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EDITORIAL POLICY
Contributions are welcomed for consideration by the Editorial Panel. Preference is given to contributions related to the objectives of the Mulga Research Centre. Intending contributors should submit material for consideration in typed format, with double spacing. References should follow the style contained in the current volume. Figures and tables should be clearly presented. A page charge will be made depending on the level of sponsorship for a given volume.

Referees for reviewing the Journal papers are drawn from appropriate members of the scientific community.

AVAILABILITY
Back issues may be purchased from Curtin Bookship, Kent Street, Bentley, W.A., 6102.

CONSTITUTION OF THE MULGA RESEARCH CENTRE

(as amended at the Annual General Meeting of 6 Feb. 1987)

1. NAME
The name of the Association shall be "Mulga Research Centre".

2. OBJECTIVES
2.1 To promote field and laboratory studies in the biology, ecology, pharmaceutical and agricultural potential, and other appropriate uses of Western Australian trees and shrubs, with emphasis where appropriate on those of the Mulga Zone.

2.2 To sponsor field studies for educational purposes, with priority to the Mulga Zone; meetings to inform the public of the results of work undertaken; reports to cover the results of investigations to be published in the manner of a journal, with an editorial review panel, on an approximately annual basis.

2.3 To assist scholars engaged in appropriate related studies.

2.4 To raise funds from appropriate sponsors to enable 2.1, 2.2 and 2.3 above to be undertaken.

2.5 To report work undertaken in journal format.

3. MEMBERSHIP
Membership shall be by invitation to scientists active in pursuit of studies compatible with the objectives of the Mulga Research Centre. Associate membership may be granted to students who participate in appropriate studies; field work or related investigations.

Representatives from Companies and other organisations sponsoring activities will be invited to attend the Annual General Meeting, to be classed as financial members, and to vote on changes or additions to this Constitution (see below).

4. SUBSCRIPTIONS
Subscriptions shall be minimal. At each Annual General Meeting the Treasurer shall recommend a subscription which shall be approved or otherwise.

5. OFFICE BEARERS
Office Bearers shall consist of a Director, a Secretary, a Treasurer and two or more Committee Members.

6. MANAGEMENT COMMITTEE
The appointed Office Bearers and two or more Committee Members shall constitute the Management Committee. The Management Committee is empowered to co-opt additional persons to assist with organising any functions held in persuance of Objective No. 1; and to appoint suitably qualified persons to advisory subcommittees for the purpose which may arise should funds generated by Objective 4 be required to be divided.

7. FUNCTIONS OF THE COMMITTEE
A suitably responsible person not a member of the Mulga Research Centre shall be appointed Honorary Auditor. His report shall be read at the Annual General Meetings. An annual report will be prepared to cover each calendar year, this to be available as soon as practicable in the following year.

8. MEETINGS
Members shall meet together in a formal manner on a day to be appointed by the Secretary each year. This meeting will constitute the Annual General Meeting. Items for discussion should be lodged with the Secretary prior to the meeting. Other meetings of members may be held in conjunction with organised public meetings should any pressing business require that a formal meeting be held. At any meeting where there will be voting on proposed amendments to the Constitution, financial members unable to attend may approve proxies (in writing) to the Secretary.

9. QUORUM
A quorum shall be 20 percent of the financial, excluding associate members, provided that the Director and Secretary (or a nominee) are present.

10. PATRONS
A Patron of the Mulga Research Centre is appointed in recognition of considerable financial assistance. Patrons are entitled to one copy of all publications sponsored or produced by the Mulga Research Centre.

11. GENERAL ADMINISTRATION

11.1 Location: The location of the Mulga Research Centre is C/- School of Biology, Curtin University of Technology, Kent Street, Bentley, W.A., 6102.

11.2 Bank Account: An account will be opened at the South Bentley branch of the R & I Bank. Signatories shall be the Director or Secretary and the Treasurer or a nominee of the Committee should the appropriate office bearer be overseas or otherwise unable to fulfil his duties.

11.3 Changes or Additions to Constitution: Any changes in the Constitution of the Mulga Research Centre must be carried by a majority of two thirds voting, after notice of motion has been circulated to all financial members one month prior to the meeting when the matter is to be discussed.

This manuscript was prepared at the School of Biology, Curtin University of Technology by Ms Sallie Grayson.

The following persons are thanked for reviewing papers in Volume 9: I. Abbott, E.M. Bennett, I. Colquhoun, P.J. Curry, J. Dodd, J. Gardner, E.D. Kabay, B.G. Muir, J.R.H. Riches and B.H. Tan.

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GENERAL PAPERS

PRELIMINARY OBSERVATIONS ON GERMINATION AND SEEDLING ESTABLISHMENT IN ERODIUM CYGNORUM

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Summary

The seed of **Erodium cygnorum** is contained in a mericarp surmounted by an awn. When moisture is imbibed the awn twists like a corkscrew driving the end of the mericarp containing the seed into the ground.

Seed incubated at 20°C gave greatest germination. Removal of the awn did not significantly reduce germination but delayed seedling emergence. Mericarps with cut awns germinated at a greater rate than whole or awnless mericarps. An experiment to contrast the ability of the seed to germinate into material of differing bulk densities failed as the material produced surface crusting on wetting.

Seedlings emerged sooner with frequent watering but emergence was delayed with flooding. Heaviest plants were obtained with higher levels of soil moisture and root growth declined with lack of water.

Emergence from depths greater than 3cm was severely reduced. Seed buried at 3cm produced more emergents in a shorter time than surface sown seed or other burial depths. Root production was greatest from seed buried at 1.5cm.

Germination appeared to be best from seed placed horizontally in the soil when buried at 1cm depth.

Introduction

The generic name **Erodium** comes from the Greek word for heron 'erodios'. In fruit the five mericarps clustered together resemble the head and beak of a heron. There are some 60 species of herbs and subshrubs in Europe, Asia, America and Africa (Marchant **et al** 1987). **Erodium** can be distinguished from its close relative **Geranium** as it has 5 fertile stamens alternating with 5 staminodes, whereas **Geranium** has 10 fertile stamens.

The genus **Erodium** (family Geraniaceae) includes several widely distributed weedy species. This has led to some uncertainty as to which of the various species are native or introduced to Australia. Beard (1970) lists 3 species native to W.A. - **E. cygnorum** Nees, **E. crinitum** Carolin and **E. aureum** Carolin. Willis (1972) listed 6 species in Victoria and classified **E. crinitum** as a synonym of **E. cygnorum**. It is currently accepted that the latter two are separate and the checklist of Green (1985) lists **E. angustilobum** Carolin, **E. crinitum** and **E. cygnorum** as native to W.A., and **E. aureum, E. botrys** (Car.) Berthol., **E. cicutarium** (L.) L'Her. and **E. moschatum** (L.) L'Her as introduced species.

In Australia the biology and agricultural significance of **Erodium** species have not been studied closely. **E. cygnorum, E. botrys** and **E. crinitum** are valued as fodder plants in western New South Wales and South Australia (Jackson and Jacobs 1985), while **E. cygnorum** has value as sheep fodder in winter pastures of station country in the eastern goldfields of Western Australia. However, Lamp and Collett (1976) considered that **Erodium** caused photosensitisation in stock and that **E. moschatum** invaded pastures and caused wool fault. **E. moschatum** and **E. cicutarium** are not viewed as good fodder plants (Jackson and Jacobs 1985).

More work has been undertaken on **Erodium** in the United States, where plants of the genus are known as 'filaree'. In California, with a similar climate to parts of Western Australia, **Erodium** is used as forage and can dominate the vegetation locally. The plant's deep tap root supplies water to the above ground portion of the plant during continuous dry weather (Pitt and Heady 1978), enabling it to successfully outcompete shallow rooted species (e.g. grasses) during comparatively dry winters.

Pitt and Heady (1978) studied responses of **Erodium** species to temperature and rainfall patterns in Northern California. The proportion of filaree in herbage fluctuated annually between 4 and 48 percent, indicating long term dormancy. Seed dormancy is a characteristic of many desert annuals (Freas and Kemp 1983). Although reproductively conservative in the number of seeds produced and seedlings established, **Erodium** species will commence to germinate within the first few days of rain for that season (Bartolome 1979). Laude (1956) found that dormancy (delayed germination) was an important factor influencing the percentage of seed germination in **E. botrys**. Low germination resulted from recently harvested seed (6 months), but a delay of one year gave 39 percent total emergence and a two year period yielded 91 percent.

Rice (1985) suggests that **Erodium botrys** and **E. brachycarpum** survive to a greater extent, and produce more seed per plant, when growing on bare soil, in comparison with growth in litter and from within gopher mounds. In these two species the widely fluctuating temperature of exposed soil surfaces effectively breaks dormancy (Rice 1985).

In Australia, **Erodium cygnorum** is variously known as 'blue crowfoot', 'wild geranium' or 'blue heronsbill', and is a common annual herb. It is generally found in the open, and appears to be more common on sandy soils in arid and semi-arid areas (Carolin 1958). The seed is enclosed within a mericarp 7-10mm long with an awn, up to 100mm long attached to it. The awn is very sensitive to moisture. In moist, humid conditions it is straight, but when dry, it assumes a helixical shape. This mechanism enables the mericarp to drive itself into the ground where it lies, in the same manner as described for **E. cicutarium** (Stamp 1984). Self-sowing or burial is also facilitated by the very sharp pointed tip of the mericarp which is covered with stiff hairs that point away from the tip.

In the eastern goldfields germination occurs in late autumn/early winter. This study was undertaken to examine the influence of itemperature, moisture and soil hardness on germination and establishment of **E. cygnorum**. The effects of propagule orientation, burial depth and removal of the awn were also examined.

Methods

Mericarps (actually fruit material, referred to subsequently as seeds) of **Erodium cygnorum** used in the experiments described had been collected at Jeedamya (29 24'S, 121 16'E) in October 1984 and stored in an airtight glass jar in a laboratory (ambient temperature 20-21°C). The experiments were conducted over the period July-October 1985. Experiment 1 utilised constant temperature growth cabinets and Experiments 2-5 were conducted in a well-ventilated glasshouse with no artificial lighting or heating.

Experiment 1

The aims of this experiment were to test germination response to temperature and to determine whether germination could be achieved without the awn and whether cutting half the awn would affect successful germination. Differing incubation temperatures were tested to estimate optimum temperature. This experiment also sought to provide a measure of germinability for other experiments.

Four temperatures and three seed treatments were used, as shown in Table 1. Awns were separated (and discarded)

TABLE 1. Awn treatments, temperatures of growth cabinets, and numbers of seeds per petri dish used in Experiment 1.

Awn Treatment	Incubation Temperature (°C) (dark)			
	15	20	25	30
Whole	20	20	20	20
Cut	20	20	20	20
No awn	30	30	30	30

from 120 seeds. Half the awn was cut off a set of 80, and for a further 80, intact seeds were used.

After surface sterilisation with 5 percent sodium hypochlorite, seeds were counted out onto filter paper in covered petri dishes and placed in growth cabinets. Enough deionised water was added to the petri dishes to moisten the seeds. Germinants were counted and removed at daily intervals up to 10 weeks, germination being defined as protrusion of the radicle.

Germination rates (G.R.) were calculated as mean days (Hartmann and Kester 1975) where G.R. in mean days is:

$$\frac{(n_1 \times t_1) + (n_2 \times t_2) + \ldots + (n_x + t_x)}{\Sigma^1_{xn}}$$

In this equation, n_1 is the number of germinants at the first day of observed germination, at t_1 the time in days from initiation, and n_x is the number of germinants on the final day of observed germination.

Experiment 2

The second experiment sought to examine the ability of the awn of **Erodium cygnorum** to drive the seed into soil surfaces of idiffering hardness, achieved by compacting soil to different bulk densities. The soil used was Ate-Overburden, an interburden spoil layer from the Muja Basin, Collie.

Small square-sided plastic pots 70 x 70 x 100mm were used, their drainage holes masked to prevent loss of soil. Oven dried soil was weighed into pots to give five replicates of each of five bulk densities: 1.0, 1.2, 1.4, 1.6 and 1.8. The soil was then compacted so that all pots were filled to the same depth. Two seeds were surface sown to each pot and the soil was moistened daily with a hand-held spray.

Seeds were sown on July 23rd, plants were harvested 79 days later. Emergence rate in this, and subsequent experiments, was calculated as for germination rate in Experiment 1.

Experiment 3

In this experiment five watering treatments were applied to pots each surface sown with two seeds. Each treatment had eight replicates, with a total of 16 seeds each. The growing medium used was a mixture of equal parts of coarse sand, fine sand and peat. Pot dimensions were as in the bulk density experiment. The watering regimes used deionised water applied as follows: a) 80ml per pot daily; b) 40ml daily; c) 40ml every second day; d) 40ml every fourth day; and e) saturation. In e) pots were stood in shallow trays of deionised water.

The experiment commenced on July 31st. Plants were harvested on October 10th, 71 days later.

Experiment 4

The effect of depth of seed burial on emergence was examined in this experiment. Pots and soil mixture were as in the watering regime experiment. Five replicate pots were sown with two awnless seeds each. These were placed on the surface in one set of five pots. Treatments were seed burial at 0, 1.5, 3, 5 or 7cm below the soil surface. Pots were inspected frequently and soil moistened to about field capacity every second or third day. All seeds were positioned horizontally.

Seeds were sown on July 24th. Observations on emergence were recorded for 80 days thereafter.

Experiment 5

This was designed to examine the effect of mericarp position on germination. Soils and pots were as in the other experiments. Awns were removed from all seeds to prevent changes in position due to awn activity. Five positions were used. In three treatments, each seed was buried 1cm below soil surface; either a) seed vertical, tip down; b) seed vertical, tip up; c) seed horizontal. In the other two treatments, each seed was buried to half its length; either d) tip up; or e) tip down. There were five replicate pots per treatment, with two seeds per pot. The watering regime was as in the previous experiment.

Treatments were set up on September 1st. The appearance of cotyledons was recorded as germination and observations were made for a period of 36 days.

Results

Germination by awn treatments, and temperature

Table 2 gives percentage germination recorded at each incubation temperature.

TABLE 2. Percentage germination at four incubation temperatures for three awn treatments.

Awn Treatment	(n)	Temperature (°C) 15	20	25	30	Mean
Whole	(20)	60	85	75	5	56.3
Cut	(20)	45	95	90	5	58.8
No awn	(30)	57	77	60	0	48.3
Mean of total	(70)	54.3	84.3	72.9	2.9	53.6

Germination percentage was highest at 20°C for all treatments, and second highest at 25°C. Germination was poor at 30°C. In whole propagules 85 percent germinated at 20°C, indicating the overall germination capacity of the seed. Contrasts between numbers for the three treatments and temperatures 15-25°C using values scaled for n = 30 were tested for significance, with analysis of variance. There were no significant differences between awn treatments. Temperature levels showed a significant difference (F 6.29, p 0.05 = 5.14) and the least significant difference test revealed that numbers germinated at 20°C were significantly greater than those at 15°C. Other contrasts were not significantly different.

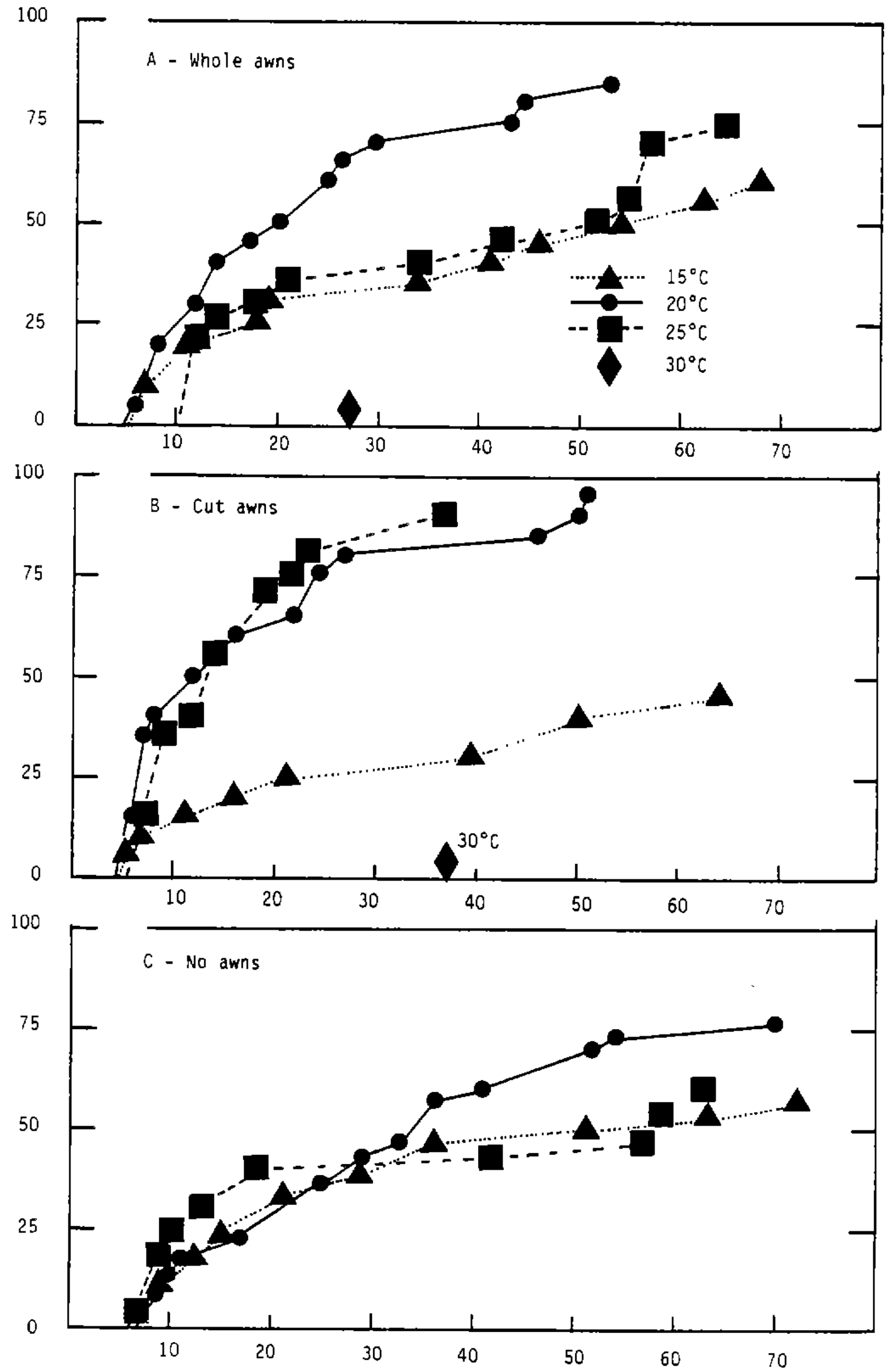

FIGURE 1. Cumulative germination percentages by treatments of awn.

Seed with half an awn produced more germinants than whole mericarps at both 20° and 25°C. Complete removal resulted in lower percentage germination than for whole seeds at all temperatures. The overall germination across the temperatures was similar for whole and cut seeds. The main differences were at either end of the temperature range with more whole seeds germinating at 15°C and more trimmed seeds at 25°C.

The cumulative germination percentage for each treatment is shown in Figure 1. Germination generally commenced 4-7 days after seeds were first moistened. There was little difference in time to first germination, although awnless seeds took slightly longer.

Table 3 contrasts the time taken for 25 and 50 percent of seeds which germinated in each treatment to germinate, and germination rates for them.

Whole seeds reached 25 and 50 percent germination within 10 and 19 days respectively at 20-25°C. The seeds required mean times of 7.8 and 12.0 days to reach these levels. Analysis of variance revealed no significant differences in numbers germinated between 10 and 50 days from first moistening of seed. However, trimmed seeds germinated faster than whole seeds at both 20 and 25°C. Awnless seeds also germinated more rapidly for the 25 and 50 percentiles.

TABLE 3. Length of time taken (days) for 25 and 50 percent of maximum germination in a treatment, with germination rate (mean days taken).

Awn Treatment	Temperature (°C) 15 Time	G.R.	20 Time	G.R.	25 Time	G.R.
a) 25% germination						
Whole	10	8.0	10	7.8	12	10.5
Cut	11	7 7	7	6.4	8	7.2
No awn	12	9 6	17	10.2	9	8.6
b) 50% germination						
Whole	19	12.0	17	10.6	34	16.1
Cut	21	12.0	12	7.7	14	8.9
No awn	20	12.7	28	16.2	13	9.7

TABLE 4 Percentage emergence. emergence rate (mean days), and harvest values for five bulk density levels (harvest weights mg).

Observations	Bulk Density Level 1.0	1.2	1.4	1.6	1.8
% Emergence	30	30	10	30	10
Emergence rate (mean days)	63	45	37	48	29
Proportion of seedlings surviving to harvest (%)	33	100	100	100	100
Mean dry weights					
top	3.1	6.0	3.3	4.4	5.4
root	3.5	3.4	3.1	1.8	2.6
total	6.6	9.4	6.4	6 2	8.0
Top/root ratio	0.9	1.8	1.1	2.4	2.1

Bulk density

The Ate-Overburden material used compacted well and formed a hard surface crust on wetting. Very few seeds were able to germinate. Table 4 summarises the results of this experiment.

Plants were recorded as emergents when cotyledons appeared. From the total of 50 seed sown only 11 plants were produced overall. Plant growth was poor throughout, probably reflecting the effects of surface crusting rather than compaction or bulk density per se. Analysis of variance revealed no significant differences between top, root and total dry weights. However, it is noted that, beyond bulk density of 1.2, mean top dry weight at harvest increased with increasing bulk density values.

Top/root ratios were highest in the two most compacted treatments.

Watering regime

Table 5 summarises emergence levels (appearance of cotyledons) by different treatments.

The number of plants recorded was much lower than anticipated from the germination experiment, with only 9 emergents out of 16 sown from the best treatment. Although first emergents appeared at 11 or 12 days in the two daily watering treatments, there was a gap in emergence until 35-50 days from sowing (Figure 2). This was probably associated with warmer weather in the latter part of August - all three cumulative emergence curves for the best treatments show similar bursts in percentage emergence at that time.

A total of 19 plants survived to harvest (Table 6). Greatest biomass production was in the frequent, heavier watering regime with a tendency for root growth to fall away with infrequency of watering. There were no survivors in the saturation treatment.

