be much more localised.

Providing liberal quantities of fertilizers are avoided it would appear that other species in the vicinity would be able to adjust. However, it has been suggested that significant changes may become apparent many years later.[31] Other things considered the soil nutrient levels following fire may return to pre-fire status within a year or so of burning.[25]

The massive mineralization which follows fire has been contrasted with rates of recycling likely when dead plants decay following drought.[15] Should drought follow a period of enhanced growth due to fertilizer, in which life cycles may have been accelerated[31], then it is possible that species such as *B. attenuata* may be favoured in subsequent regeneration.

Conclusion

In examining the results to determine which of the treatments applied is most likely to give best results in routine nursery production, treatments 1, 6 and 7 may be discarded in view of poorest survivals. Of the remainder, treatment 2 must also be discarded due to chlorosis. Of the three remaining treatments, treatment 4 produced plants with the most unbalanced shoot/root ratios and treatment 3 had a sharply declining R.G.R. in the latter half of the experiment but otherwise had grown consistenly well. Treatment 5 had greatest dry weight and dry root weight at termination, and, apart from treatment 7, also had the lowest shoot/root ratio. This treatment consistently had a lower shoot/root ratio than the mean of all plants at each harvest. It also showed perhaps the best pattern in dry weight growth and had an R.G.R. better than the other fertilizer treatments and one similar to that of the control plants.

The unbalanced shoot root ratios of treatment 4 present a more straightforward case for rejection of this treatment. Also the fact that both treatments 1 and 2, with higher levels of phosphorus, are unsatisfactory suggests that treatment 4 may have suffered rejection if the experiment had been continued longer.

Treatments 3 and 5 on the other hand are close in the sense that rejection of one or the other as the "most suitable" depends largely on the representativeness of the final harvest. Here only two plants of treatment 3 were available compared with 8 of treatment 5.

Treatments 3 and 5 were similar, differing only in that 3 had trace elements present and a slightly lower phosphorus supply than treatment 5. Over much of the experiment treatment 3 gave better results.

Nevertheless, we conclude that treatment 5 is likely to give the best results in production of potted plants for later out planting.

Summary

Seven fertilizer treatments applied to *Banksia attenuata* showed no effect on germination. Survival was poorest in the no treatment control, due to temporary droughting, and in treatments with nitrogen alone or nitrogen with high phosphorus.

Severe chlorosis occurred with high phosphorus in the absence of nitrogen, but with potassium and trace elements present. The treatment with high phosphorus, nitrogen and trace elements present but potassium absent, produced plants with highest shoot/root ratios.

There was little to choose between two treatments with a "low" level of phosphorus combined with nitrogen and potassium, one of which had trace elements also present. However there was no apparent advantage to trace element presence other than that this treatment had greatest dry weight and root weight at 80-118 days from sowing.

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COMPETITION BETWEEN UNDERSTOREY AND PLANTED EUCALYPTUS SPECIES IN REHABILITATED BAUXITE MINED AREAS

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Introduction

Western Australian bauxite mines are currently rehabilitated by tree planting, direct seeding of trees and understorey or by separately returning the thin, seed bearing layer of topsoil from which plants may regenerate.[3] The first two approaches may be used separately or various combinations of methods may be adopted.

The aim of this investigation was to see what the competitive influences of seeded understorey might be on growth of planted *Eucalyptus* spp. trees. Pit JW425 at Alcoa's Jarrahdale Number 2 minesite provided an ideal natural experiment in which to follow this question. This pit was planted with *Eucalyptus marginata, E. patens, E. saligna* and *E. wandoo* in 1979. The area was simultaneously seeded by air with a mixture of native plant species. The mix contained seven *Acacia* spp., two *Kennedia* spp., two *Eucalyptus* spp., one *Callistemon* spp. and a number of other species. The traverses of the aircraft created swathes of dense understorey growth with intervening sparsely vegetated ground. As a result we were able to compare growth of the four planted *Eucalyptus* spp. in the densely and sparsely vegetated areas.

Methods

Ten trees of all but one *Eucalyptus* species were selected from both the densely and sparsely vegetated areas. Only four *E. marginata* trees were located in the dense vegetation.

The height of the growing tip of each tree was measured using a clinometer and the girth of the stem at a height of 30 cm was obtained using tape measures.

Understorey cover and density was assessed using a 2 m rod, modified from Levy and Madden[1], which was divided into 25 cm intervals. Three 50 m transects were marked out in both densely vegetated and sparsely vegetated areas. Fifty equidistant rod placings were made along each transect. The numbers of contacts of vegetation touching the rod at each 25 cm interval were counted. The results of the three transects from each respective understorey regime were then amalgamated. Various parameters were calculated from the resulting data. Percentage cover of vegetation was obtained by calculating the percentage of the one hundred and fifty recordings which touched any plant. Plant cover density, a measure of the thickness of the vegetation in places where it occurred, was obtained by dividing the total number of plant contacts by the number of rod placings which resulted in any vegetation contact. This calculation was performed for the total length of the rod in order to obtain an overall measurement of cover density and, also, for each 25 cm interval in order to construct a vertical profile of cover density.