Analysis of variance revealed no significant differences between treatments for harvest weights when all replicates were taken into consideration. For the best 3 treatments a comparison of the heaviest 4 replicates showed a significant difference between root weights (F 6.34, p 0.05 = 4.26) and the least significant difference test revealed that the 80ml per day treatment had significantly heavier root mass than the lighter watering treatments.

TABLE 5. Seedling emergence with different watering regimes.

Observations	Watering Regime 40ml 1 in 4 days	40ml 1 in 2 days	40ml daily	80ml daily	Saturated
% Emergence (10 wks)	37.5	31.3	25.0	56.3	37.5
Emergence rate (mean days)	48	50	39	44	39
Days to first emergence	24	23	11	12	24
Days to last emergence	62	83	64	82	54
Nos to 25 days	1	1	1	1	1
Nos to 50 days	3	3	3	7	5

Burial depth

Table 7 presents emergence levels from burial depths.

Surface sown seeds and those buried up to 3cm gave similar levels of emergence. Burial beyond 3cm inhibited emergence considerably. Seedlings emerged fastest from 3cm burial and completed emergence soonest. Emergence from 1.5cm was the second best treatment. Seeds on the surface tended to dry out and although 3 seedlings had emerged by 25 days, the remaining 3 seedlings did not emerge until 45, 51 and 69 days from the start. The third plant to emerge from 5cm depth was recorded at 62 days.

χ^2 analysis of the proportion of emergents and non-emergents (line 1 of Table 7) confirms significance of these results. (χ^2 calculated 10.15; χ^2 table p 0.05 = 9.49).

Harvest weights for survivors at 1.5, 3 and 5cm depths of sowing are given in Table 8. Root weights tended to be greater from more shallowly sown seed, but top dry weight was similar across all three depths. Analysis of variance showed no effect of burial depth on dry matter production.

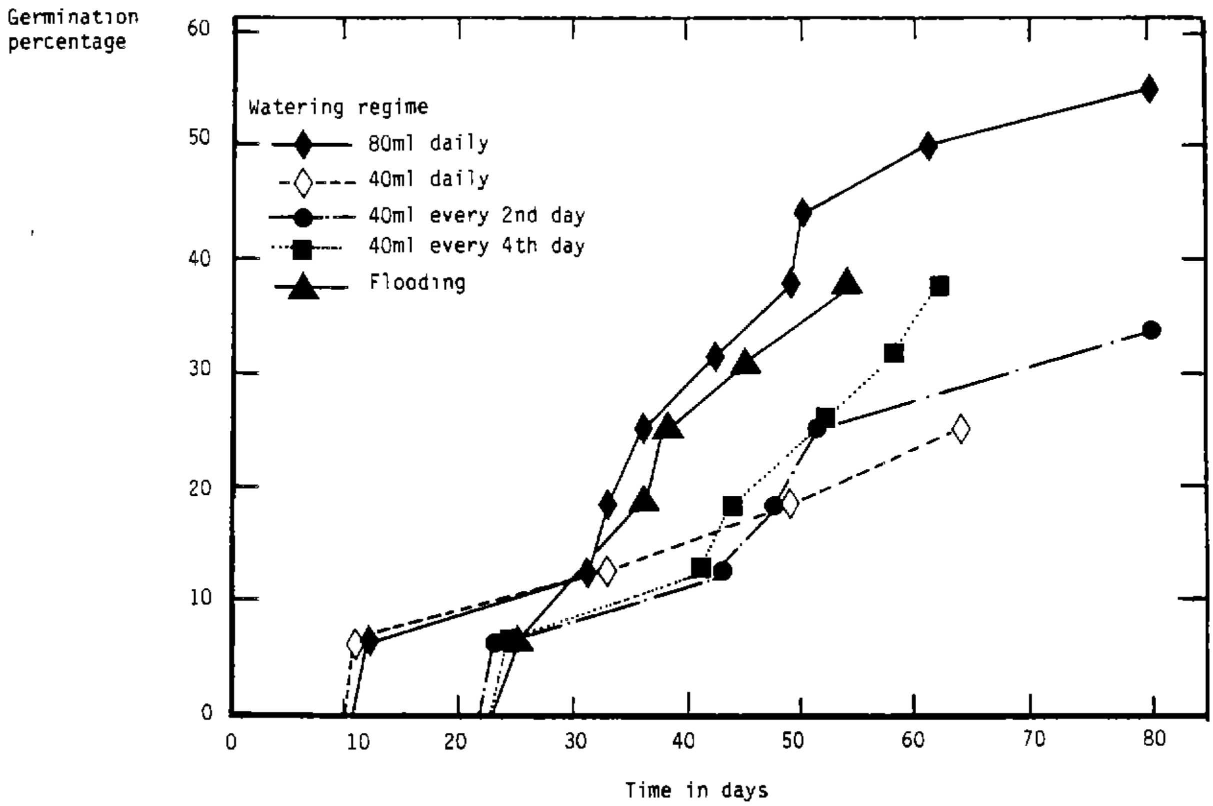

FIGURE 2. Cumulative germination percentages with different watering regimes.

TABLE 6. Harvest values for different watering regimes (harvest weights in mg).

	Watering Regime			
Observations	40ml 1 in 4 days	40ml 1 in 2 days	40ml daily	80ml daily
Survivors to harvest	1	5	4	9
Mean dry weights				
top	23.1	20.2	19.3	25.2
root	5.2	12.7	11.8	18.1
total	28.3	32.9	31.1	43.3
best 4, root	N/A	14.2	11.8	32.0
Top/root ratio	4.4	1.6	1.6	1.4

TABLE 7 Emergence from different burial depths

	Depth of Sowing (cm)					
Observations	0	1.5	3	5	7	Mean
% Emergence after 80 days	60	60	70	30	10	46
Emergence rate (mean days)	39	24	17	37	42	28
Days to first emergence	18	13	13	18	42	21
Days to last emergence	69	33	24	62	42	46
Nos to 25 days	3	4	7	1	0	3
Nos to 50 days	4	6	7	2	1	4

TABLE 8. Harvest values for seedlings emerging from different burial depths (harvest weights in mg).

Observation	Seed Burial Depth (cm) 1.5	3	5
Survivors to harvest	5	6	3
Mean dry weights			
top	53.9	58.7	58.7
root	33.3	26.8	20.1
total	87 2	85.5	78.9
Top/root ratio	1.6	2.2	2.9

TABLE 9. Seedling emergence from different positions (n = 10 per treatment).

Observations	Position * (a)	(b)	(c)	(d)	(e)
% Emergence	40	60	90	70	30
Days to first emergence	12	13	13	12	13
Days to last emergence	37	22	36	31	15
Emergence rate (mean days)	23	18	24	21	14
Nos to 18 days	2	4	5	3	3
Nos to 36 days	4	6	9	7	3

* Positions as follows: Buried 1cm below soil surface: a) seed vertical, tip down; b) seed vertical, tip up; c) seed horizontal. Buried to half seed length: d) tip up; e) tip down.

Seed position

Emergence levels for the five positions tested in the fifth experiment are given in Table 9.

Best emergence came from seeds buried horizontally (c) where 9 of the 10 sown had emerged by 36 days.

χ^2 analysis of the proportions of emergents and non-emergents (line 1 of Table 9) revealed that these results lacked significance (χ^2 calculated 9.37; χ^2 table p 0.05, 9.49).

Discussion

The provision of hairs along the carpel, extending to the awn, is shown in Figure 3. The self-burying mechanism is partially illustrated in Figure 4. As the awn is moistened the coils unwind driving the seed into the soil (Figure 4A). During the course of the experiments, it was noted that the small pot size used tended to restrict awn spiralling, when units lay close to the sides of the pots.

When incubated under moist conditions in the dark, germination in **Erodium cygnorum** was highest at 20°C of the temperatures used. The optimum for the species probably lies between 20 and 25° C. Seed viability was around 85 percent for these artificial conditions. It is of interest that the first seed to germinate in a set took about the same time across the treatments. This was repeated in several experiments and indicates that some seeds may be able to germinate faster than others. Whether this is due to mechanical/structural differences which allow more rapid uptake of moisture requires further investigation. Some winter annuals appear to be unable to germinate all their seeds in the first year after dispersal, even with optimum environmental conditions (Freas and Kemp 1983). The reduced time to germinate observed for cut awns suggests that a mechanical barrier may have been removed by cutting, whereas removal of the awn, resulting in lower germination, may have damaged the seed.

When the seed is unable to penetrate the soil surface, but sufficient moisture is available for germination, the radicle tends to part from the carpel (Figure 4B). Seed sown onto the surface of compacted soils germinated and achieved some root penetration and seedling growth. This may have been associated with constant wetting rendering the crusted surfaces slightly more penetrable, as well as allowing germination to proceed. The proportion of emergents was much less and time taken much longer than for seeds in petri dishes. Root penetration into the more compacted soils was generally poor, partly due to the surface crusting. The increase in top dry weight with compaction level (Table 4) may be related to effectiveness of root penetration but the number of established replicates was too few to confirm this and dry matter production was low. Stamp (1984) reported that **E. cicutarium** requires

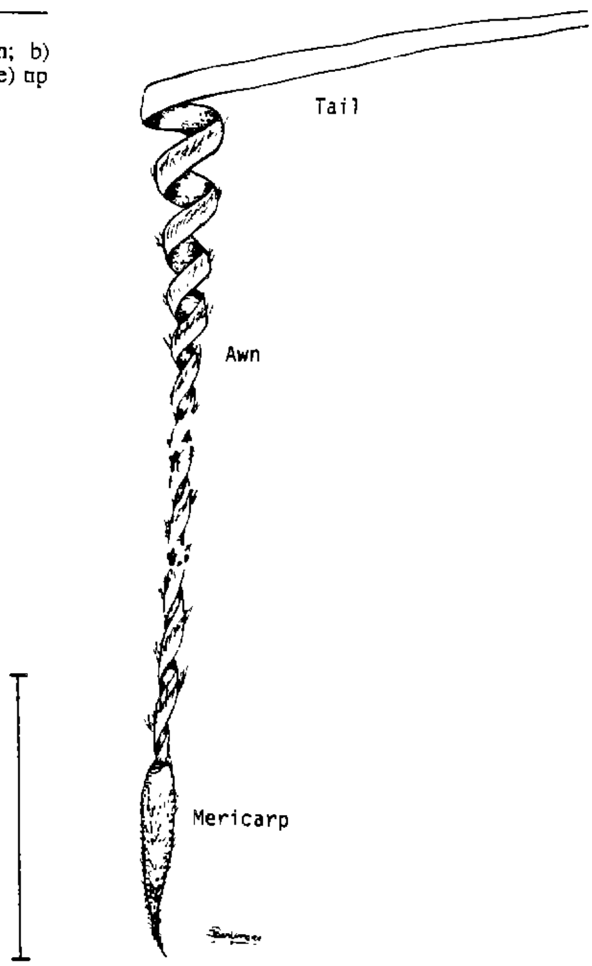

FIGURE 3. Mericarp of Erodium cygnorum, at eleven months from collection. (Bar is 1cm).

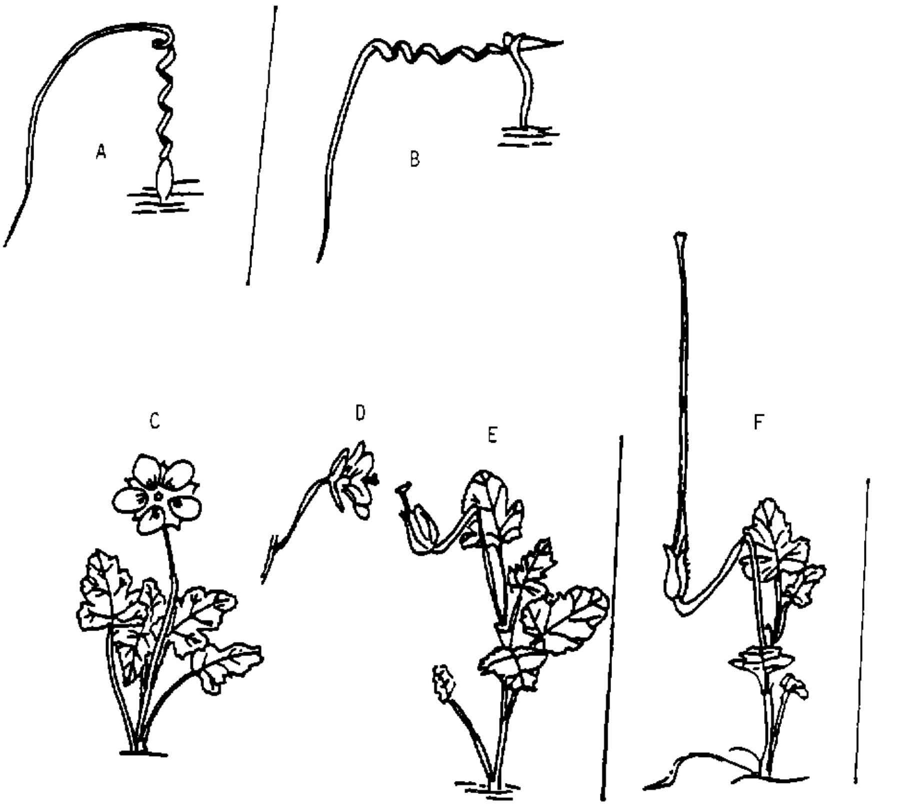

FIGURE 4. **Erodium cygnorum** A) normal self burying mechanism; B) surface germination with exposed radicle; C) plant from 3cm sowing depth; D) side view of flower; E) plant at 58 days; F) same plant as E at 65 days, fruit grew 6.7cm in one week.

All bars represent 5cm.

surface irregularities (crevices) for successful self-burial. Our experiment suggests that the self- burial mechanism of **E. cygnorum** does not allow successful establishment into crusted surfaces. The mechanism is more likely to be successful with crevices as in **E. cicutarium**.

Burial at 3cm resulted in best establishment. The action of self-burial may serve to abrade the mericarp shell and render it more likely to allow uptake of water. Burial at 5 and 7cm depths gave little emergence. It seems unlikely that the self-burial process would place the seed deeper than 3cm in nature. The deeper the seed is buried, the less is the likelihood that it will successfully establish a seedling. It is, however, possible that larger seed may emerge more effectively from greater depth (Roach 1986). At 3cm total emergence most closely resembled the value of 85 percent for seed germinability inferred in the incubation experiment. Emergence rate from this depth was much greater than from other depths and not dissimilar to the germination rate for seeds in petri dishes. The investigation did not allow sufficient discrimination between light and darkness to show whether greater light availability for surface sown seed may have inhibited metabolic processes.

Most frequent and heaviest application of water (80ml daily) provided the best regime for emergence and growth. The next best (40ml daily) was no better than a level equal to half its moisture supply (40ml every second day). The lag in emergence (Figure 2) may be associated with a proportion of the propagules requiring a longer period of favourable conditions (Freas and Kemp 1983). Although the driest treatment probably did not attain "limiting" moisture conditions in the experiment reported, it is noted that differences in emergence may also be related to seed size. Roach (1986) suggests that when moisture is limiting small seed may emerge sooner and be more successful than large seed. Alternatively, the delay in germination shown by the bulk of sown seed may be due to impermeability of the coat to water. Hard seededness aids persistence of **E. botrys** (Jackman and Jacobs 1985).

The moisture level experiment further confirmed the importance of the self-burial mechanism for field establishment. The propagules subjected to the saturation treatment did not self- bury as easily as those of other treatments: constant moisture prevented them from going through the uncoiling-coiling process. In addition the moist surface provided no roughness. Seedlings from this treatment either died soon after emergence or produced only thin, poorly developed roots and shoots.

Seeds with tips downwards were anticipated to yield the best results from seed positioning. Surprisingly those treatments with seed position tip down (the normal self sowing position) (treatments a and e in Table 9) gave poor results. In this experiment all seed were awnless and this damage may have confounded the results. Those with tips uppermost produced larched-over radicles but otherwise seemed to grow well. Horizontally planted seed in nature would not be able to exert leverage when buried to assist in self-burial.

Conclusion

The seeds of **Erodium** species are most interesting structures. Part of the structure is the long coiled awn. The principal role of the awn, in common with many grass species (Peart 1984), appears to be that of enabling the seed to be buried in the soil, where germination is most likely to occur. Few seeds germinate and produce vigorous seedlings if on the soil surface. Self burial then is primarily to get the seed into position for germination. It also may result in less seed-predation, avoidance of high surface temperatures, radicle penetration, and in minimising loss due to surface fire (Stamp 1984). The awn can make up to 60-80 percent of the total seed weight in **E. cygnorum**. The awn quite easily breaks off once germination has taken place, when it has already served its self-burial function. If removed before germination, although germinability might not be reduced, the likelihood of germination under field conditions would be greatly reduced without the awn. It has been shown that removal of the awn of other plant species substantially reduces germination (Sheldon 1978).

The drilling action of the **Erodium** seed may act to abrade the seed coat and promote imbibition of water, although mericarps in petri dishes had a fairly high germination rate. The drilled-in seed is in the dark once underground, and thus does not require light in order to germinate.

The temperature at which **E. cygnorum** best germinates is 20ºC. Germination is poor at 30ºC although 25ºC is still favourable. This is possibly due to a survival mechanism that prevents seed from germinating during summer, when seedlings would quickly dessicate in the dry heat. Surface germination will produce 'straggly' plants, as roots cannot become well established, and also plants will be likely to have higher rates of respiration due to higher temperatures. The ideal depth for **E. cygnorum** seed to germinate and successfully reach the surface with its cotyledons is 1.5-3cm. This is the depth at which it is likely to be when it self-buries naturally.

Frequent wetting is required for high rates of establishment of seedlings. Clearly a certain amount of water needs to be imbibed before germination can take place. It is suggested that autumn or early spring conditions generally provide the appropriate conditions for germination in the eastern Goldfields.

E. cygnorum germinated into compacted material but seedling establishment was poor. To penetrate a soil mass, the radicle has to exert a pressure greater than the resistance of the soil (Sheldon 1978). This species cannot self-bury effectively into hard soils. However, under field conditions, hard soils might develop cracks which may favour self-burial.

The observations reported suggest that it would be of interest to examine the relationship between germinability and time from seed irelease. It is not known whether seed matured on the plant has a period of natural dormancy or whether the inhibition of germination at higher temperatures effectively minimises germination after summer rainfall.

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PRELIMINARY ESTABLISHMENT TRIALS ON CASSIA NOTABILIS EXAMINING RESPONSE TO VARIOUS WATER REGIMES AND TWO SOIL MEDIA

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Introduction

Cassia notabilis (F Muell.) is a member of the family Caesalpiniaceae. This is the smallest of the Legume families. Of the fifty two Caesalpiniaceae species listed by Green (1985) as native or naturalised Western Australian plants, 36 are in the genus **Cassia.** Many of these occur in the north-west of the State (Keighery 1984) **Cassia notabilis** is widely distributed. It has been found from North-West Cape in the Eremean province to the Kimberleys (Erickson **et al.** 1979), and is widely distributed in central Australia (Jessop 1981).

The average rainfall of W.A.'s north-west is 250 to 350mm. This rainfall is variable but the bulk comes from summer thunderstorms or cyclones between January and March with some winter rain.

C. notabilis is a low shrub to about 70cm in height. It has hirsute pinnate leaves with six to thirteen pairs of leaflets 2.5 x 1cm (Figure 1). The leaves are 10 to 15cm long (Jessop 1981). Bright yellow flowers to 1cm across are produced on erect terminal and axillary racemes to 15cm length from August to October (Beard 1965), after which yellow to black seed pods are formed. The distinctive pods give this plant its common name of "Cockroach bush". Although the species tends to be ephemeral, the attractive flowers, seed pods and foliage together with its low mature stature suggest possible horticultural importance for **C. notabilis**, perhaps as a rockery, border or tub species.

The species produces highly viable seed. For example, in germination trials by Meney and Fox (1986), seeds incubated at 25°C after pre-treatment with boiling water, gave germination rates of 100 percent after 24 hours. Despite the ease of germination several previous attempts to grow **C. notabilis** to maturity at the Curtin Field Trial Area have met with little success. Few individuals maintained any healthy vigorous growth after the cotyledon stage. Lack of an appropriate water regime was thought to be a major contributing factor. It was hypothesised that the plants received too much water for a species from the semi-arid northwest region.

The present report deals with a preliminary experiment devised to examine the effect of water levels on survival. Two contrasting potting soils were also examined.

Materials and Methods

Cassia notabilis seeds were obtained from the Department of Conservation and Land Management. On the 16th September 1986 these seeds were pretreated with boiling water poured onto them. The water was allowed to cool to room temperature and the seeds were surface sterilised by placing them in a 3 percent solution of sodium hypochlorite for 30 seconds. The seeds were rinsed with deionised water several times. After this treatment the seeds were sown onto a seedling tray of washed coarse river sand and lightly covered with coarse sand. The tray was placed in the glasshouse with automatic overhead watering.

Sixty black plastic pots (70 x 70 x 100mm) were lined with vermiculite and filled with washed coarse river sand. Seeds which had germinated overnight were planted on 17th September at a rate of two per pot. The average radical length of these germinants was 6.2mm. Another sixty pots were prepared as before but using a soil mix of 1 part loam / 1 part fine sand / 1 part coarse sand. Two plants were transplanted into each of these pots on 18th September 1986. The average radical length of these germinants was 16mm.

All pots were maintained in the glasshouse under automatic overhead watering until midday on the 19th September 1986 to reduce planting shock.

Six sets of 20, comprising ten pots with coarse sand and ten pots with soil mix, were then stood in six 29 x 35cm plastic seedling trays for ease of handling during subsequent treatments.

One set (seedling tray) was assigned to each of the following watering regimes, with watering from below for Treatments 1-5.

Treatment 1 (T1) - once a week
Treatment 2 (T2) - twice a week
Treatment 3 (T3) - three times a week
Treatment 4 (T4) - once a fortnight
Treatment 5 (T5) - constant bottom water
Treatment 6 (T6) - overhead water, daily.

Seedling trays of treatment sets 1-4 (bottom watered plants) were placed into a larger trough of water until soil had reached field capacity. This was taken to be when the surface of the soil was moist. The tray of constant bottom watered plants was placed in a trough with a water level maintained at approximately 2.0cm. The water within this trough was replaced each Monday. The tray of top watered plants was placed in the glasshouse with an automatic overhead watering system, triggered by a mercury leaf sensor.

The watering regimes commenced on 19th September 1986 and continued for seven weeks. Treatment 3 approximated most previous attempts to grow this species.

Daily maximum and minimum temperatures and maximum relative humidity recordings were obtained with a thermohydrograph set up in the non-watered side of the glasshouse Daily readings were averaged to give weekly means.

As a prevention against fungal attack all plants were sprayed with "Previcur" systemic fungicide on 29th September and 15th October 1986.

Daily counts of plants remaining alive were taken (weekends excepted). The number of open mature compound leaves was counted and the longest open mature compound leaf was measured at the sixth (28th October) and seventh week (6th November 1986). A leaf was considered mature if the blade was fully open. Leaf length was taken as the distance from the node to the apex of the leaf.

Results

The average weekly maximum, minimum and mean temperatures and average maximum humidities for the duration of the trial are presented in Figure 2.

Combined percentage mortality of plants in all treatments for each week of the trial are given in Figure 3. Percentage mortalities for each soil type as well as a combined mean percentage of both soils are presented separately. Percentage mortality was defined as·

$$\frac{\text{number of deaths in week y}}{\text{Number of plants alive at week (y-1)}} \times 100$$

The highest mean maximum relative humidity occurred during week 1 and the lowest during week 5. The overall average mean maximum relative humidity was 83 percent throughout the duration of the trial.

Mean temperatures generally increased over the duration of the trial with highest temperatures recorded over weeks 5 and 6. The greatest range in temperature occurred during week 5 (17.2°C range) and the minimum range during week 2 (10.1°C range). Weeks 5 and 2 corresponded to greatest and least mean percentage mortality rates.

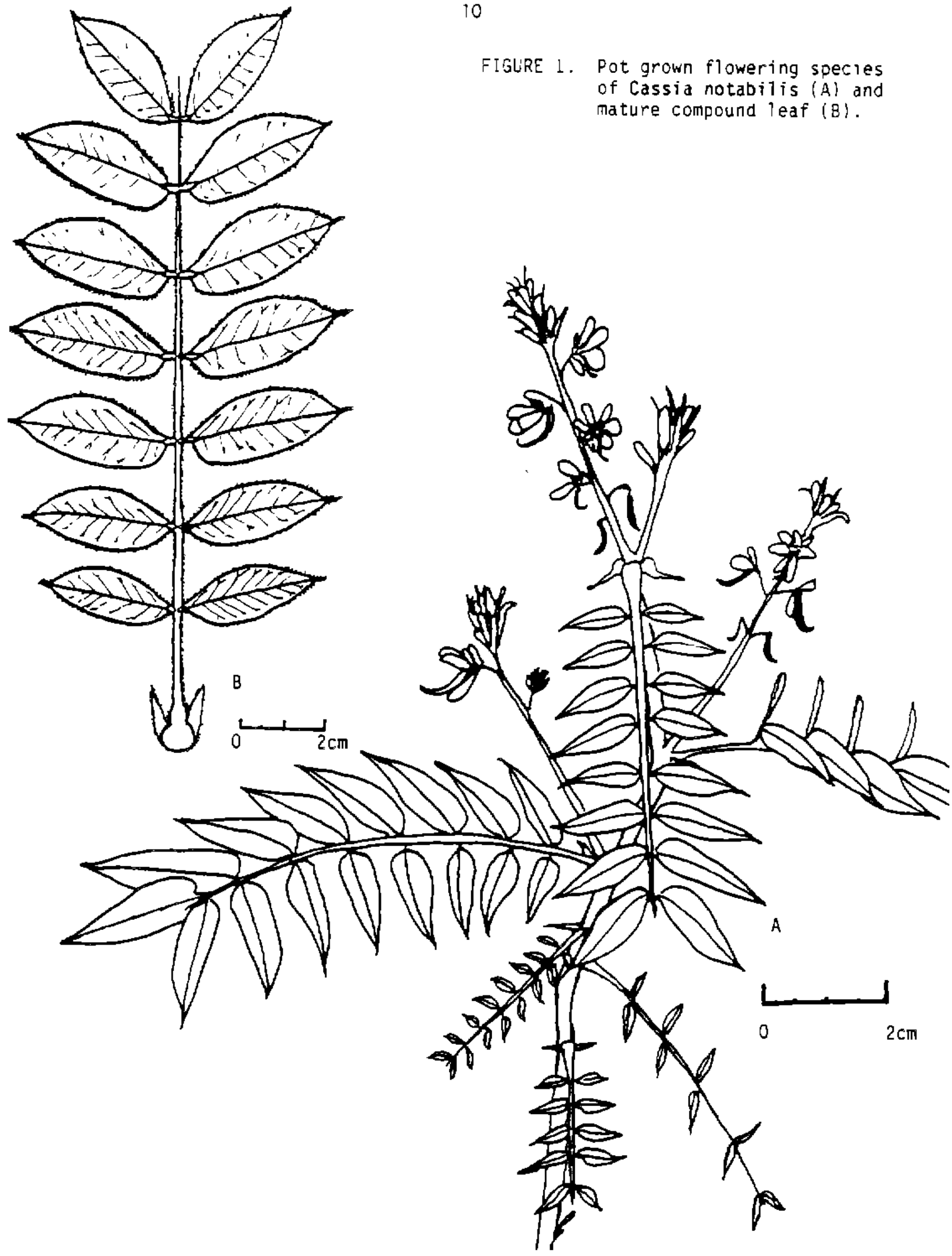

FIGURE 1. Pot grown flowering species of *Cassia notabilis* (A) and mature compound leaf (B).

In the first 5 weeks a greater percentage of plants died in coarse sand than in the mixed soil. By week 6 there were few plants remaining in those coarse sand treatments not receiving either constant or very frequent water.

Plant Survival by Treatment

The numbers of surviving plants in each treatment at weekly intervals are shown in Figures 4 (coarse sand) and 5 (soil mix).

In treatment 1 a greater number of survivors was noted in the coarse sand compared to the soil mix to week 3. Thereafter remaining plants in coarse sand died rapidly but one plant remained in the soil mix at the end of the trial.

With treatment 2 at all stages there were more live plants in the soil mix than in coarse sand. Most individuals were found to be necrotic after week 3 in coarse sand and after week 4 in soil mix. There were no live plants at the end of the experiment.

Treatment 3 plants in coarse sand died more rapidly than those in soil mix. All plants remained alive in the soil mix until after week 4, after which mortality was high. Survival was zero by week 6 in the coarse sand and at week 7 in the soil mix.

In treatment 4 the plants in soil mix survived for longer than those in coarse sand. Numbers of live plants declined rapidly in both soils in the first week of the trial, dramatically so in coarse sand. By week 7 there were no survivors in either soil.

Plants in treatment 5 showed best survivals. At the end of the trial all plants were visually healthy, showing no chlorosis or signs of stress. Survivals to week 7 were 18 plants in coarse sand and 20 plants in soil mix.

In treatment 6 there were more survivors at all stages in the soil mix than in coarse sand. Four plants survived in the coarse sand and 10 plants in soil mix to the end of the experiment. This was the second best treatment overall.

For the experiment as a whole, more deaths occurred in the less frequently watered plants. The constant water

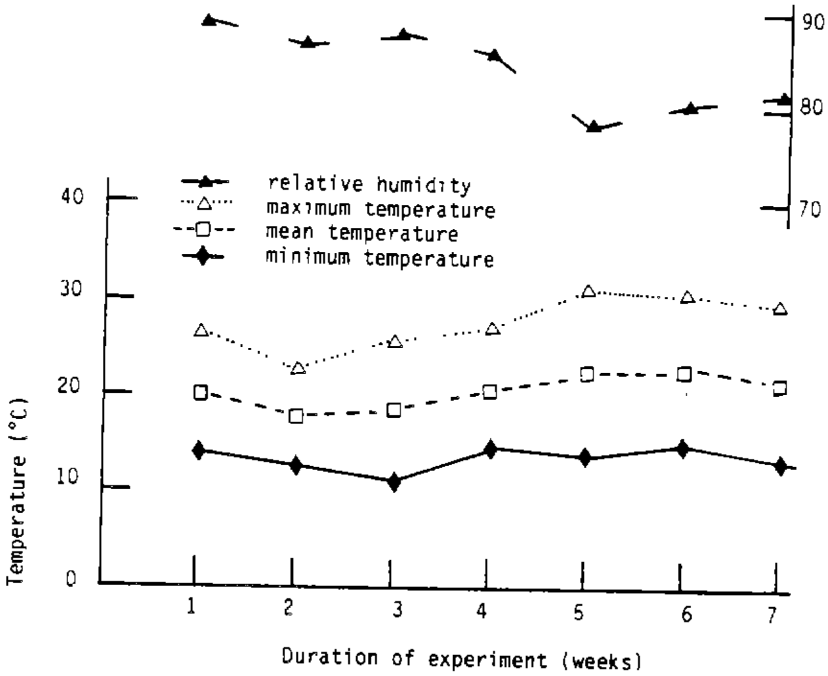

FIGURE 2. Mean relative humidity; maximum, mean and minimum temperatures over the duration of the experiment.

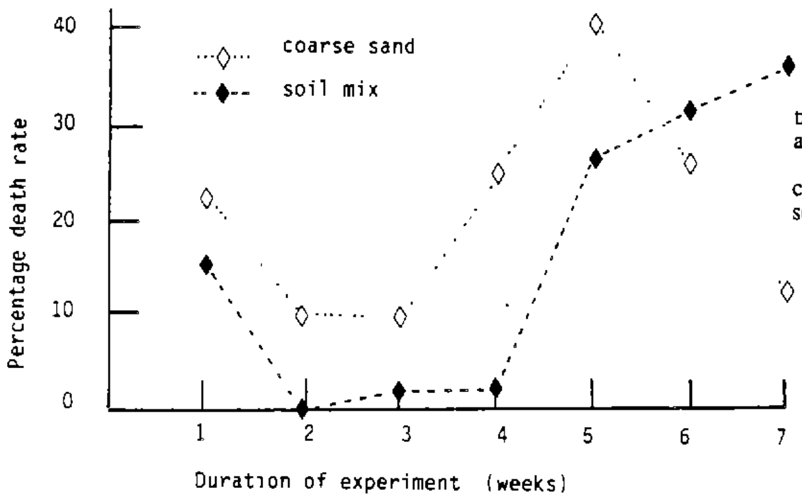

FIGURE 3. Percentage death rate each week for coarse sand and soil mix treatments combined.

treatment (T5) proved to be best. In order of best survival at week 7 treatments were:

coarse sand T5 > T6 > all other treatments
soil mix T5 > T6 > T1 > all other treatments.

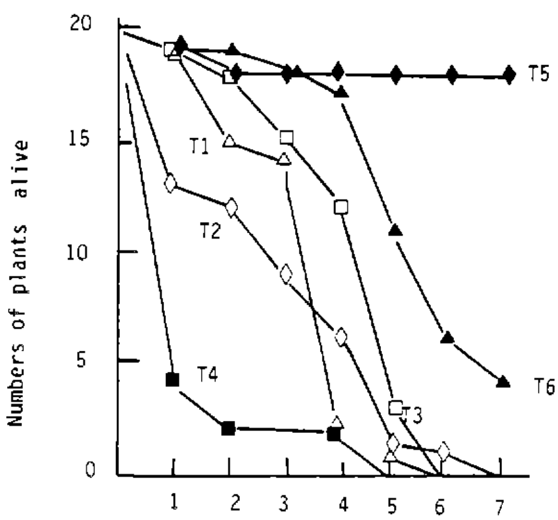

FIGURE 4. Numbers of live plants remaining each week for coarse sand treatments.

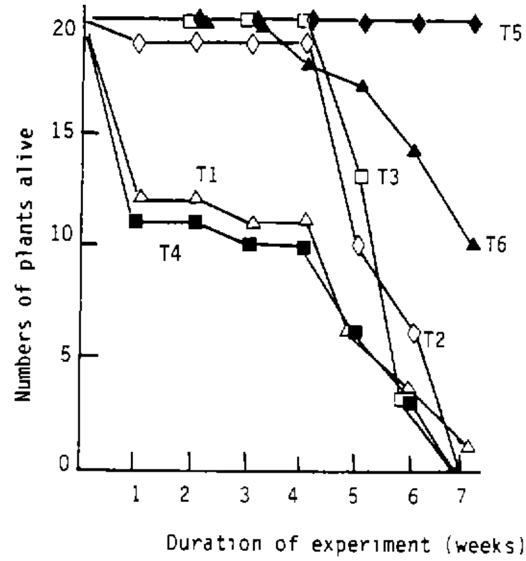

FIGURE 5. Numbers of live plants remaining each week for soil mix treatments.

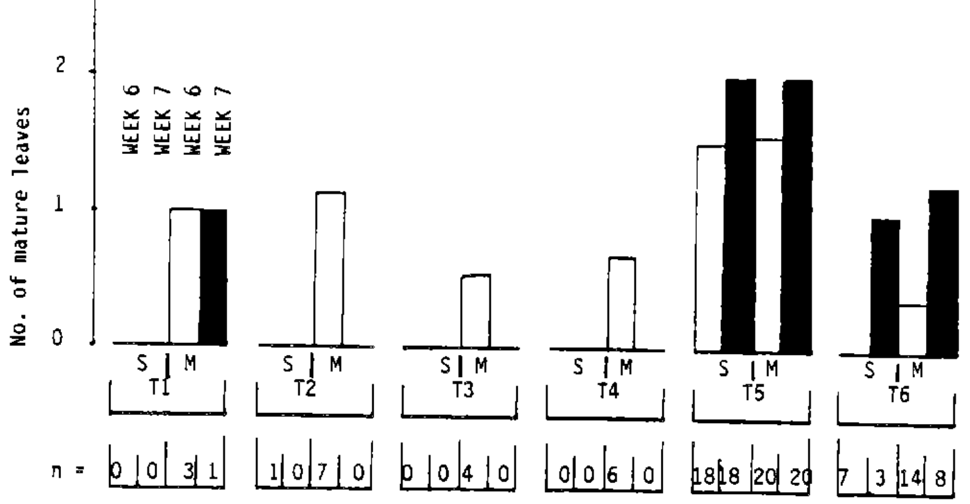

FIGURE 6. Mean number of mature leaves per plant at 6 and 7 weeks from start of experiment, for all treatments. S, sand; M, soil mix.

Mature Leaf Measurements

The mean number of mature leaves per plant and the mean length of the longest leaf per plant for each treatment are presented in Figures 6 and 7 respectively. It should be noted that at week 7 results of T1 are based on 1 plant only.

Mean numbers of mature leaves per plant were greater for seedlings growing in the soil mix than those of plants in coarse sand. Ranking of numbers by treatments at week 7 (greatest to least number of mature leaves) were:

coarse sand - T5 > T6 > all other treatments
soil mix - T5 > T6 > T1 > all other treatments.

This corresponds to the ranking of survival for each treatment. The ranks of treatments with greatest length of mature leaves to least length, for week 7 were:

coarse sand - T5 > T6 > all other treatments
soil mix T5 > T1 > T6 > all other treatments.

Mean number of mature leaves and mean length of mature leaves in both soil types were both greatest in T5 at each of the recording dates.

Other observations included general notes on root condition and on leaf colour. Root growth was poorer in coarse sand than in soil mix. There were few differences in leaf colour other than changes occurring with the onset of mortality

Discussion

Plants tended to die at a more rapid rate in coarse sand than in soil mix. Coarse sand is not suitable as a growing medium for **Cassia notabilis**, except when bottom water is available.

The soil mix used (equal parts fine sand, coarse sand and loam) was a more water- retentive medium than coarse sand. Organic material was present in the loam and the fine soil particles would have allowed a longer period of water retention. The soil mix was a consistently better medium for growing **C. notabilis**. There is some similarity between the soil mix used and Pindan soils near Derby where **C. notabilis** occurs naturally. A typical Pindan soil consists of medium sand 32%, fine sand 29% and clay 31% (Anon. 1983). A soil medium such as German Peat Moss and sand mix or Pindan soil may produce improved results due to the more water-retentive nature of these soils.

There was a tendency for plants with the least applications of water to show necrosis at a fairly early stage.
Of the most successful treatments (constant bottom water and daily overhead water) it is important to note that all plants watered from above showed a considerable amount of chlorosis during the first four weeks of the trial. There was minimal improvement at later stages. Plants in bottom water treatments appeared to show a much healthier colour. Plants in several of the poor survival treatments were a brighter green than those of the

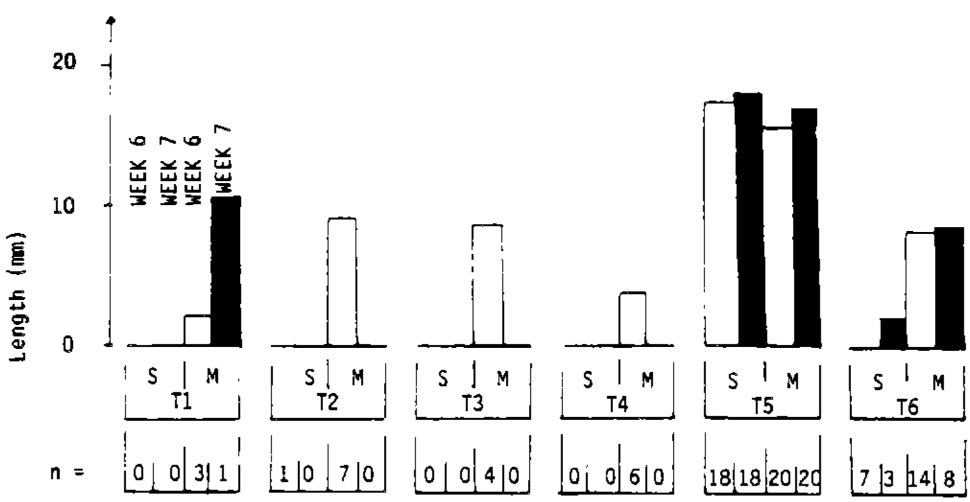

FIGURE 7. Mean length of longest mature leaves at 6 and 7 weeks from start of experiment, for all treatments. S, sand; M,soil mix.

overhead water treatment. This treatment cannot therefore be rated as successful in terms of health and vigour although ranking highly in survival. The reason for the chlorosis is uncertain. However the root system was considerably less well developed in the overhead water treatment compared with bottom water treatments. Perhaps overhead watering did not encourage root development. The chlorotic condition of plants in the overhead water treatment contrasts with relatively good results in terms of mature leaf number and size.

The most successful treatment in terms of survival, mature leaf numbers and mature leaf size was the application of constant bottom water. This is in contrast to initial expectations as **C. notabilis** grows naturally in arid or semi-arid areas and is often exposed to extremes in temperature with relatively low rainfall for several months of the year. These results suggest a high dependency on readily available water at least during the initial stages of growth.

It is possible that best growth of **C. notabilis** in its natural habitat is associated with moist soil. Summer precipitation on water retentive soils will cause waterlogging and flooding, at least temporarily. Such conditions may persist for several weeks, sufficient to allow good root development. The species is frequently found on river frontage areas and on road verges where additional water irunoff would be expected after heavy rains. Although frequent, such conditions rarely persist for long. It may be expected that a prolonged period of constant water could be detrimental to the species and a hardening off stage would be essential.

With **Cassia notabilis** it is possible to obtain 100 percent germination from seed and an initial survival rate of 100 percent with constant bottom water. It seems unlikely that the same percentage of plants would reach maturity. Other factors such as nutrient requirements are likely to play a major role in later establishment of the species. Fertilizer trials in conjunction with water regime trials would be necessary to examine the optimum application rates for successful establishment of **C. notabilis** under cultivation.

Representatives of the most successful treatment will continue to be grown in anticipation of achieving growth of **C. notabilis** to maturity at the Field Trial Area. Other plants will be maintained with a constant bottom water regime in order to determine how long they will thrive under or tolerate these conditions.

Conclusions

The results presented suggest small seedlings of **Cassia notabilis** are unable to survive conditions of water stress. A large number of plants died when the mean temperature was above 20 C and maximum relative humidity was under 85 percent. Best survival and growth were obtained from a water regime which provided plants with a constant and plentiful amount of water available from below the pot. Under these conditions the water-retentive medium achieved a 100 percent survival rate, and coarse sand was almost equally as good.

This result differed from initial expectations. It was considered that as this is a species adapted to desert growth, earlier poor results may have been due to overwatering. **C. notabilis** naturally occurs in arid and semi-arid areas of Australia where annual rainfall is relatively low. Although this is a preliminary trial the results are of sufficient interest to encourage a more detailed study into requirements for optimum growth of **C. notabilis**.

Acknowledgements

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THE ROLE OF ANTS IN DEGRADED SOILS WITHIN DRYANDRA STATE FOREST

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Introduction

The soils of the W.A. wheatbelt have become degraded as a result of unsound farming practices (Conservation and Environment Council, 1983). Degradation can occur through compaction of soil by the passage of heavy farm machinery, trampling by stock or through changes in microclimate due to reduction in shading by plants. Degradation of soils is further exacerbated by the depletion, or elimination, of large soil animals which are of crucial importance in maintaining soil structure (Abbott **et al** 1979).

Ants have recently been shown to play a key role in the maintenance of soil structure (Cowan **et al.**, 1985) and their importance in soil turnover in parts of eastern Australia has been found to exceed that of earthworms (Humphreys, 1981). Ants are of particular interest in degraded soils since they are one of the earliest groups to colonise disturbed land (Majer, 1981). In this paper we report some preliminary investigations on the abundance and role of ants in degraded farmed land within Dryandra State Forest.

Methods

Two plots within Dryandra State Forest were selected for this investigation which was carried out in March 1986. These were an unfarmed woodland control and an adjacent farmed paddock. The woodland was vegetated by wandoo trees (**Eucalyptus wandoo**) with an understorey of **Gastrolobium microcarpum**. The farmed area which was about 100m to the east, had previously supported a similar plant community but was now thinly covered with dried pasture species and weeds. The soil in both plots ranged from clayey- to sandy-loam and the farmed area was currently grazed by sheep.

A 30 x 30m study plot was marked out in both areas Recordings of soil physical variables were taken in both plots although ants were only sampled in the paddock. The ant fauna within native vegetation at Dryandra had earlier been surveyed (Majer, 1985).