All recordings were made during March, 1981.

Results

The percentage plant cover and overall plant cover density for the densely and sparsely vegetated areas are shown in Table 1. Both parameters were considerably higher in the densely vegetated areas and were mainly influenced by the preponderance of *Acacia* spp. under this regime.

Table 1. Percentage plant cover and overall cover density in the densely and sparsely vegetated areas of pit

	Understorey Regime	
	Dense	Sparse
Percentage Plant Cover	81.3	10.4
Overall Cover Density	19.5	2.5

The vertical profile of understorey cover density, measured at 25 cm intervals, is shown in Figure 1. Vegetation was thickest at all levels in the densely vegetated areas and was prominent up to 2 m, the highest strata measured by the Levy[1] rod. The maximum height of vegetation recorded in the sparsely vegetated area was 1 m.

The mean tree height and stem girth for each of the four *Eucalyptus* spp. in the two understorey regimes are shown in Table 2. This Table also shows the percentage height and girth suppression noted if the trees in the densely vegetated areas are compared with those growing in sparse understorey.

Table 2. Mean tree height (a) and stem girth (b) of four *Eucalyptus* spp. growing amongst dense or sparse understorey. The percentage difference in height and girth in the two understorey regimes is also shown.

Tree Species	Tree Height (m)		Percentage
	Dense Vegetation	Sparse Vegetation	Difference
(a)			
E. marginata	1.9	3.6	47
E. patens	2.1	3.8	45
E. saligna	2.7	5.0	46
E. wandoo	1.6	2.3	30
	Tree Girth (cm)		
(b)			
E. marginata	3.7	6.6	44
E. patens	5.0	7.5	33
E. saligna	5.1	8.8	42
E. wandoo	3.6	5.3	32

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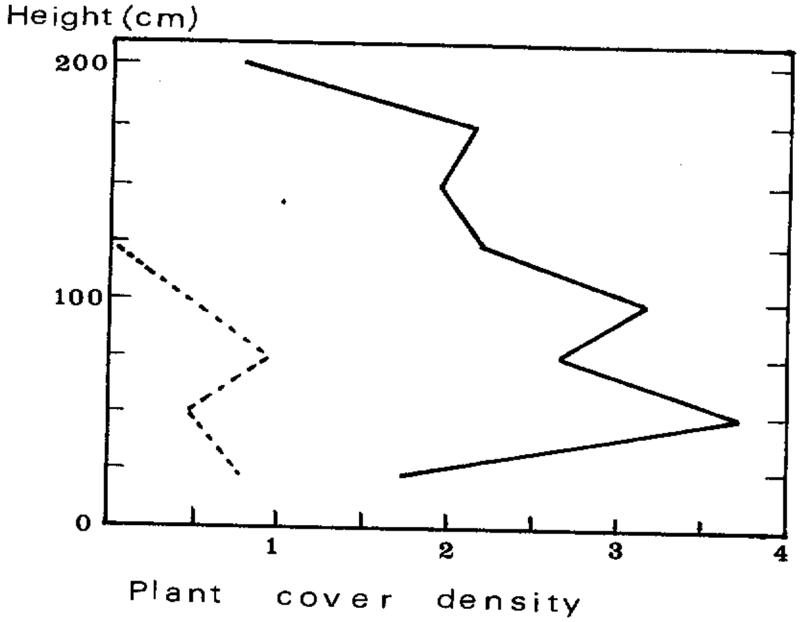

Figure 1. Plant cover density profiles for the densely (——) and sparsely (-----) vegetated areas of bauxite pit JW425 during March, 1981.

In all species the height and girth of trees was considerably less in areas of dense understorey. All differences in tree performance under the two understorey regimes were shown to be significant at the <0.05 level using the Mann-Whitney U-test[2]. In terms of both height and girth *E. marginata* exhibited the greatest growth suppression in dense understorey and this species was followed by *E. saligna* and then *E. patens*. *E. wandoo* exhibited the lowest growth suppression of the four species.

Discussion

The data suggest that the growth of four *Eucalyptus* spp., currently planted in bauxite mined areas, is suppressed by understorey of the density experienced in parts of pit JW425 This occurs despite the beneficial effect which leguminous plants have on the nitrogen levels in the soil.

Table 2 shows that the height of all four *Eucalyptus* spp. studied was, in the densely vegetated areas, no higher than that of much of the understorey (Figure 1). It may be that the growth suppression which we observed had resulted from competition for light. If so, then this influence is likely to diminish once the trees exceed the height of the understorey.

The greatly reduced growth rates of trees observed in the densely vegetated areas suggest that understorey-tree competition is an important phenomenon in rehabilitated mines and one which merits further attention.

One further observation which is worthy of note is the paucity of *E. marginata* trees in the densely vegetated areas. We experienced no difficulty in finding trees of this species in the strips between the densely vegetated areas. This, and the fact that *E. marginata* exhibited the greatest growth suppression of all four species, suggests that *E. marginata* mortality may have occurred under dense understorey.

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