The farm plot was carefully inspected for ant nests which were then marked. The area was searched so that representative ants could be collected for identification.

Soil inpenetrability, or compaction, was determined using a penetrometer. This measures the pressure required for a 2.5mm spike to penetrate the soil to a depth of 5cm. Forty random measurements were taken from both the farm and woodland plots.

Rate of water infiltration was measured using an infiltrometer. This involved hammering a hollow, 155mm diameter metal cylinder firmly into the ground so that it was sealed at ground level. It was then filled with water (1416cm3) to a fixed depth. The time taken for this water to percolate into the soil was recorded. Ten recordings were taken from both the farm and woodland plots. In addition, a set of recordings was taken with the infiltrometer placed over ten nests of each of the four commonest ant species in the farm plot.

Soil moisture content was determined by taking scoops of soil to a depth of 10cm and obtaining the difference between wet and dry weights of the soil. This was then expressed as a percentage of the total dry weight. Once again, ten samples were taken from both the farmland and woodland plots.

The mean values of the physical parameters recorded in each plot were calculated. These were compared between plots by the Mann- Whitney U-test.

Table 1. Comparison of soil physical characteristics in the field and wandoo (**Eucalyptus wandoo**) woodland plot.

Soil Characteristic	Farm ($x \pm$S.E.)	Woodland ($x \pm$S.E.)	Significance of difference
Soil impenetrability (compaction) (kPa)	4395 ± 179	4068 ± 348	n.s.
Soil moisture (%)	1.9 ± 0.3	2.9 ± 0.2	*
Infiltration rate (min/l)	27.2 ± 3.9	15.1 ± 4.5	*

* significantly different at $p < 0.05$; n.s. not significant.

Results

Mean soil inpenetrability was slightly greater in the field than in the woodland although the difference was not significantly different (Table 1). It is interesting to note that the variability was lower in the farm than in the woodland indicating the more homogeneous nature of the soil in the farmed plot. A number of woodland sites were either more, or less penetrable than the range exhibited by the farmland soils (Fig. 1).

Soil moisture values were significantly lower in the farm than in the woodland plot (Table 1).

Water infiltration was, on average, almost twice as rapid in the woodland as in the farmland soil and the differences between the means was statistically significant (Table 1)

Numbers of ant nests of the various species found are shown in Table 2. Six species were found in the plot although other, less common or conspicuous species may also have been present. **Pheidole** sp. 1 was the most abundant species, comprising almost half of the total nests (46%) **Tetramorium** sp. 1 and **Melophorus** sp 1 were the least abundant (1.8%). The previous survey (Majer, 1985) indicated that at least 16 species occurred in wandoo woodland plots of similar area to that studied here The **Pheidole** spp. and **Monomorium** sp. which were common in the farmland were not common in the native vegetation.

TABLE 2. Density of nests of various ant species observed in the 900m^2 farm plot.

Subfamily	Species	Number of nests	%
Ponerinae	**Rhytidoponera inornata**	14	8.4
Myrmicinae	**Monomorium** sp. 1	45	27 1
	Pheidole sp. 1	77	46 4
	Pheidole sp. 2	24	4.4
	Tetramorium sp. 1	3	1.8
Formicinae	**Melophorus** sp 1	3	1.8
Total		166	100.0

The water infiltration rates on the nests of the four most abundant species are shown in Table 3. Nests of **Rhytidoponera**, the largest of the four ants, had the fastest infiltration rate (5.6 min/l) while **Monomorium** nests had the slowest rate (11.2 min/l).

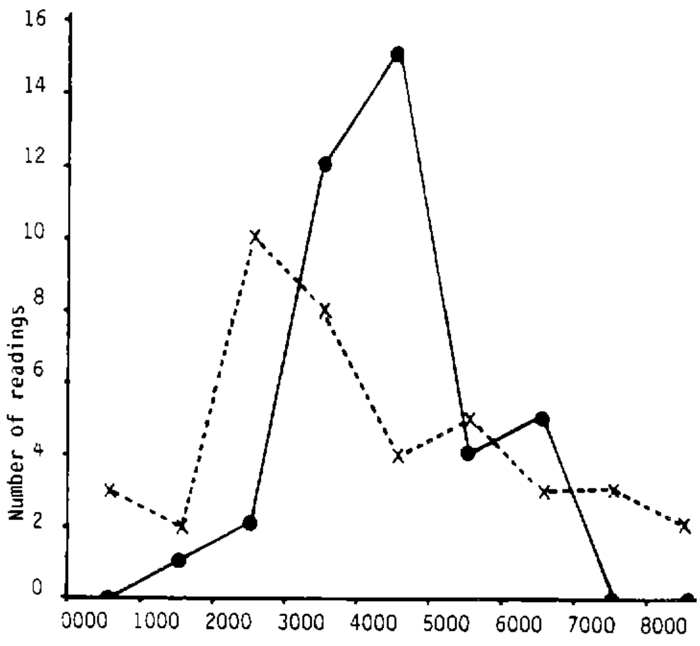

FIGURE 1. Frequency of soil impenetrability values in 1000 kPa range classes for farm (●____●) and woodland (x----x) soils (n = 40).

TABLE 3. Comparison of water infiltration rates on nests of the common ant species in the farm plot.

Ant Species	Infiltration rate (min/l) (x ± S.E.)
Rhytidoponera inornata	5.6 ± 2.5
Monomorium sp. 1	11.2 ± 2.8
Pheidole sp. 1	8.6 ± 2.8
Pheidole sp. 2	7.7 ± 2.2
Mean of all species	8.3 ± 5.4

Discussion

This study has confirmed the findings of earlier studies that farmland soils are of inferior physical quality to that under native vegetation. The farmland soil was generally more difficult to penetrate indicating that it was more compacted and/or more cemented than much of the soil under the wandoo iwoodland (Fig. 1). The soil was also more uniform in this regard than that of the woodland suggesting that there are fewer opportunities for organisms which require either hard or soft soil to survive.

The lower water infiltration rate of the farmland soil was probably a reflection of the compacted nature of this soil and also of the paucity of channels made by burrowing animals or plant roots. Evidence for these poor infiltration characteristics could be seen in the presence of shallow erosion gulleys across the surface of the soil. The low infiltration of water could also explain the low soil moisture levels in the farmland soil. However, the absence of shade in the farmland would lead to higher soil temperatures and hence faster evaporation rates. This would also contribute to low soil moisture levels.

This investigation, which concentrated on only one component of the soil mesofauna, indicates that ants are present, and relatively abundant in the farmland soil - at least 5.4 nests per m2. The diversity of ants in the farm is lower than that of the woodland areas (cf. Majer, 1985) but nevertheless, their nests are a conspicuous part of the environment.

That they were at least in part responsible for the mixing of soil strata at Dryandra, was indicated by the fact that the soil of the ant nest mounds was of a lighter colour than the surrounding surface soils. The presence of ants also had beneficial effects on the water infiltration characteristics of the soil, with infiltration rates on soil around ant nests being more than three times as rapid as in the surrounding soil ($p < 0.001$ using the Mann-Whitney U-test). Thus, although ant nests cover just over 0.14% of the total soil surface (assuming a mean nest diameter of 10cm), they contribute at least 0.48% to the total water infiltration in the farmland soil.

Although these results are from a preliminary study, they do highlight the deteriorating structure of agricultural soils and some of the benefits which ants can bring about. Further investigations are clearly needed to confirm and extend these findings. However, even at this stage it is clear that agriculture might benefit if steps were taken to encourage the colonisation and survival of ants and other animals in farmland soils. If this were done there would doubtless be improvements to the quality of the soils in these farmlands.

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GERMINATION AND SEED WEIGHTS OF UNUSUAL FORMS OF ACACIA ANEURA FROM THE NORTHERN TERRITORY

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Introduction

As part of a continuing study of the variation in **Acacia aneura** this paper presents some seed characteristics for 7 batches of seed including two unusual forms of the species from the Northern Territory. The unusual forms are known as 'weeping mulga' and 'Christmas tree mulga' (Fox 1986a). Seeds were collected in central Australia during October-November 1982 by S.J. Midgley of the Seed Centre, CSIRO, Canberra. Tests were made of viability on four lots at three months. Further germination tests were undertaken at Bentley in May 1983, six months after collection.

An attempt has been made throughout the mulga ecotype study to restrict germination tests to seeds from single parent trees (Fox 1980). In the present case seed batches came from sets of between one and 18 parents. Care was taken to ensure similarity for bulked collections.

A synopsis of each collection is as follows:

Description of each collection

<u>Collection No. 13717</u>
Taken at 23°12'S, 132°51'E, at 620m a.s.l.

Described as a regular central Australian mulga with double stemmed, spreading trees (or tall shrubs) and narrow phyllodes. Seeds collected from five parent trees of diameter, breast, height (dbh) 9-23cm, total height 4.5-6m. Location 0-500m past Narweitooma turnoff on Tanami Road.
Soil - red, sandy, pH 5.5
Mean seed weight 19.57mg

<u>Collection No. 13721</u>
Taken at 22°03'S, 131°20'E, at 640m a.s.l.

A "weeping mulga" with pendulous phyllodes to 15cm length. Seeds collected from two parent trees of dbh 8-12cm, total height 4-5m, very straight boles. Location Mt Doreen Homestead, Tanami Road. At three months from collection the seed was tested and gave 94 percent viability.
Soil red skeletal soil with rock fragments, pH 6.0.
Mean seed weight 18.38mg

<u>Collection Nos. 13723/480 and 481</u>
Taken at 23°36'S 132°24'E altitude 660m a.s.l.

Regular central Australian mulga with double stems. Seeds collected from two separate trees SM480 with broader phyllodes and SM481 narrower phyllodes. Trees of dbh 12-20cm and height 6m. Collected 30km west of Glen Helen. At three months average viability was 86 percent.
Red sandy soil with rock fragments, pH 5.5.

Mean seed weight for SM480 was 15.74mg and for SM 481 was 13 09mg.

<u>Collection No 13724</u>
Taken at 23°31'S, 132°26'E, at 660m a.s.l.

Seeds collected from a single tree of "weeping mulga" with long, pendulous phyllodes to 20cm, dbh 19cm, height 8m, straight bole of 3m with spreading crown This was noted as being the largest Acacia in the vicinity and a valuable seed source. Location 17km northwest of the junction of Namingina Drive and Hermannsberg- Haast Bluff Road. At three months from collection, seed was 92 percent viable
Soil - red, sandy
Mean seed weight 24.24mg.

<u>Collection No. 13725</u>
Taken at 25°21'S, 131°15'E, at an altitude of 580m a.s.l.

Described as "desert mulga", multi-stemmed shrubs of height 2.5m and stem diameters of 2-4cm Collection taken from 18 separate plants and bulked. Soil a red sand. Location 30km east of Uluru National Park visitors' centre on old main road. At three months seed was 70 percent viable.
Mean seed weight 11.15mg.

<u>Collection No. 13726</u>
Taken at 22°15'S, 130°50'E, at 640m a.s.l.

"Christmas-tree mulga", cypress-like, strongly apically dominant with horizontal branches. Seeds collected from 10 trees (and bulked), about 7m tall. Soil rocky ridge, pH 5.0. Location 3km northeast of Vaughan Springs Mean seed weight was 15.52mg.

Methods

Batches of 100 seed from each collection were individually weighed. Table 1 summarises seed weight characteristics using a similar notation to that given in Fox (1981).

Sets of seeds (usually 50 per dish) were given the standard hot water treatment. This involved pouring boiling water onto the seeds in test tubes, sufficient to cover the seeds with 2-3cm of water. The test tubes were then left to cool. Seeds were rinsed in deionised water and placed on filter paper in petri dishes. One dish was incubated from each collection at each of 15, 20, 25 and 30°C. Observations on numbers germinated were recorded twice a day The time course of germination for each dish is illustrated in Figure 1. From the twice daily records a series of seed quality measures (Hartmann and Kester 1975) was obtained. These data were calculated in hours rather than days Hard seeds from two batches were retreated.

Germinated seeds were transplanted to pots in a glasshouse and phyllode development was observed at 42 days from the start of germination tests.

Results

Seed weights

Seed weight histograms using 2mg size classes are presented in Figure 2 in the same style as those for Gindalbie (Fox 1981).

The Northern Territory seeds were generally heavier than other batches examined in detail. For comparison, Gindalbie **Acacia aneura** (Fox 1981) sets had values between 7.11 and 17 70g per 1000 seeds. Of 10 Gindalbie collections two were lighter than these Northern Territory sets and three of the seven N T. sets were heavier than the Gindalbie ones.

Germination

A summary of germination characteristics is presented in Table 2.

Taking each accession in turn it is noted that for 13717 mean viability for all seeds at 6 months was 97 percent Mean time to germinate was 42 hours at 30° and 64 at 25°C, with germination completed after 65 and 96 hours

TABLE 1. Seed weight characteristics of 7 Northern Territory collections of **Acacia aneura.**

Collection No	Individual weight (mg)			Range (mg)	1000 seed (g)	S E.	No of seed per kg
	Mean	Min.	Max.				
13717	19.57	7.73	32.25	24.52	19 57	5 01	51,100
13721	18.38	9 48	26.74	17.26	18.38	3.80	54,400
13723/480	15.74	8.07	23 00	14.93	15.74	3.36	63,500
13723/481	13.09	5.66	19.92	14.26	13.09	6.44	76,400
13724	24.24	6.85	35.42	28.57	24.24	5.31	41,300
13725	11.15	3.49	17.19	13.70	11.15	7.50	89,700
13726	15.52	6.74	26.18	19.44	15.52	4.16	64,400

respectively At 42 days after moistening of seeds, 54 percent of potted out seedlings had developed phyllodes.

In the case of collection no. 13721, the mean viability of seed at 6 months was about the same as at 3 months, with 97 percent of all seeds tested germinating. Germination levels at 20-30oC were similar with mean times of 45-48 hours and completion in 96-120 hours. At 42 days, 75 percent of seedlings had developed phyllodes.

For collection 13723/480 at 6 months viability had fallen to an overall level of 39 percent of seed tested. At 30oC, 50 percent of seeds germinated with a mean time of 39 hours, and all had germinated by 72 hours. At lower temperatures germination percentages were less and times required were longer. Phyllodes had developed on 67 percent of seedlings by 42 days after moistening of seeds.

In 13723/481 viability was retained with a mean level of 95 percent at 6 months. Mean time taken was least at 30oC with 57 hours, but completion times were shortest at 20 and 25oC. Only 23 percent of seedlings had developed phyllodes by 42 days after seed moistening.

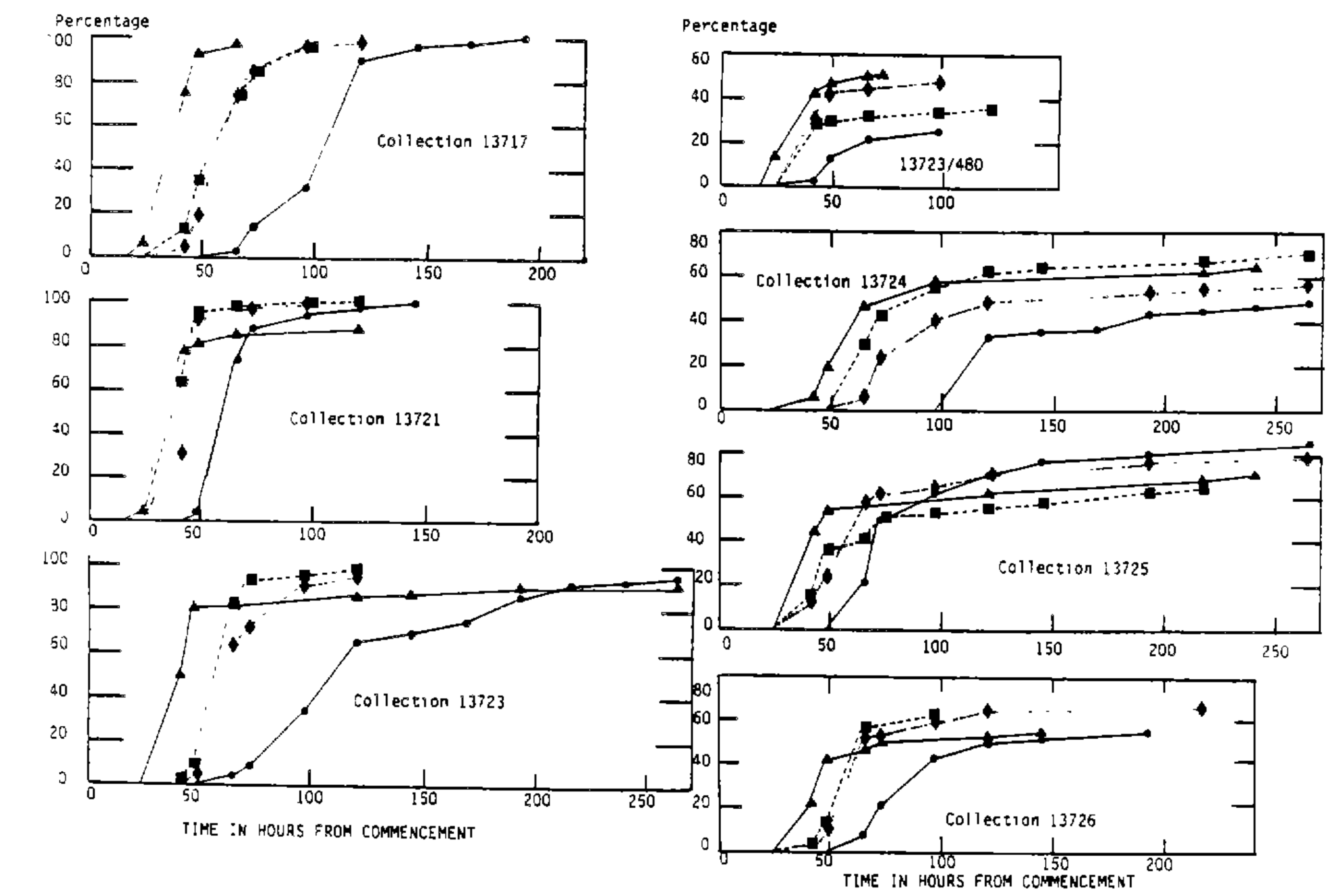

FIGURE 1. Time course of germination for 7 Northern Territory collections of Acacia aneura. Collection numbers shown. Incubation temperatures 15° circles; 20° diamonds; 25° squares; 30° triangles.

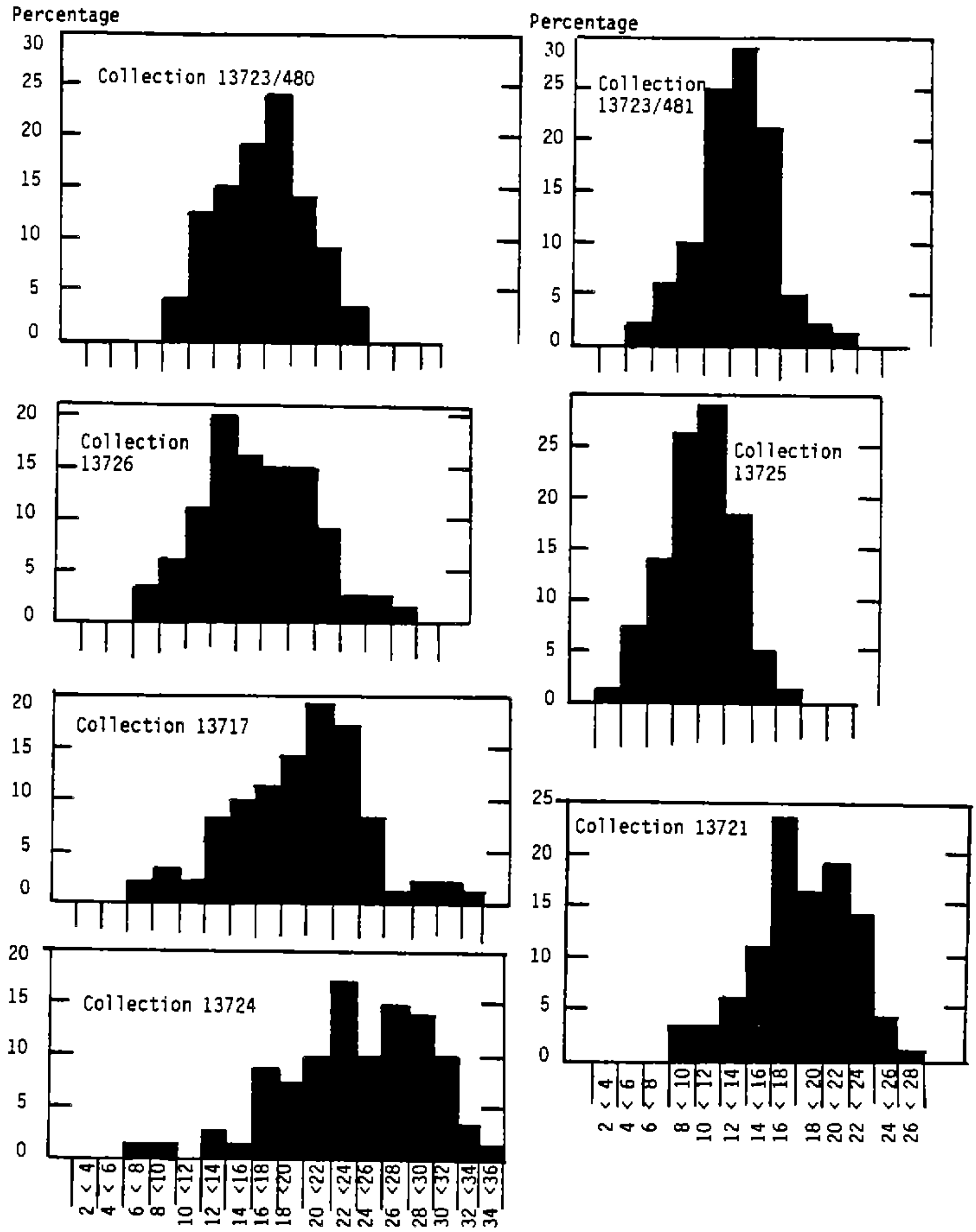

FIGURE 2. Seed weight histograms for 7 Northern Territory collections of <u>Acacia aneura</u>. Collection numbers shown with histogram.

Viability fell in collection 13724 with only 60 percent germinating at 6 months. Values were higher at 25 and 30°C, and lower at 15 and 20°C. Germination rate and completion times were fastest at 30°C. At 42 days 97 percent of seedlings had developed phyllodes.

In collection 13725 the 6 month mean viability at 74 percent was little different from that at 3 months. A higher percentage of seeds germinated at lower temperatures but mean time taken was shortest at 30°C and time to completion was faster at 25°C. Fifty nine percent of seedlings had phyllodes present at 42 days from seed moistening.

Finally, for collection 13726, the mean viability at 6 months from collection was 59 percent. Mean time to germinate was shortest at 30°C and time taken to complete germination was quickest at 25°C. By 42 days from seed moistening 52 percent of seedlings had phyllodes present.

In general, germination was faster at higher temperatures and slower at lower temperatures. All batches, apart from 13726, germinated fastest when incubated at 30°C. Four batches reached 50 percent germination in two days or less, a further three batches took three days, and 13724 took four days. In the case of 13726, time to reach 50 percent germination was shorter for seed incubated at 20 and 25°C than for seed at 30°C, but all three sets reached 50 percent germination in three days or less. In a number of cases the bulk of seed germinated very rapidly but a few seeds germinated later. It has been noted that some seed which fails to germinate following conventional hot water treatment may be 'soft' seed which is killed by the treatment (Fox 1980). In the present work at least two batches appear to have had exceptionally 'hard' seeds.

No further seed germinated after 11 days. A number of seeds appeared to be hard and unimbibed in both

13723/480 and 13724. These seeds were removed from original petri dishes and reboiled. They were then incubated at 30°C. For 13723/480 a total of 111 seed were reboiled and of these 38 germinated within 24 hours. At 14 days a total of 46 germinants had been observed and 41 apparently hard seeds remained.

Batch 13724 had 56 hard seed subjected to a second boiling treatment. Of these, 8 germinated within 24 hours. At 14 days a total of 39 germinants had been removed and 7 hard seed remained.

TABLE 2. Germination characteristics for 7 Northern Territory collections of **Acacia aneura**.

BATCH	Value	Incubation temperature (°C) 15	20	25	30
13717	MH	111.7	66.7	63.9	42.4
	CV	0 90	1.50	1.56	2.36
	GV	225	540	689	1636
	%	100	98	96	96
	t	192	120	96	65
13721	MH	70.9	48.3	45.8	45.4
	CV	1.41	2.07	2.18	2.20
	GV	489	1150	950	793
	%	100	100	100	90
	t	144	96	120	120
13723/480	MH	60.4	46.7	51.3	39.1
	CV	1.66	2.14	1.95	2.56
	GV	51	255	113	436
	%	25	48	36	50
	t	96	96	120	72
13723/481	MH	131.7	73.5	65.9	56.7
	CV	0.76	1.36	1.52	1.76
	GV	115	460	606	326
	%	95	96	98	91
	t	264	120	120	264
13724	MH	147.0	106.8	94.4	83.7
	CV	0.68	0.94	1.06	1.19
	GV	29	53	88	111
	%	49	57	70	65
	t	264	264	264	240
13725	MH	102.0	81.8	77.2	74.0
	CV	0.98	1.22	1.30	1.35
	GV	125	153	142	187
	%	85	79	65	70
	t	264	264	216	240
13726	MH	96 1	75.4	63.7	55.2
	CV	1 04	1.33	1.57	1.81
	GV	65	140	328	185
	%	55	66	62	54
	t	216	216	96	144

MH, mean hours to germinate as defined by Hartmann and Kester (1975); CV, coefficient of velocity - Kotowski (1926); GV, germination value of Czabator (1962); %, final germination percentage after time t (hours) at last germination.

Discussion

With optimal competitive conditions it has been generalised that larger seed provides better survival possibilities than smaller seed (Heydecker 1972). Comparative data on **Acacia aneura** germination are available from Laverton seed (Fox 1980) and a set of differing phyllode forms from Gindalbie, north-east of Kalgoorlie (Fox 1981). In these more southern localities, neither 'weeping mulga' nor 'Christmas tree mulga' have been noted.

In **Acacia aneura** it has been observed that, for seed within a batch, light seed may be less viable than heavier seed. The rate of germination appears to be more dependent on incubation temperature than on seed size (Fox 1980). Later tests on seed taken from single tree batches (Fox 1981) showed some tendency for higher viability with heavier seed batches. It may be hypothesised that a higher proportion of light weight seed has failed to reach maturity and that this characteristic may be influenced by the particular environmental conditions experienced during the period up to seed collection. Such environmental influences may override any genetical component of seed weight influence on long term survival. The Northern Territory collections support, in some general respects, the notion that heavier seeds are more likely to produce seedlings. Collections 13717 and 13721 both reached 50 percent germination in less than 2 days at 30°C and showed highest mean viability of 98 percent. Failure of some seed at 30°C was associated with infection, a phenomenon common to all batches tested. These two collections had heavier seed than all except for 13724; this latter being one of the two batches with residual, hard seed at 11 days from treatment.

Reboiling hard seed from batches 13723/480 and 13724 lifted the overall germination percentages from 39 to 63 and from 60 to 82 percent respectively. Presumably both batches had at least some seeds with exceptionally resistant seed coats. It is hypothesised that this characteristic may influence field germination responses such that not all available seed germinate with the first appearance of favourable conditions. This is borne out by field observations of extended germination following destruction of parent trees by fire in the Goldfields of Western Australia (Fox 1986b).

Both the hard seed batches were comparatively slow to germinate. 13723/480 required 3 days to attain 50 percent germination at 30°C, and 13724 took 4 days. All other batches reached this level of germination in less than 3 days. This supports the suggestion that harder seed coats are associated with the viability results attained. The seed weight histogram (Figure 2) suggests an abnormal weight distribution for 13724. Weight distribution across temperature treatments may have further complicated the pattern for this batch.

It would be of considerable interest to examine the viability of seeds within contrasting batches divided into seed weight fractions. When this can be repeated for seed from the same trees in different years, then considerable advances in our understanding of the competitive advantages of seed attributes will be possible. It is possible that some trees may consistently produce heavier seed, independently of the seasonal variations in rainfall which appears to have greatest effect on the total seed production.

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A PRELIMINARY INVESTIGATION INTO THE PLANT-WATER RELATIONSHIPS OF PLANT SPECIES OCCURRING IN THE HAMERSLEY RANGES

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Summary

Aspects of plant-water relationships of plant species from the Hamersley Ranges of W.A. were investigated.

Transpiration rates of five species (**Acacia aneura** F. Muell. ex Benth., **A. pachyacra** Maiden & Blakely, **A. pruinocarpa** Tind., **Eucalyptus terminalis** F. Muell., **E. leucophloia** Brooker) were measured in the laboratory over a 24 hour period under 3 conditions (high temperatures-high available water; high temperatures-limited available water; low temperatures-little available water).

The **Acacia** species showed a clear depression in transpiration between 1100 and 1400 h during summer conditions when available water was limited. The transpiration rates of the **Eucalyptus** species did not decrease during the daylight period.

Acacia species wilted at lower soil moisture percentages than the **Eucalyptus** species. Results indicated that the **Acacia** species used were more drought resistant than **Eucalyptus** species.

Evapotranspiration estimates of **Acacia aneura** (mulga) communities were made using field and laboratory data. Minimum and maximum evapotranspiration ranged from 0.1-1.4mm d^{-1} and 3.8-14.7mm d^{-1} respectively.

Introduction

The Hamersley Ranges are situated in the eastern Pilbara region of Western Australia. The climate is considered to be tropical. It is semi-arid with summer rain and precipitation averaging 300mm y^{-1} (Beard 1975). The area is endowed with ranges of mountains and broad valleys which include a variety of plant associations (Van Leeuwen and Fox 1985). Woodlands of mulga (**Acacia aneura**) are found throughout the area. Density, size and species diversity of pristine mulga stands appear to be strongly related to moisture regimes. On the desert loams and valley floors low mixed woodlands are found with **Triodia pungens** R.Br. (soft spinifex) ground cover, particularly on sandier soils. Low mulga communities are distributed in grove/intergrove patterns on the gentle slopes of the outwash fans along the contours. In valley bottoms and water collecting sites tall stands of mulga occur.

Where the mountain slopes are steep, mulga communities grow mainly on the south facing slopes, whereas northern aspects support low open **Eucalyptus** communities with hard spinifex species dominant as hummock grassland. (Van Leeuwen and Fox 1985). Little work has been reported on the water usage of mulga and associated communities in the Pilbara.

Slatyer (1961a) has described work on the water use of mulga woodlands in Central Australia while Pressland (1976a, b) reports studies in the Charleville district of Queensland. In places where mulga occurs in groves some redistribution of rainfall via runoff is achieved so that groves may accumulate more soil moisture then intergroves. In addition the vertical orientation of mulga branches allows a high quantity of intercepted rainfall to be delivered to the base of the tree as stem flow (Slatyer 1961a). Following rain soil moisture close to tree boles tends to be higher than further from the tree (Pressland 1976b).

After heavy cyclonic summer rain maximum soil water storage may be achieved. At this stage the whole soil profile would be at field capacity. As soil moisture is lost growth will eventually cease. Mulga has the ability to extract water held at a potential as low as -120 bars (Slatyer 1961b). It can withstand high soil moisture deficits though little comparative data appears to have been published to contrast mulga and other arid zone trees and shrubs (Pressland 1976b)

This study utilised field and laboratory data to estimate water usage of plants found in different habitats. Field observations were made during the summer of 1983 (January). Laboratory studies were made in an attempt to estimate water usage, physiological drought stress adaptations and stress limits of 5 plant species from the Hamersley Ranges (**Acacia aneura, A. pachyacra, A. pruinocarpa, Eucalyptus leucophloia** and **E. terminalis**). The objective was to estimate transpiration and contrast water usage of plants found in different environments.

Methods

Seed of three acacias, **A. aneura, A. pachyacra** and **A. pruinocarpa** and of two eucalypts, **E. terminalis** and **E. leucophloia** from West Angeles were sown in pots. Pilbara sandy loam containing no gravel and a peat-sand mixture were used as the two potting mixes. Plants were used for transpiration studies at between eight and ten months from sowing.

Acacia aneura has been noted to occur in at least two phyllode forms from the area of seed collection (Van Leeuwen and Fox 1985). In the present study, seedlings were classified as short and narrow, long and narrow or broad and falcate. Diurnal transpiration was measured separately for plants of each category of phyllode growing under the three different soil moisture regimes.

Soil Moisture Characteristics

Slatyer (1967) defines the water balance as

$$P - O - U - E + \Delta W = 0$$

where ΔW is change in water storage (initial minus final) during a study period and for the depth of measurement; P, O and U are precipitation, run-off and deep drainage respectively. U is the amount of water passing beyond the root zone or the amount passing below the lowest point of measurement. Evaporation is E (including transpiration) from the plant and soil surfaces. All the symbols have dimensions of length and all the elements can be measured or estimated to derive E by difference.

Field measurements of soil moisture were made in January enabling some use of the water balance to be made. Measurements were taken at six grove and seven intergrove sites at Munjina on 8th January. A 19mm rainfall event (cyclone 'Jane') occurred on the 9th January. Soil moisture levels were re-assessed on 11th January.

In the laboratory the water holding capacity and field capacity of the soils used were obtained and expressed as percentage soil moisture. Water holding capacity was determined by saturating oven-dried soil with water. At this stage 1 drop of water added to the top of the pot results in 1 drop falling from the bottom of the pot Samples of oven-dried soil were weighed (W1) in 7 x 7 x 10cm plant containers, saturated with water and reweighed (W2). They were then left to drain for 48 hours before weighing again (W3).

$$\%\ \text{soil moisture} = \frac{\text{wet weight(W2 or W3)} - \text{dry weight(W1)}}{\text{dry weight (W1)} - \text{container weight}} \times 100$$

Field capacity is the moisture content when soil material at water holding capacity has been allowed to stand for 48 hours. The standing period allows gravitational water to drain away and the soil water content to become relatively stable.

The infiltration rate of water into the soil was determined by pouring 20ml water on the surface ($10cm^2$) of oven dried (2-3 percent moisture) Pilbara soil in a 250ml measuring flask and noting the rate at which the standing water was absorbed (Slatyer 1967).

Two treatments were prepared to measure evaporation. One represented a barren soil surface and the other represented a mulga grove surface. The latter contained some leaf litter and other organic matter and was slightly shaded by a mulga branch. Both treatments were in columns 23cm high and had $10cm^2$ of exposed surface. Every gram weight loss was equivalent to 1mm of evaporation In order to simulate field conditions a controlled environment growth cabinet was used to control temperature and day length. A 12 hour photoperiod was used in combination with the temperature regimes given in Table 1

Plant Measurements

Plant performance of a range of Pilbara species under water-logged conditions was assessed by placing potted plants in containers filled with water thus restricting aeration of the root system. The experiment was performed under high February temperatures. Plants were maintained for 70 days and the numbers of survivors were observed.

TABLE 1. Growth cabinet settings for summer (high moisture) and winter (low moisture) conditions based on the temperature regime at Packsaddle (22°54'S, 118°42 E)

Time of day	Temperature (°C) February	July
0100	25	10
0200	25	10
0300	24	08
0400	24	08
0500	24	08
0600	23 Lights on	07
0700	25	06 Lights on
0800	27	09
0900	29	14
1000	31	17
1100	32	19
1200	33	20
1300	33	20
1400	34	21
1500	33	22
1600	33	22
1700	32	20
1800	31 Lights off	19 Lights off
1900	30	16
2000	29	15
2100	28	14
2200	27	13
2300	26	12
2400	25	11

Transpiration measurements were made on pot plants in the laboratory over twenty four hour periods. Pots were placed in plastic bags tied around the base of the stem. Any water loss would therefore be a result of transpiration. Each pot was weighed at regular intervals. Temperature and light regimes were the same as described for evaporation. Three soil moisture regimes were used:

* average hourly temperature for February (Table 1) with soil at field capacity, 26-30 percent H_2O
* average hourly temperature for February, soil at half moisture content, 12 percent
* average hourly temperature for July, soil moisture at quarter moisture content, 6 percent.

Permanent wilting point was estimated using potted plants and plastic bags as for transpiration. They were left to wilt until no recovery could be achieved (Lamont 1977). Percentage soil moisture was determined gravimetrically.

A high-powered microscope was used to count stomata on the ad- and abaxial surfaces. One representative leaf or phyllode from each plant was used.

Field Sites

Field studies were undertaken in the East Pilbara of Western Australia. Study sites were located at the Munjina area, centred on 22°45'S, 118°45'E; and at Sandhills (22°47'S, 119°37'). These areas have mean annual rainfall of the order of 280mm with the hottest months January to March receiving 60 percent, and the six months November to April, 75 percent of the mean annual rainfall. Sites at both areas were located in areas of mulga woodland. All trees were measured for height and crown diameter.

Biovolume ha^{-1} was obtained from field plot data according to the formula:

$$\text{Biovolume} = \text{sum of: } \left(\frac{\text{crown diameter}}{2}\right)^2 \times \text{height}$$

A rough correlation of leaf surface with biovolume was obtained after harvesting three trees, covering a range of heights, of a broad phyllode ecotype of **Acacia aneura** grown at the Field Trial Area on the Curtin University campus.

The laboratory measured transpiration rates (ml day^{-1}) of the broad phyllode variety multiplied by total estimated leaf area ha^{-1} gave estimates of maximum and minimum transpiration rates for mulga stands.

Soil evaporation values, as determined in the laboratory, were added to transpiration to provide generalised estimates of evapotranspiration rates.

Results and Discussion

Soil Moisture Characteristics

Water holding capacity and field capacity of soils are given in Table 2. The water holding capacity of both the sand-peat mixture and gravel-free Pilbara sandy loam was about 30 percent by weight. After settling, the Pilbara sandy loam had reduced capacity, probably because of smaller pore spaces. Presence of gravel also reduced water holding capacity. Pilbara sandy loam retained moisture longer than the peat-sand mixture and hence its field capacity was higher.

Ponded surface water infiltrated in 11.5 minutes, i.e. at a rate of 104mm h^{-1}. The water had reached a depth of 54mm in 11.5 minutes. After two hours water had penetrated to 90mm depth. Surface flow was not observed in the field.

There was little difference in evaporation between barren and litter covered surfaces (Figure 1). Initially water was lost linearly at an average rate of 3mm a day under the February regime until soil moisture reached about 13 percent at about day 20. After this time evaporation continued exponentially with a mean evaporative water loss of 0.5mm day^{-1} Regression equations were obtained

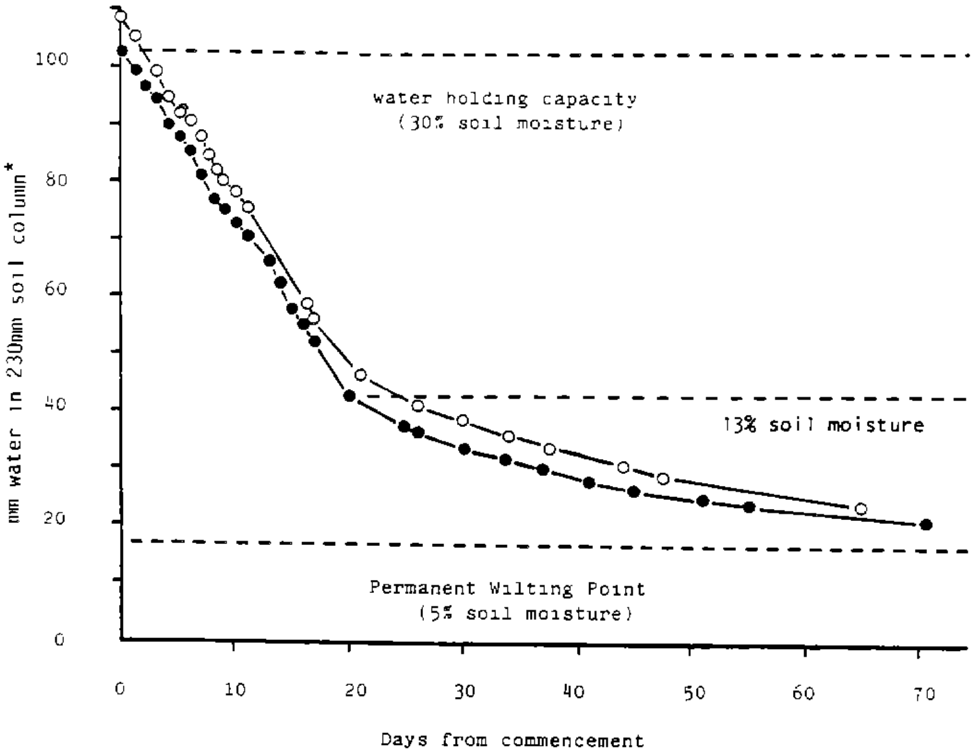

FIGURE 1. Evaporation of water from Pilbara sandy loam 1 from mulga intergroves under average temperatures for February

● = barren surface
0 = suface covered by mulga litter and slightly shaded
--- = water holding capacity and permanent wilting point of soil.

* Based on bulk density of 1.45g cm^{-3}

for all parts of the curves. By extrapolation it was calculated that soil would reach permanent wilting point 98 (range 76-131) days after being at water holding capacity under February temperatures. For average June temperatures an evaporation rate of 1.2mm day was measured for the linear section of the curve.

The difference between unvegetated intergrove and grove sites for soil water storage addition after rainfall is a function of interception and transpiration. Loss of moisture in the intergrove is due to evaporation. Stem flow may intercept 18-40 percent of rainfall over the tree canopy which is then redistributed in soil close to the tree bole (Pressland 1976b). The soil bulk density was 1.45 Two days after 19mm of rainfall the top 20cm of intergrove soil had increased water storage by 11.9mm. This suggests a maximum evaporative loss of 3.6mm day^{-1} By contrast, the increase in water storage in groves was 4.6mm. These data provide a simple estimate of water balance·

Rainfall 19mm	
Stem flow (35%)	6.7mm (after Slatyer 1965)
Interception	2.0mm (after Slatyer 1965)
Evapotranspiration	5.8mm (by deduction)
	14.4 + 4 6 = 19 0mm.

TABLE 2. Water holding and field capacities of potting soils used, measured in g water $100g^{-1}$ ovendried soil. Mean X, standard deviation SD, number of plants n.

Soil Type	Water Holding Capacity X	SD	n	Field Capacity X	SD	n
Peat-sand	29.6	1.5	10	26.2	1.4	10
Pilbara sandy loam						
No 1*	30.5	4 6	9	28.6	1 0	9
(settled)	(26.5)	(2.0)	(11)			
No 2	21 1	1.9	10	18.2	1.4	10

*No. 1 was collected from mulga intergrove and contained no gravel; No. 2 was a similar soil with gravel present.

Some redistribution of estimated stem flow water is assumed to equate evaporative losses from the bare intergrove with evapotranspiration from the grove soils. Thus, the reasonable expectation is that field evaporation from soil was of the order of 3.6mm day^{-1} in January.

The growth cabinet results were 3.0mm day^{-1} for the same depth of soil and fall within the error range of field measurements. Differences due to higher radiation and wind strength and possibly lower humidity in the field are sources of discrepancy. These are not accounted for in this preliminary exercise.

Plant Measurements

Under waterlogged conditions one out of three **A. pachyacra** died after 35 days and one out of ten **A. aneura** died after 38 days. All other species survived 70 days. **A. pachyacra** tends to occur on well drained sandy soils. It is possible that this species is less tolerant of prolonged excess soil moisture than the other species.

For A. **aneura** growing in Pilbara sandy loam (Figures 2-4), transpiration rose sharply starting around 6am and remained elevated until slightly after 6pm when it decreased sharply. Plants of the differing phyllode types showed different patterns of variation during the course of the day with those plants having long and narrow phyllodes reaching the highest rate (about 9ml $10cm^{-2}$ hr^{-1}). Plants with broad and falcate phyllodes had the lowest rate (5.5ml $10cm^{-2}$ h^{-1}).

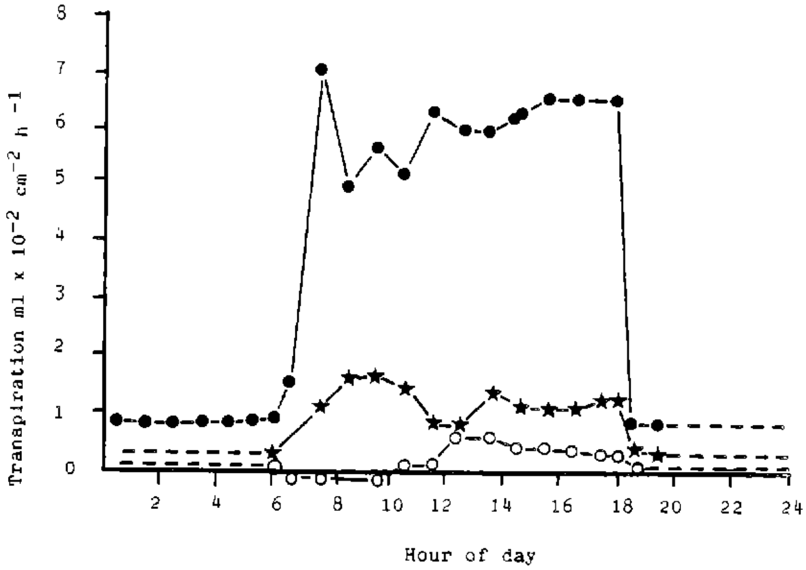

FIGURE 2. Mean diurnal transpiration of **Acacia aneura** with short narrow phyllodes growing in Pilbara sandy loam.

● - optimal conditions
★ - medium conditions
0 - stress conditions

number of plants (n) = 2.

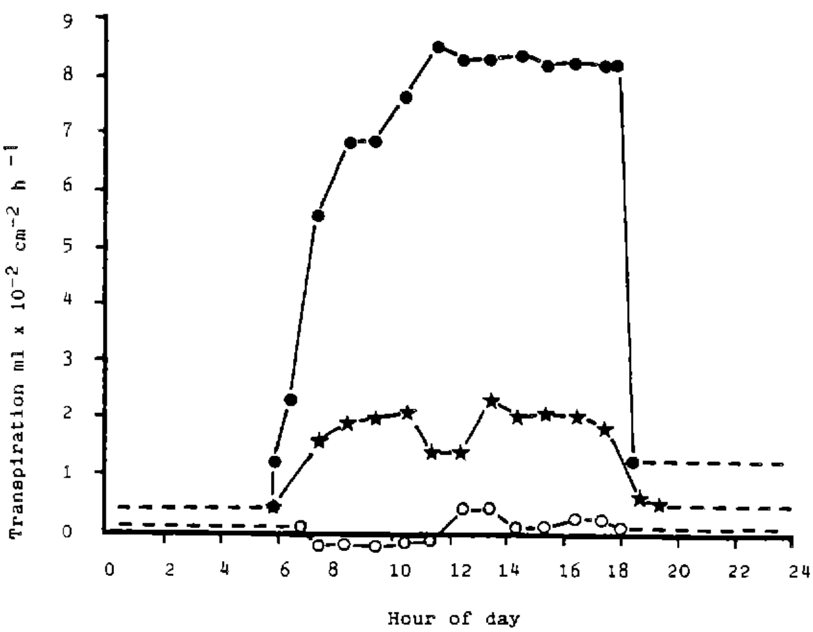

FIGURE 3. Mean diurnal transpiration of **Acacia aneura** with long and narrow phyllodes growing in Pilbara sandy loam.

● - optimal conditions
★ - medium conditions
0 - stress conditions

number of plants (n) = 7 for optimal condition
= 6 for medium and stress.

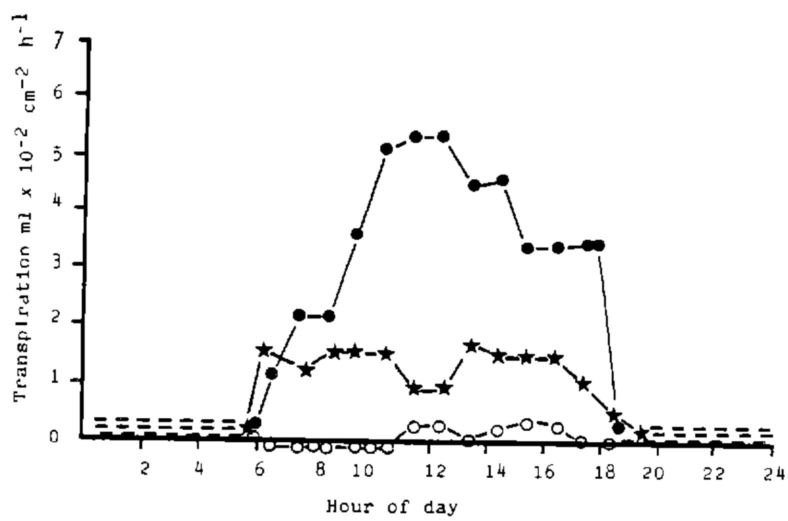

FIGURE 4. Mean diurnal transpiration of Acacia aneura with broad falcate phyllodes growing in Pilbara sandy loam.

● - optimal conditions
★ - medium conditions
O - stress conditions

Number of plants (n) = 4 for optimal conditions
= 3 for medium and stress conditions.

Under medium conditions of moisture availability the transpiration rate peaked at about 2ml $10cm^{-2}$ h^{-1}. Each rate decreased to about half for a few hours around midday.

When water stressed plants were at lower temperatures, an increase in weight occurred for the first four or five hours of the morning. The phyllodes appeared to absorb small amounts of water. Even at peak transpiration the rate was always well below 1ml $10cm^{-2}$ h^{-1}.

The experiments were repeated with **A. aneura** plants growing in a peat and sand potting mix. Transpiration rates of **A. pachyacra, A. pruinocarpa E. dichromophloia** and **E. leucophloia**, growing in peat and sand, were similar to those for **A. aneura** growing in sandy loam except that the midday reduction in transpiration was not always apparent and positive transpiration continued even under "stress" conditions. Tables 3 and 4 show transpiration per plant per day and per unit leaf area per day respectively. It can be seen from Table 3 that soil moisture level in the peat/sand mix was higher, at all three experimental levels, than that for the Pilbara sandy loam. This was particularly important in relation to lack of symptoms of drought stress attained for all plants at the lowest soil moisture treatment level.

TABLE 3. Transpiration per plant per day for three soil moisture levels (ml $plant^{-1}$ $24h^{-1}$). (Gravimetric determination of actual soil moisture given as % H_2O).

SPECIES	SOIL MOISTURE LEVEL											
	Water-holding capacity				Medium soil moisture				Stress			
	$\bar{x}$	SD	n	% H_2O	$\bar{x}$	SD	n	% H_2O	$\bar{x}$	SD	n	% H_2O
Pilbara sandy loam												
A.aneura(ln)	21.07	4.48	6	25.3	5.46	1.20	6	11.5	0.77	1.51	6	5.7
A.aneura(sn)	16.80	1.25	2	29.6	4.14	0.63	2	21.9	0.82	0.72	2	11.5
A.aneura(bf)	11.58	3.73	4	26.3	3.82	0.95	3	13.0	0.20	0.14	3	6.5
Peat-sand												
A.aneura(sn)	18.43	6.51	14	33.4	9.55	3.11	14	15.3	1.73	0.72	14	9.6
A.aneura(bf)	21.65	6.69	4	-	11.38	3.52	4	-	2.98	0.67	4	-
A.pachyacra	18.69	5.88	9	39.7	16.51	5.39	7	20.9	1.11	0.19	7	14.8
A. pruino-carpa	23.89	8.00	11	37.1	19.25	4.71	11	19.4	2.77	1.46	10	12.8
E. leuco-phloia*	21.93	-	1	34.4	27.06	-	1	16.9	2.04	-	1	9 6
E. termin-alis	18.38	4.93	16	34.5	14.03	3.67	16	16.4	2.86	0.81	16	10.0

* Leaf growth between experiments may have led to an underestimate of transpiration for optimal conditions.

TABLE 4. Transpiration per unit leaf area per day for three soil moisture levels (ml cm^{-2} 24 h^{-1})

SPECIES	SOIL MOISTURE LEVEL					
	Water holding capacity		Medium soil moisture		Stress	
	$\bar{x}$	SD	$\bar{x}$	SD	$\bar{x}$	SD
Pilbara sandy loam						
A. **aneura** (ln)	0.966	0.244	0.259	0.052	0.038	0.057
A. **aneura** (sn)	0.744	0.009	0.183	0.012	0.032	0.043
A. **aneura** (bf)	0.549	0.250	0.194	0.090	0.013	0.012
Peat-sand						
A. **aneura** (sn)	1.088	0.573	0.552	0.218	0.153	0.225
A. **aneura** (bf)	0.453	0.072	0.249	0.084	0.068	0.027
A. **pachyacra**	0.905	0.400	0.684	0.292	0.047	0.017
A. **pruinocarpa**	0.341	0.102	0.276	0.059	0.040	0.016
E. **leucophloia**	0.119	-	0.147	-	0.038	-
E. **terminalis**	0.280	0.206	0.192	0.077	0.051	0.039

Number of samples and percentage soil moisture as in Table 3.

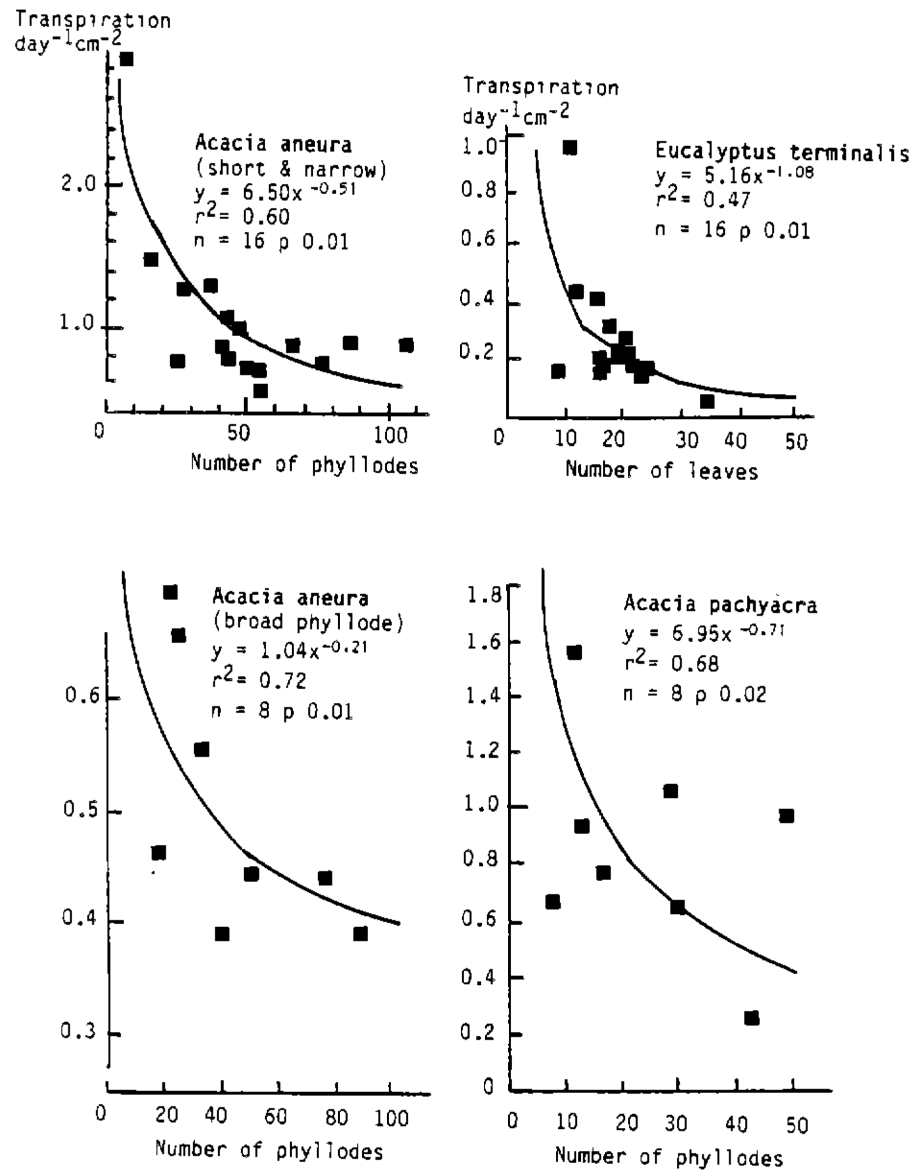

FIGURE 5. Relationship between number of phyllodes or leaves and transpiration at water holding capacity (ml $day^{-1}cm^{-2}$) in small plants of similar age.

TABLE 5. Permanent wilting points of **Acacia** and **Eucalyptus** seedlings studied. Standard deviation SD, number of plants n.

SPECIES	Mean % Soil Moisture	SD	n	Soil Type
A. aneura (long & narrow)	4.59	0.65	5	Pilbara sandy loam
A. aneura (broad & falcate)	5.37	0.42	4	Pilbara sandy loam
A. aneura (short & narrow)	0.53	0.10	10	peat-sand
A. pruinocarpa	0.63	0.24	4	peat-sand
A. pachyacra	0.91	0.46	4	peat-sand
E. terminalis	0.66	0.20	11	peat-sand
E. leucophloia	0.76	0.00	1	peat-sand

Diurnal transpiration rates for each species under optimum and medium conditions were statistically indistinguishable and the differences in maximum rates were not significant for any acacia or eucalypt species. However, the eucalypts (particularly **E. leucophloia**) did not reduce transpiration to the same extent under low soil moisture conditions (Table 4). In the peat/sand mix **A. pachyacra** showed the strongest reaction to low moisture conditions followed by the short and narrow **A. aneura** and **A. pruinocarpa**.

Strong negative exponential correlations were observed between transpiration under optimum moisture conditions and leaf/phyllode numbers (Figure 5). These patterns were taken into consideration in calculating estimated transpiration from larger plants based on seedling data.

Permanent wilting point occurred when soil moisture reached levels shown in Table 5. **A. aneura** (broad) wilted before **A. aneura** (long and narrow) in Pilbara soil. In peat and sand potting mix the order of wilting was **A. pachyacra, E. leucophloia, E. dichromophloia, A. pruinocarpa, A. aneura** (short and narrow). This suggests that at least in the seedlings studied, the acacias showed a tendency towards better drought resistance than the eucalypts. However the standard deviations were such that the distinctions are not clear.

With the exception of the leaflets of **A. pachyacra** with 35 percent more stomata on the lower surface, and leaves of **E. leucophloia** with 104 percent more stomata on the upper surface, ad- and abaxial surfaces of the leaves or

TABLE 6. Stomatal count for ad- and abaxial surfaces of phyllodes or leaves from three **Acacia** species and one **Eucalyptus** species. Standard deviation SD, number of plants n.

Species/Surface of Leaf	Stomatal Density stomata per mm^2			Size of Stomata ($mm\ 10^{-6}$)	
	Mean	SD	n	Length	Width
A. aneura (short & narrow)				20	7.5
Adaxial	110	17	5		
Abaxial	117	31	5		
A. aneura (broad & falcate)				20	7.5
Adaxial	104	11	7		
Abaxial	98	2	5		
A. aneura (long & narrow)				20	7.5
Adaxial	120	12	5		
Abaxial	123	15	5		
A. pruinocarpa				12.5	5
Adaxial	164	24	9		
Abaxial	161	9	5		
A. pachyacra (leaflet)				12.5	5
Adaxial	175	22	5		
Abaxial	231	44	5		
Adaxial (phyllode)	194	26	5	12.5	5
Abaxial	197	7	5		
E. leucophloia				15	5
Adaxial	359	20	5		
Abaxial	177	23	5		

phyllodes of each species had similar numbers of stomata (Table 6). Size differences between stomata of acacias and eucalypts may be important in influencing transpiration. A relationship appears to exist between stomata number and transpiration rate for the phyllode types of **A. aneura**, with the form having the highest stomata density also having the highest transpiration rate.

Field Studies

Biovolume is a very rough estimate of transpiration surface (Table 7). Phyllodes used to estimate surface area were broader than those of **Acacia aneura** from the East Pilbara and may have contributed to an over-estimation of transpiration.

Estimated daily transpiration in winter (0.1-1.4mm) and evapotranspiration of 3.8-14.7mm in summer under optimal soil conditions covers the range of other workers (e.g. Pressland 1976a, Hellmuth 1970).

Natural transpiration was estimated from laboratory studies. In the laboratory air humidity was not controlled and plants were well watered, which could lead to morphological and anatomical modifications. Test plants also had a high percentage of young phyllodes, which often have a higher rate of transpiration (Hellmuth 1970).

Soil evaporation was higher in the field than under laboratory conditions. Using the water balance method (Slatyer 1961a, Pressland 1976b) evaporation was estimated at 3.6mm day^{-1} in January in the field. The results are however within the same range: probably higher radiation and wind strength with lower humidity of the natural stand contributed to these differences.

TABLE 7. Biovolume, phyllode area and estimates of evapotranspiration range for Mulga stands at Munjina and Sandhills areas.

PLOT	Biovolume ha^{-1} (m^3)	Phyllode area (cm^2) x 10^8	Daily evapo-transpiration (mm) Min.*	Max.
Munjina				
1/20	28963	1.9223	.25	5.10
7/1	19642	1.3004	.17	4.41
2/2	25237	1.6751	.22	4.83
2/3	38072	2.5269	.33	5.78
2/3	29368	1.9251	.25	5.11
2/5	69975	4.4633	.58	7.94
46700	38876	2.5803	.34	5.84
6000	25878	1.7176	.22	4.87
Lake	16283	1.0807	.14	4.16
7500	25054	1.6629	.21	4.82
43500	47532	3.1548	.41	6.49
45000	44968	2.9845	.39	6.29
28100	11753	0.7801	.10	3.83
45800	157701	10.4673	1.36	14.66
23500	32767	2.1749	.28	5.39
4000	25698	1.7060	.22	4.86
21000	42820	2.842	.37	6.14
Sandhills				
14	100713	6.6847	.86	10.43
13	96938	6.4340	.84	10.15
12	82408	5.4692	.71	9.07
10	60948	4.0454	.53	7.48

* only transpiration in the absence of reliable field values for evaporation.

Conclusions

Basic information on some soil characteristics and plant species from the East Pilbara has been recorded viz. water holding and field capacities of the soil, water infiltration and surface evaporation rates, ability of plants to withstand waterlogging, their permanent wilting point and some stomatal and transpirational characteristics. These preliminary studies indicate that estimates of such variables as those investigated in the laboratory may be related in an approximate manner to conditions in the field.

Acknowledgements

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GERMINATION AND PLANTING OUT TECHNIQUES FOR THE WESTERN AUSTRALIAN SANDALWOOD (SANTALUM SPICATUM)

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Introduction

In a previous note (Crossland 1982) a comparatively simple technique for germinating the seed of Western Australian sandalwood (**Santalum spicatum** (R.Br.) A.DC.) was outlined. This note describes the method currently being used at Curtin University. People interested in growing sandalwood will be able to adapt the technique described to suit their particular circumstances.

Stages

1. Remove the leathery to cardboard-textured exocarp. Hold the nut firmly in wooden tongs. Using a band saw make a shallow cut (5-8mm long) in the hard outer shell (endocarp), being careful not to damage the fleshy, white endosperm within. It is not important where the cut is made.

2. Line a seed tray with a paper towel or similar absorbent material with a good wet strength and partially fill the tray with coarse washed sand.

3. Place seeds 3-4cm apart on the sand bed. Orientation of the seed is unimportant. Cover with a layer (about 1cm) of sand to prevent drying out.

4. Place the tray on a glasshouse bench (cooler months) or in a warm, shady spot and keep it moist but not saturated. Too much water will encourage fungal growth.

5. Germination will take place between 2 weeks and several months but most batches of seed will produce some germinants after 3 weeks, with the bulk germinating within 3-8 weeks.

6. Germination percentage will vary considerably depending on the seed characteristics and age. We have recorded germination as high as 93 percent and as low as 8 percent. Older seed tends to be less viable than recently collected material.

7. Check for germination at least once a week by carefully turning the sand by hand or with a small tool such as a trowel or a ruler. When the radicles are 1-2cm long, the germinants can be transplanted into pots or directly into the field. Germinants should be handled with care because their roots are very brittle. If a root breaks, the germinant should not be discarded as lateral roots will probably form and the seedling may well recover.

8. The best time for transplanting is in cool, humid weather during May-June.

9. So as not to deprive potted plants of the opportunity of finding suitable hosts, they should be planted out within a few months. If plants remain potted for longer periods it will become increasingly difficult for them to make the haustorial connections which are necessary for their survival.

10. Acacias and other leguminous plants appear to be effective hosts although haustoria can attach to many native Australian and other species, such as eucalypts, casuarinas and grasses. Trials at Curtin University have shown higher survival rates when sandalwood is planted in close proximity to the intended host(s). For example, planting could be within centimetres of a clover or grass plant, perhaps 20cm from a young, established acacia, and 0.5-1.0m from larger trees.

11. Young sandalwood grows appreciably better in the first 15-18 months if planted in 50-80% shade rather than in more sunny positions. In many cases host plants may provide this shade.

12. Losses due to fungal attack can occur when germinants are grown in pots or in the field. A light spray with a fungicide such as "Previcur" about once a fortnight is a good control measure in the early months.

13. Plants should not be allowed to dry out nor should they be allowed to become waterlogged. They will stand a good chance of survival if they are watered through the first and possibly the second, dry season.

Plates are photographs of seed from Peron Station in the Shark Bay area germinated at Curtin University.

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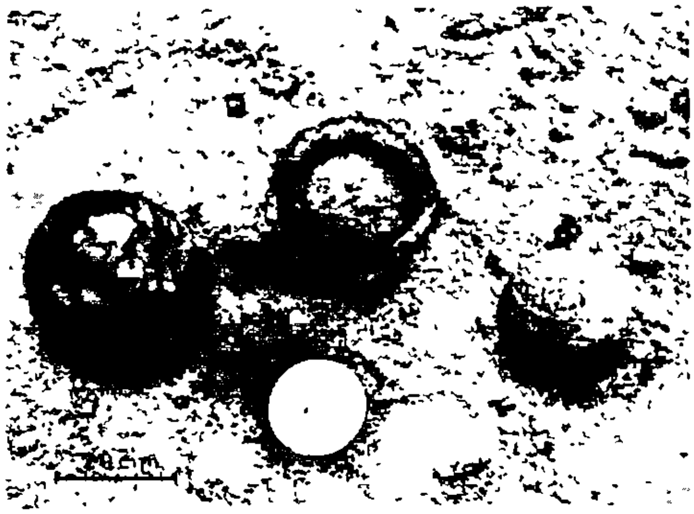

PLATE 1 Entire ripe fruit; fruit with dry outer cover partially removed to expose hard nut; nut with smooth, hard endocarp

PLATE 2. Nuts showing band saw cuts in endocarp; germinating seed with emerging radicle. Notice small lateral roots forming on root which had its meristematic tip accidentally removed

PLATE 3. Radicle has entered soil and shoot is emerging. Two strap-like structures (suspensors) connect the seedling to the endosperm. Notice that the shoot does not necessarily emerge where the band saw cut was made. This cut merely allowed the entry of air and water which initiated swelling of the endosperm and subsequent rupture of the endocarp.

PLATE 4. Young seedling two and a half months after sowing. It is still connected by 2 straps to the seed endosperm. The endosperm is being depleted as it is used as food for the growing seedling. After another month or so the nut will fall off and the suspensors will wither.

INITIAL OBSERVATIONS ON FLOWERING AND FRUITING IN SANTALUM SPICATUM (R.BR.) A.DC. THE WESTERN AUSTRALIAN SANDALWOOD

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Introduction

The 10 genera and 46 species of Santalaceae found growing in Australia are described by Hewson and George (1984). **Santalum spicatum**, a Western Australian member of the family, is a tree highly prized for its aromatic wood. It is a slow growing root hemiparasite which produces edible nut kernels. **S. spicatum** is closely related to another fragrant species, the Indian sandalwood (**S. album**) and to the Quandong (**S. acuminatum**) which grows across the southern half of Australia. **S. album** has been studied extensively for many years because of the value of its wood. **S. acuminatum** has more lately received attention because of its potential to provide a cultivated fruit and nut crop. Studies of the floral structure and fruit of **S. album**, **S. acuminatum** and other **Santalum** species (Gardner 1929, Rao 1942, Paliwal 1956, Grant and Buttrose 1978, Sykes 1980, Sedgely 1982) have been reported in the literature. The floristics of **S. spicatum** however, have not been studied in much detail. This paper presents some initial observations in an ongoing study of flowering and fruit production in this species.

Materials and Methods

The study area known as the Field Trial Area, is 2.5ha of fenced land on the Curtin University Campus at Bentley, W.A. Fifteen years ago, the site was part of a pine plantation. The soil is Bassendean sand containing very little humus and with low water retaining properties. The 10 sandalwood trees studied are growing amongst mulga (**Acacia aneura**) and other Australian species. They are irrigated during the dry season (summer). The trees studied were planted as seeds in February 1981 and transferred as seedlings to sites in the Field Trial Area in August of the same year. They are six years old and have both a mean height and a mean crown diameter of 2.6m. Most have borne flowers and fruit once a year for the past 3 years, that is, from an age of 4 years. The trees appear to be very healthy.

The number of inflorescences per tree were counted individually. Individual flowers in 20 inflorescences were counted and the mean value used to calculate the approximate number of flowers per tree. Ripe fruits were collected weekly from the ground beneath the trees. The exocarps were removed and the nuts counted. At the end of the fruiting season all the nuts from a particular tree were mixed well. One hundred nuts were then randomly taken from the bulk collection, weighed and each diameter measured from the pedicelar to the distal end. The kernel weight and diameter is the mean of 30 measurements.

Observations

Flowering commenced at different times on different trees. Some trees bore flowers from early January, others not until March or April. Flowers could be found on each tree for about four months although individual open flowers did not persist more than about 2 weeks. Buds, flowers and well-formed fruit were thus often found together on a particular tree (Figure 1).

The flowers are bisexual with typically 4 tepals but occasionally 5 or 6 tepals (Figures 2, 3 & 4). This is in contrast to the description given by Hewson and George (1984) in which flowers of this species are noted as possessing only 4 tepals. In bud, the tepals are green yellow, but as the flower opens and ages the tepals and receptacle become progressively red brown, with the older flowers sometimes quite darkly coloured. The tepals are triangular ovate, 1.5-2mm long, fleshy, with a flaky inner

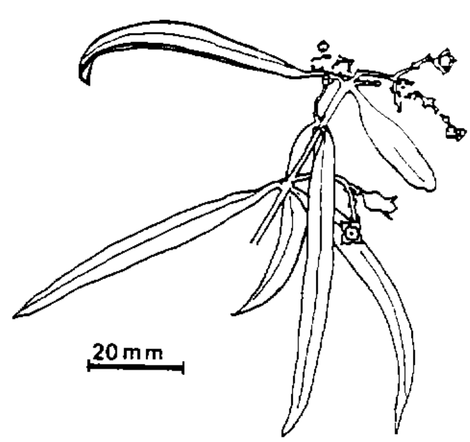

FIGURE 1. Sketch of a portion of a flowering branch showing terminal and axillary inflorescences. Notice unopened buds, flowers and developing fruit.

surface and hair tufts which arise behind the stamens. The tepals persist in fruit. The stamens are central to, opposite and attached near the base of each tepal. The filaments are short and the 2-locular anthers are flatly 2-lobed. The disc is slightly lobed, fleshy and cup-shaped when young, flattening out as the flower ages, the granular surface glistening with nectariferous exudation. The ovary is inferior with the short, bilobed stigma arising in the centre of the disc.

The pedicels of mature flowers are usually between 0.5mm and 2mm long, depending on age. The receptacle is elongate and forms a continuation of the pedicel from the abscission layer to the swelling of the disc. With fruit development the elongate portion of the receptacle swells to become part of the fruit. The peduncle bearing the three flowers is between 1 and 2mm long when bearing mature flowers but shorter when flowers are immature. Occasionally the peduncle is elongated and thickened (Figure 6C, central ray).

The flowers are small and very numerous giving an overall red-green appearance to the trees. With few exceptions they occur in triads fashion along the length of racemes or rays of simple or compound panicles. The inflorescences are either axillary or terminal. There are commonly between 5 and 10 paired flowering groups and a terminal group of 5 on any ray. Usually the triads occur in pairs and are arranged in an opposite and decussate fashion along the rays. Sometimes, though, the pair members do not occur opposite each other but are staggered on the flowering ray (Figure 6D).

The central flower within any group of triads opens first. Opening commences from the axillary end of the ray with the central bud of the first dichasial pair opening first. The central bud of the second, third and subsequent pairs open successively. The two lateral buds of each triad then open, usually together with the opening of these lateral buds proceeding progressively along the arm towards the apex. By the time the lateral buds open the central bud has usually fallen off. When buds near the apex are opening, those which opened first may have already aborted if they had not been fertilized, or a young fruit has commenced development. The central flower in most cases seems to abort although sometimes a fruit does develop in this position.

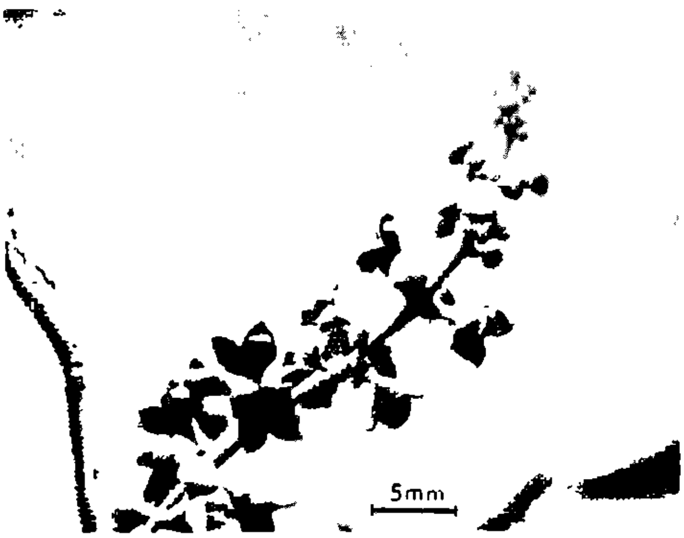

FIGURE 2. An inflorescence ray. On this ray flowers have four tepals. They open from the axillary end and the buds are grouped in threes along the ray in an opposite and decussate fashion.

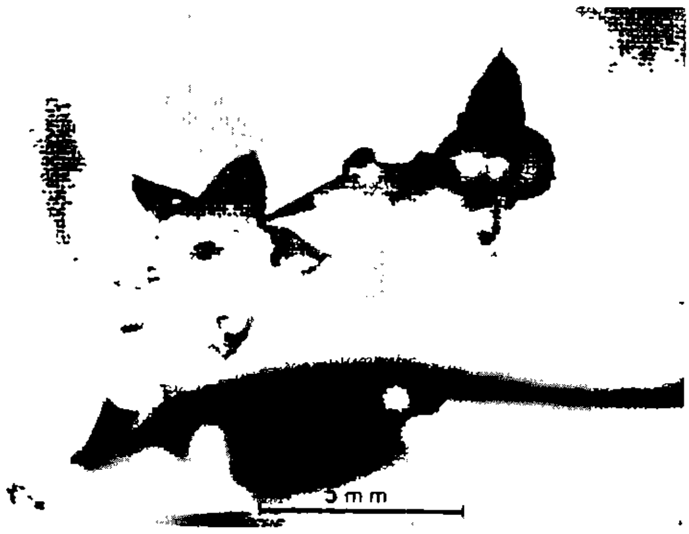

FIGURE 3. Senescing flower with 5 tepals.

FIGURE 4. Senescing flower with 6 tepals.

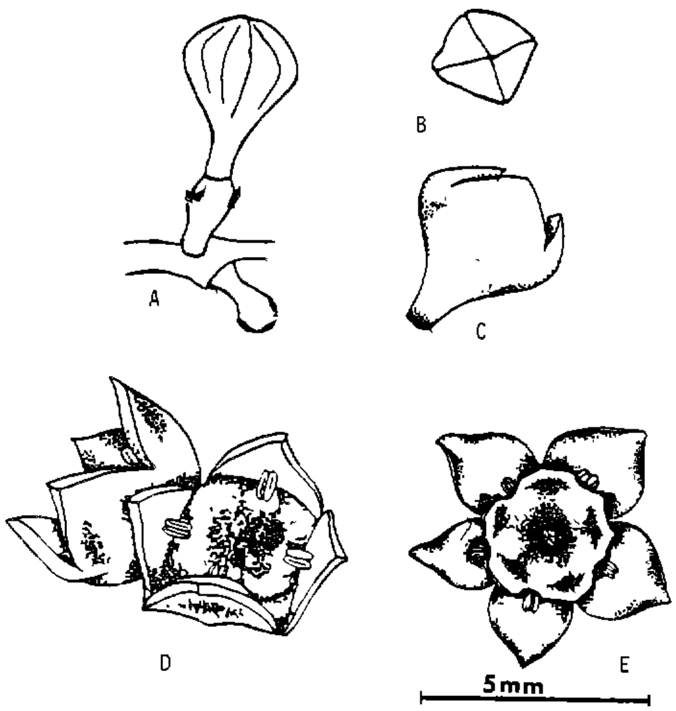

FIGURE 5. Sketches of floral structure. A, side view of unopened bud; B, surface view of unopened bud; C, bud beginning to open; D, newly opened flower with tepals forming a cup; E, mature flower with tepals fully opened on a plane with the disc. This is an unusual flower with 5 tepals.

Diagrammatic representation of the progression of flowering in an inflorescence is given in Figure 6. The sequence of opening, in arm E is typical. The first two paired positions have lost all flowers, while in the third position, the central flower has already been lost but the pairs of lateral flowers are open. In the fourth pair the central flower has been lost but the laterals are still in bud. In the fifth pair the central flowers are present and open with lateral buds smaller than those of the fourth pair. In the sixth pair no flowers have opened but the central buds are larger than the laterals. Terminal groups typically, as is the case here, have five buds with the central bud surrounded by four less developed buds, one pair being more developed than the other pair.

The flowers are mildly, but distinctly, carrion scented and nectariferous. During flowering the crowns are alive with flies, bees, wasps, ants and native cockroaches. Many of the visitors were observed lingering on the glistening surface of the disc, probing the juices with their probosces (Figure 4).

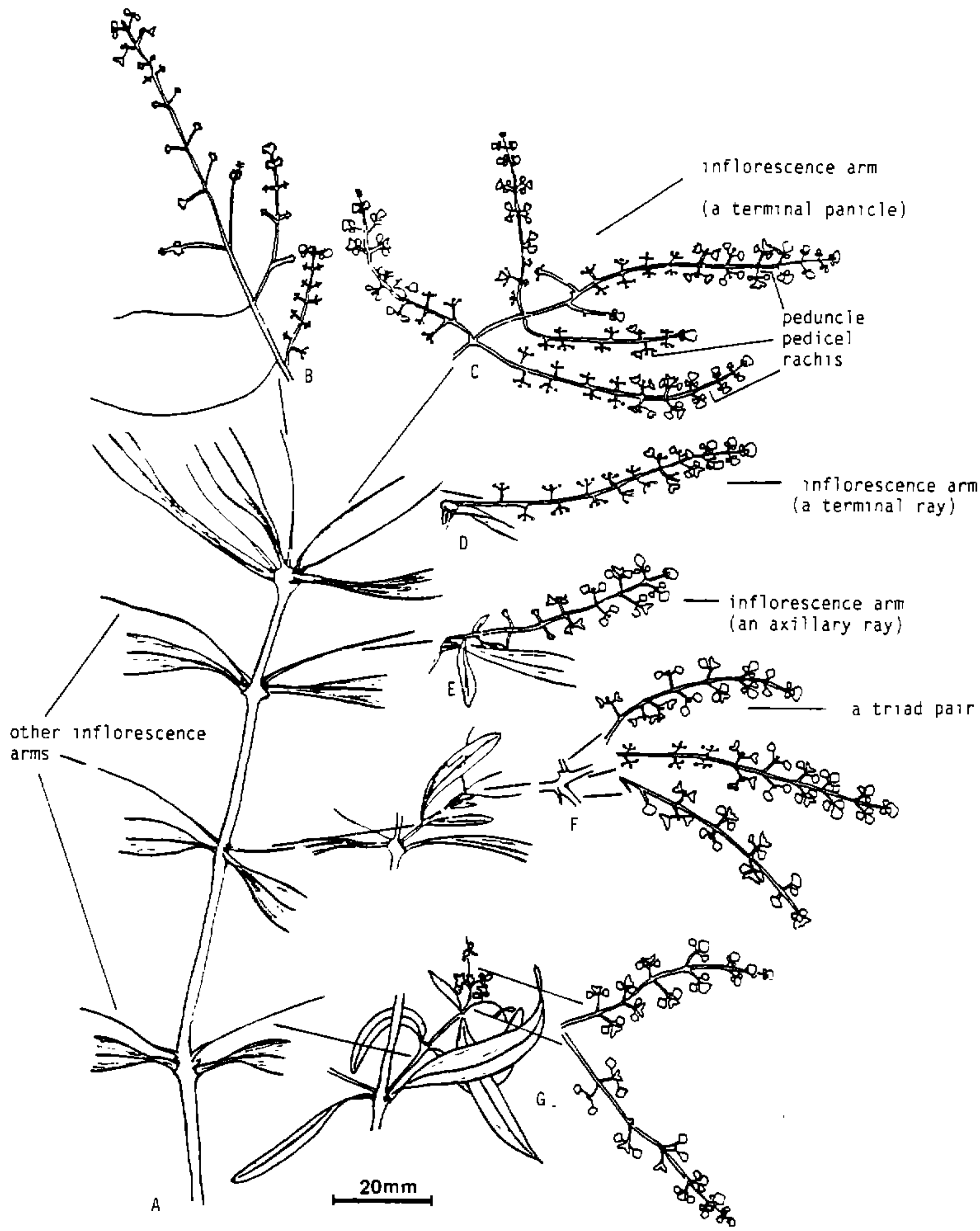

FIGURE 6. Diagrammatic sketches of a flowering branch. A, showing opposite and decussate arrangement of leaves and inflorescence arms; B-G, inflorescence arms which may be single rays (racemes, e.g. D) or compound heads (e.g. C) made up of spike-like rays. Notice order of maturation of buds: ᛙ = scar of fallen flower; ♀ = unopened bud; ⚲ = open flower.

TABLE 1. Number of fully mature **S. spicatum** fruit formed during the 1987 fruiting season on 6 six year old trees.

	Tree Number					
Date Collected	52	53	57	68	95	108
02.07	0	0	0	0	0	0
22.07	0	0	0	6	0	0
31.07	0	0	0	0	0	0
06.08	0	0	0	3	0	0
18.08	0	0	0	3	0	0
27.08	0	0	4	3	0	0
03.09	11	0	6	8	0	0
07.09	6	0	8	4	0	0
17.09	45	4	69	17	0	0
24.09	202	110	338	12	17	0
29.09	162	132	165	9	30	0
05.10	114	136	136	7	13	0
13.10	60	201	31	8	27	0
19.10	10	77	15	11	11	0
28.10	11	21	22	15	7	1
03.11	9	34	14	17	11	1
13.11	4	4	10	5	15	0
17.11	0	0	0	0	2	0
Total no.	634	719	817	128	133	2

TABLE 2. Numbers of flowers and fruit formed in 1987 on six year old trees.

	Tree Number	
	52	68
No. of inflorescences/tree	1850	890
Mean no. flowers/arm	90	100
Calculated flowers/tree	168,000	90,000
Fruit matured/tree	634	128
Flowers/mature fruit formed	270	700

TABLE 3. Numbers, mass and size of nuts and kernels from 1987 crop of 6 six year old **S. spicatum** trees.

Nut parameters mass (g) diameter (mm)	Tree Number 52	53	57	68	95	108
Total no. of nuts	634	719	817	128	133	2
Mean diameter±S.D.	17.6 ±1.3	15.4 ±1.1	15.5 ±1.2	18.3 ±1.3	20.0 ±1.1	18.1 ±1.7
Mean mass/nut	2.15	1.67	1.75	2.72	3.51	2.50
Total mass of nuts/tree	1363	1201	1430	384	467	5
Mean kernel diam.±S.D.	9.3 ±1.5	10.5 ±0.9	10.8 ±0.8	12.1 ±0.9	13.1 ±0.9	-
Mean mass kernel	0.45	0.63	0.66	0.92	1.22	-
Total mass of kernels/tree	285	453	539	118	162	-

Fruit on our trees took about six months to mature. At first, the green epicarp and mesocarp adhere closely to the endocarp. As the fruit nears maturity the exocarp becomes firm, about 1mm thick, with a texture similar to leather or soft cardboard. This covering forms a loose, easily removed, red-brown envelope around the smooth hard epicarp (see Figure 1, p.32, Barrett, this volume). Table 1 records the numbers of fruits maturing at different times on 6 of the trees studied.

Table 2 gives estimates of the number of inflorescences per tree and the number of flowers per inflorescence on two trees in the study group. The number of fruit which developed to maturity is also listed.

A large number of flowers do not form fruit. In addition it was observed that large numbers of young fruit fall and are lost at all stages of development. It would seem that the trees are not achieving their fruit bearing potential. The disparate numbers of nuts produced on trees of similar age and size (Tables 1, 3) suggest the problem may be nutritional or due to inherent characteristics, rather than one of carrying capacity or inadequate pollination. Nut kernel size (Table 3) is also variable. Trees producing larger quantities of fruit have smaller nuts and kernels. The kernels are not perfectly round but rather irregularly spherical.

It is hoped that continuation of this work at Bentley and in the field over the next few years will provide further new information relating to growing Western Australian sandalwood not only for its wood but also for its edible nuts.

Acknowledgements

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COMPARATIVE PERFORMANCE OF FOUR EUCALYPTUS SPECIES GROWN ON TWO COAL MINE INTERBURDEN MATERIALS

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Summary

Seedlings of four eucalypt species were grown in two interburden materials from a coal mine near Collie. Half the seedlings received fertilizer (NPK) and the other half grew in unamended material.

Significant growth responses to the addition of fertilizer were observed on both types of material for three species. Greatest relative increases in dry matter for fertilized seedlings were obtained for **E. camaldulensis** and **E. wandoo**. **E. patens** grew well in both interburden materials but showed less response. Low, non-significant growth responses to fertilizer by **E. calophylla** may be altered by applying fertilizer later.

Introduction

Rehabilitation of coal mine dumps is hindered by the nature of the material. The dumped interburden material is generally acidic, low in nutrients, and therefore not suitable for the growth of many plant species (Koch and Bell 1985). In addition, construction of steep slopes during the formation of dumps may cause erosion problems and leaching of material (Bartle and Riches 1978).

A series of experiments is being undertaken to investigate the suitability of various tree and shrub species for growth in a range of interburden materials which may be used to form the top surface of dumps. Legume species are generally favoured (Koch and Bell 1985) and in most cases liming is necessary and will be an integral part of rehabilitation procedures (Fox and Mathie 1982). Earlier experiments using undifferentiated materials suggested that species of Myrtaceae were unlikely to do well in these materials (Fox, O'Dea and Patroni 1985). However it is important to obtain data on comparative performance of alternative suites of potentially useful species, in selecting appropriate interburden layers. In forested regions, as at Collie, species of **Eucalyptus** provide an obvious choice for consideration. Despite the economic importance of eucalypts there is very little information on growth in acidic materials (Dell, Loneragan and Plaskett 1983). Seedling growth tends to be enhanced with increasing levels of nitrogen and phosphorus. These essential nutrients produce synergistic increases in dry matter accumulation (Halsall, Forrester and Moss 1983).

This report gives an account of a preliminary experiment to examine the early growth of seedlings of four eucalypt species on two interburden materials from the Muja mine near Collie. The materials were tested in both unamended form and with the addition of slow release, balanced fertilizer (Osmocote: NPK).

TABLE 1. Comparative properties of two interburden materials from the Muja Basin, Collie.

PROPERTY	INTERBURDEN Ate-Bellona (A-B)	Ceres-Diana (C-D)
Colour	grey	white
Pyrites	obvious	scarce
Acidity		
Original pH	3.9	5.0
Inherent capacity, expressed as percentage calcium carbonate for:		
Acid production	0.156	0.031
Acid neutralising	0.136	0.075
Actual pH (Bentley)	3.5	5.5
Nutrient elements (ppm)		
Phosphorus	ND	0.227
Nitrogen	180	ND
Potassium	ND	1.15

ND not detected.

Materials and Methods

The interburden materials used are described in Table 1. Materials were mixed and sieved to remove large lumps in order to reduce variability in pot culture. A set of 320 plastic square- sided pots, of top dimensions 7 x 7cm, and height 10cm, was lined with moistened vermiculite. Half the pots were filled with A-B material, and half with C-D material. These were then set out on a hard stand area at the WAIT Field Trial Area and moistened prior to planting of seedlings.

Seed of four **Eucalyptus** species were sown into germination trays on 23rd June 1982; the species used were **E. calophylla** (marri), **E. camaldulensis** (river red gum), **E. patens** (yarri) and **E. wandoo** (wandoo). On 4th August seedlings were carefully transplanted from germination trays into the pots, giving 40 of each species in each of the two interburden materials. Both **E. camaldulensis** and **E. wandoo** seedlings were small and difficult to transplant without root damage. A few deaths occurred in the week after transplanting, and on 14th August all dead plants were replaced by new seedlings from the original cohorts.

A set of 5 seedlings of each species was harvested from the germination trays on 4th August and dry weights were obtained. '90' day Osmocote slow release fertilizer, containing 14 percent nitrogen, was added to half of the pots of each species in each material giving 16 treatment sets of 20 plants on 18th August. The rate used was equivalent to 50kg nitrogen, with 21.8kg phosphorus, and 41.4kg ha^{-1} potassium. Conventional fertilizer treatment for eucalypts grown on bauxite pits provides 39kg of N, 31kg of P and 48kg ha^{-1} of K (Fox and Rhodes 1981).

TABLE 2. Mean dry weights (g) at time of transplanting and three harvests for four eucalypt species with (+) and without (-) fertilizer. Analysis of variance for harvest at 82 days* is included.

TREATMENTS	SPECIES							
	E. calophylla		E. camaldulensis		E. patens		E. wandoo	
Transplanting n = 5	0.153		0.001		0.008		0.002	
Fertilizer	+	-	+	-	+	-	+	-
TIME OF HARVEST								
30 days n = 4								
Ate-Bellona	0.419	0.316	0.004	0.001	0.023	0.017	0.004	0.002
Ceres-Diana	0.344	0.277	0.005	0.001	0.028	0.013	0.004	0.002
55 days n = 6								
Ate-Bellona	0.543	0.563	0.011	0.005	0.061	0.025	0.010	0.005
Ceres-Diana	0.467	0.487	0.020	0.003	0.119	0.026	0.033	0.006
82 days n = 5								
Ate-Bellona	0.849a	0.689a	0.182a	0.004c	0.244a	0.037b	0.071a	0.012c
Ceres-Diana	1.057a	0.755a	0.111b	0.006c	0.236a	0.040b	0.201b	0.017c
Analysis of variance	F 2.5	NS	F 28.8	***	F 30.3	***	F 125.5	***

* For the 82 day harvest treatment weights within a species have the same letter where means do not differ significantly using LSD test at $p < 0.001$. Analysis of variance: NS not significant, *** $p < 0.001$).

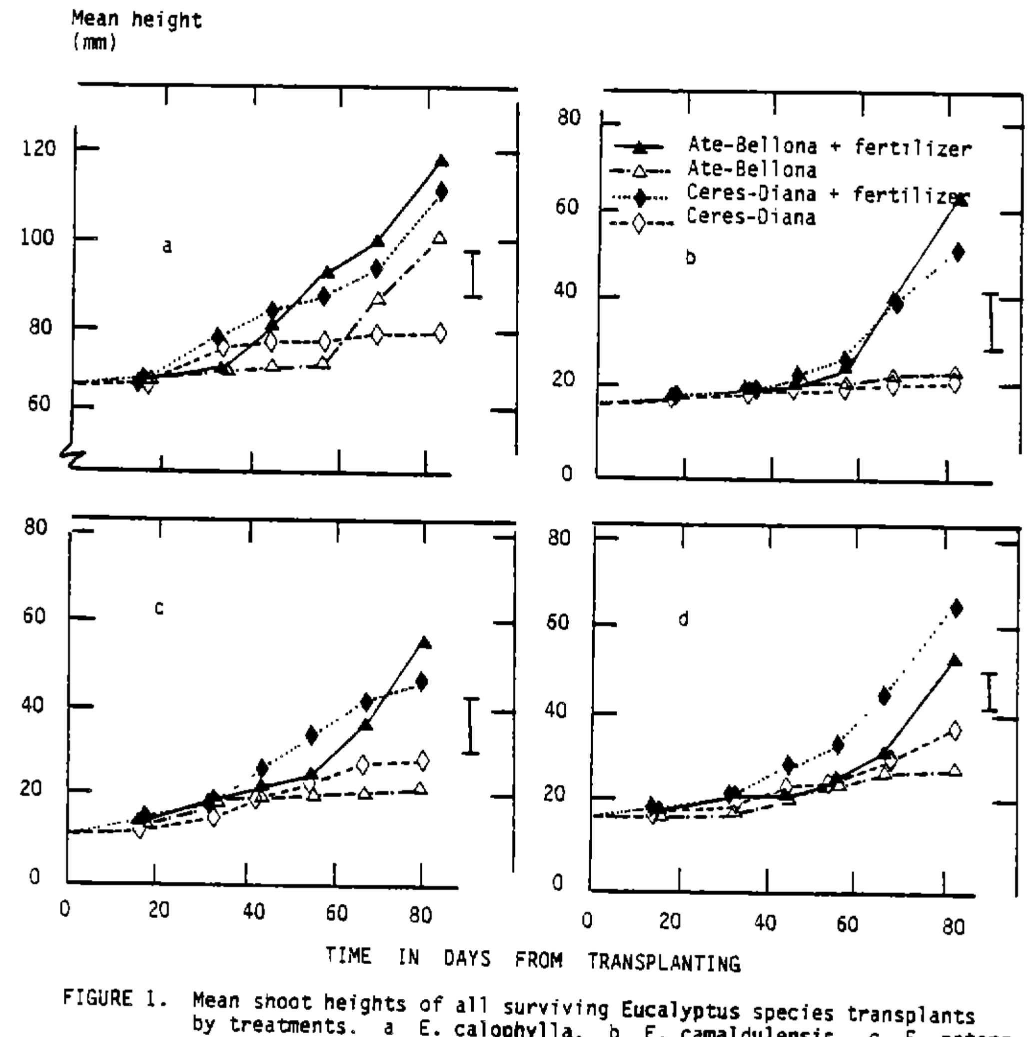

FIGURE 1. Mean shoot heights of all surviving Eucalyptus species transplants by treatments. a E. calophylla, b E. camaldulensis, c E. patens, d E. wandoo. Least significant difference at final measurement between treatments for a species ($p<0.001$) represented by vertical bars.

No lime amendment was given but we note that vermiculite often has a pH of about 8.

During the following growth period, if no rain had fallen for three days, pots were brought to field capacity by handwatering with rain water. Pots were occasionally flooded during heavy winter rain in August. Some aphids were observed on nearby plants in early September, so all experimental plants were sprayed with 'Malathion'.

Plant heights were recorded each fortnight. Three harvests were taken of four, six and five plants respectively at 30, 55 and 82 days from transplanting, from each treatment set of 20 pots. Plants were weighed fresh, then oven dried at 60 C for 24 hrs, to obtain dry weights. The pH was recorded from two pots per treatment set, after plant harvesting.

Results

pH readings confirmed that A-B interburden was consistently more acidic than C-D. Between collection and setting out, the pH of A-B became more acidic by 0.4 units (Table 1). The pH in all A-B treatments drifted higher, to pH 4 4-5.3 during the experiment.

The C-D material, in contrast, became less acidic prior to setting out. The pH also drifted higher during the experiment, to levels of 6-6.8 at final harvest. No apparent interaction between fertilizer and acidity occurred. It is possible that vermiculite lining pots may have contributed partly to lower acidity.

Mean seedling height growth is illustrated in Figure 1. Fertilized plants showed more rapid height increases. These responses to fertilizer began to show by approximately 55 days from initial treatment. **E. wandoo** grew taller in fertilized C-D, while the other three species were tallest in fertilized A-B material. The poorest treatment in respect of plant height was generally unfertilized A-B.

Mean dry weights at transplanting and for harvests are given in Table 2. Plant growth between harvests was positive except for **E. camaldulensis** in unfertilized A-B. Here the 30 day harvest was of equal yield with that at transplanting and the 82 day value less than that for 55 days.

Greatest dry matter was produced by **E. calophylla**. Analysis of variance of mean dry weights at the 82 day harvest showed no significant difference between treatments (Table 2).

E. patens produced the second largest seedlings in both materials and fertilizer addition significantly increased growth. This species was growing equally well in both fertilized materials towards the end of the trial, although best early growth was in C-D (Table 2).

E. camaldulensis seedlings grew significantly better when fertilizer was added, and growth in A-B was significantly better than in C-D (Table 2)

For **E. wandoo**, best growth was recorded from fertilized C-D and both amended materials produced significantly larger plants than the unfertilized materials.

With all except **E. calophylla** in C-D, a response to fertilizer was evident by 30 days. However, it is noted that final rankings at 82 days were not necessarily the same as at intermediate harvests.

Analysis of variance on combined mean dry weights at 82 days showed that the greatest contribution to variation was by species, followed by fertilizer. Significant differences between species, and between combined species data for fertilizer treatment, occurred. The overall mean dry weight of **E. calophylla** was significantly greater than the other species.

The combined mean dry weight of fertilized seedlings (0.369g) was significantly greater than for those not fertilized (0.195). Final weights as a percentage of initial transplant weight (Table 3) and relative growth rate (Figure 2) remove differences in species size from consideration of relative success.

Percentage changes in mean dry weight to 82 days showed **E. calophylla** had the least overall growth in fertilized treatments. Greatest growth in fertilized treatments was made by **E. camaldulensis**. **E. wandoo** responded well on fertilized C-D, and **E. patens** also grew well on both fertilized materials. **E. wandoo** showed the largest increases in both unfertilized materials.

Relative growth rates (RGR) for species (Figure 2) indicate that **E. calophylla** showed a low and decreasing RGR for all treatments except fertilized C-D. Increasing RGR for this treatment from harvest 2 to harvest 3 was correlated with the emergence of the fertilized treatment C-D being the best at the end of the trial.

E. patens exhibited a low and declining RGR for seedlings grown in unfertilized materials. An increasing RGR for fertilized A-B treatment was correlated with production of greatest dry weight by the final harvest.

E. camaldulensis seedlings had high and increasing growth rates for the fertilized materials, particularly for the biggest seedlings (in A-B). Growth rates in unfertilized material were erratic.

E. wandoo seedlings receiving fertilizer had high and generally increasing relative growth rates. Lower rates were produced in unfertilized material.

TABLE 3. Dry weight at 82 days, expressed as a percentage of transplanting weight for four eucalypt species with (+) and without (-) fertilizer, in both spoils

TREATMENTS	SPECIES							
	E. calophylla		E. camaldulensis		E. patens		E. wandoo	
Fertilizer	+	-	-	-	+	-	+	-
Ate-Bellona	556	452	14003	294	3170	485	4717	803
Ceres-Diana	693	494	8527	469	3064	521	13407	1126

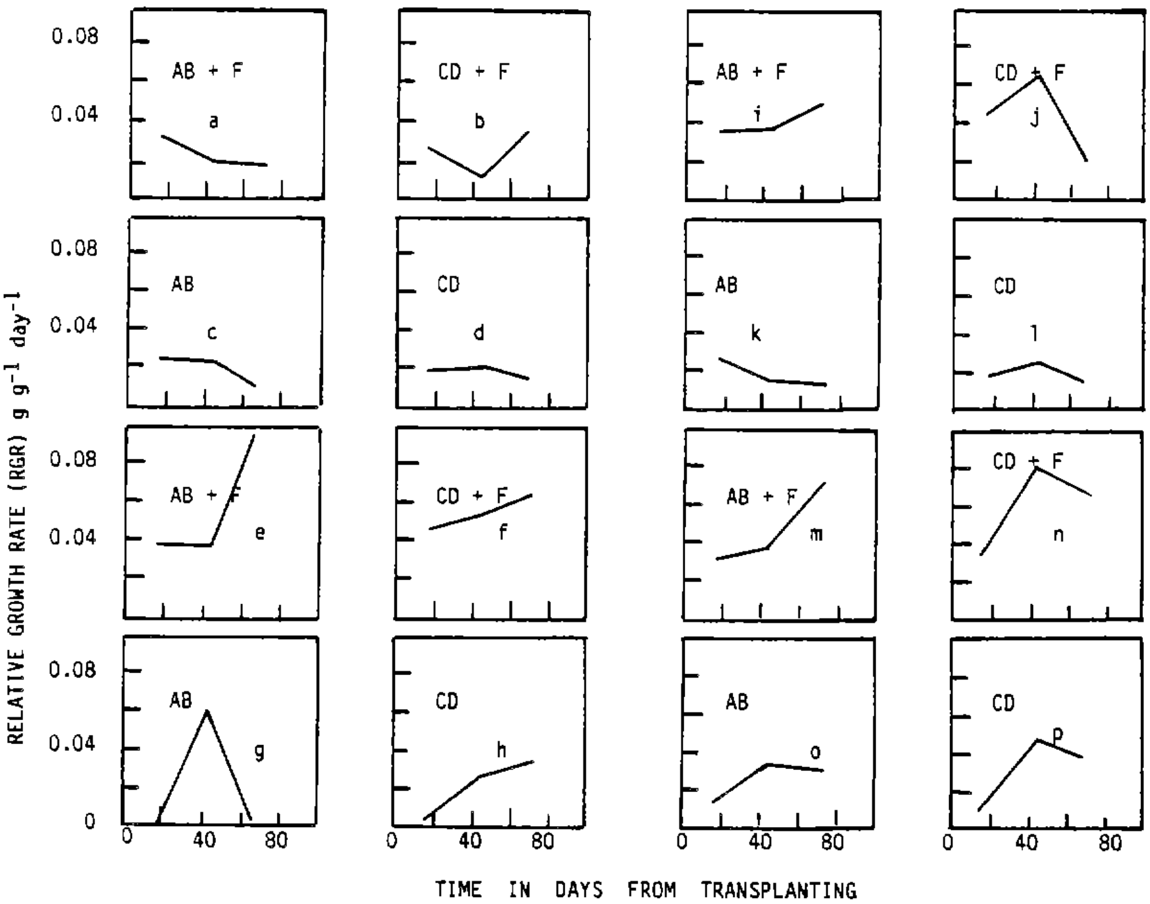

FIGURE 2. Relative growth rates from transplanting for each of four Eucalyptus species: + F refers to treatments with fertilizer; AB, Ate Bellona; CD, Ceres Diana; a, b, c, d, *E.* **calophylla**; e, f, g, h, *E.* **camaldulensis**; i, j, k, l, *E.* **patens**; m, n, o, p, *E.* **wandoo**.

TABLE 4. Mean shoot/root ratio using dry weights at time of transplanting and three harvests for four eucalypt species with (+) and without (-) fertilizer.

TREATMENTS SPECIES	E. calophylla		E. camaldulensis		E. patens		E. wandoo	
Transplanting	4.31		2.19		1.87		4.11	
Fertilizer	+	-	+	-	+	-	+	-
TIME OF HARVEST								
30 days n = 4								
Ate-Bellona	3.94	4.74	1.35	2.83	5.73	1.67	4.71	4.50
Ceres-Diana	3.64	1.73	1.18	1.78	3.06	3.84	4.74	3.13
55 days n = 6								
Ate-Bellona	2.18	1.82	1.36	1.71	3.66	2.27	2.77	2.55
Ceres-Diana	2.60	2.45	3.11	1.89	6.09	1.96	4.53	7.34
82 days n = 5								
Ate-Bellona	2.82	2.29	3.17	5.93	2.68	2.58	6.44	2.41
Ceres-Diana	2.61	2.41	2.13	3.20	1.87	1.89	2.35	2.66

Mean shoot/root ratios at transplanting and harvests are summarised in Table 4. Shoot growth was consistently greater than root growth. **E. calophylla** had the greatest initial ratio reflecting the large seedling size. **E. patens** seedlings had least shoot growth compared to root growth.

In fertilized A-B, **E. wandoo** had the highest ratio at 82 days, but it was lower than **E. patens** at earlier harvests. The latter species showed least difference associated with fertilizer in A-B at final harvest whereas at 30 days the fertilized treatment had given much higher relative shoot growth. In fertilized C-D all species showed lower values than for A-B by 82 days, and with the exception of **E. calophylla**, the fertilized C-D ratios were lower than unfertilized treatments, suggesting that adding fertilizer to C-D generally resulted in a more balanced shoot/root ratio.

Discussion

There are obvious limitations in extrapolating early seedling growth to possible field performance. Equally difficult is the effective comparison of different trials. Small transplants are difficult to establish in coal materials (Fox, O'Dea and Patroni 1985). In the present trial heavy winter rainfall resulted in some waterlogging, particularly in A-B. Waterlogging may affect eucalypt growth by reducing root uptake of nutrients or enhancing toxic ions (Clucas and Ladiges 1979). Slow release fertilizer provides an obvious advantage in conjunction with winter establishment.

Seed weight reflects phosphorus reserves. This has been associated with good root and shoot growth by **E. calophylla** in acidic material (Dell, Loneragan and Plaskett 1983). In the present trial the order of both transplant and harvest weights followed that of seed weight. **E. calophylla** seed are much larger than those of the other species, and over the same time, growth from seed produces much larger plants. This size difference was still clearly evident at the end of the trial period. However the low percentage changes in dry weight indicate little fertilizer response by **E. calophylla** under the conditions of the present experiment.

It has been reported that eucalypt seedlings made poor growth, with weak root systems, in the presence of complete fertilizer or fertilizer lacking lime and phosphorus, whereas calcium phosphate promoted root and shoot growth (Dell, Loneragan and Plaskett 1983). However, advanced transplants produced greater dry weight in the absence of phosphorus in a subtractive trial (Fox and Rhodes 1981). The results presented here for relative growth rates and percentage changes in dry weight indicate greatest responses to fertilizer were with **E. camaldulensis** in A-B and **E. wandoo** in C-D. If fertilized both species also grew well in the alternate interburden material. The lowest response to fertilizer was from **E. patens**. However this species grew equally well in both materials and the growth response was still highly significant.

In its natural environment **E. patens** is found on soils of about pH 6 (Havel 1975). On waste dumps at abandoned mines in the Collie coalfield it appears to show most impressive acid tolerance. Bartle and Riches (1978) record it as occurring on areas with surface pH as low as 4.5, whereas Bell (1984) reports pH values for the rooting zone soil to be as low as pH 2.7. Our results suggest that apparent field tolerance can be confirmed for pot culture. Of particular note is the low shoot/root ratio (Table 4) and similar growth response on both interburdens (Table 3).

For **E. wandoo** an earlier experiment indicated higher shoot/root ratios for unfertilized jarrah topsoil, enhanced growth with nitrogen and reduced growth with phosphorus (Fox and Rhodes 1981). In the present trial this species grew relatively well in the absence of fertilizer (Table 3), but this early trend may not persist, witness the declining relative growth rate (Figure 2).

E. camaldulensis has been reported as showing a significant response to liming of acidic material (Fox, O'Dea and Patroni 1985). The interaction of acidity on growth remains to be elucidated. The interburden pH changes, drifting towards neutral over the course of the experiment, would have altered the availability of nutrients, either added to or already in the material. For example, nitrogen, phosphorus and potassium all become more readily available as soil becomes less acid, whilst iron becomes less available when pH reaches approximately 6 (Bidwell 1979). C-D being the least acidic would therefore be potentially the better material with respect to nutrient availability. When comparing overall plant growth on amended and unamended materials, we note that plants generally grew slightly better on C-D material, supporting the idea of pH influence, possibly through increased nutrient availability.

The importance of early application of fertilizer for maximum benefit to the young plant is evident from early establishment of trends in response to fertilizer. The growth parameter trends shown by this experiment, particularly decreasing RGR's, suggest that unfertilized seedlings would have little chance for successful establishment in the longer term.

Conclusions

Of four **Eucalyptus** species tested, significant increases in early seedling growth were obtained with slow release NPK fertilizer for each of **E. camaldulensis, E. patens** and **E. wandoo**. Species responses to fertilizer and interburdens varied. We note the following:

E. calophylla: Poor growth was recorded and response to the fertilizer addition was slight. Rapid early growth of this species prior to treatment suggests that fertilizer application may have been more usefully applied later, as initial seedling growth is so much influenced by the large cotyledons that the application of fertilizer makes little difference until cotyledon reserves are exhausted.

E. camaldulensis: Significant responses to fertilizer occurred in both materials with better growth in A-B.

E. patens: Both fertilized materials gave similar results for this species. **E. patens** appears more tolerant of the more acidic material, (A-B) but longer term growth trials are needed for confirmation.

E. wandoo: Best response with this species was fertilized C-D although fertilized A-B also significantly improved growth.

Longer growth periods may have established more definite trends in growth responses as relative growth rates for some fertilized seedlings were decreasing by the end of this trial. **E. wandoo** appears most suited to fertilized Ceres-Diana, while **E. camaldulensis** and **E. patens** may be worth trialling on both interburden materials.

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THE PROPAGATION OF ADENANTHOS CYGNORUM BY CUTTINGS AS AN AID TO HEAVY MINERAL SAND MINING REHABILITATION AT ENEABBA

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Summary

Methods of propagation of **Adenanthos cygnorum** Diels. from tip cuttings were investigated as a means of producing large numbers of plants for mine rehabilitation purposes in the kwongan, or heath, of the northern sandplain.

The benefits of bottom heat and high humidity in mist benches were demonstrated over a winter period of root initiation. A weekly application of 5ppm indole butyric acid (IBA) plus mineral nutrients appeared to produce an auxin benefit to the 12 weeks cuttings and a nutrient benefit to the 27 weeks cuttings. The completion of the plants by shoot production was favoured in the 12 weeks rooted cuttings and in the 27 weeks rooted cuttings where bottom heat and the IBA plus nutrients solution had been used. The remaining 27 weeks extraction of treatments produced many rooted cuttings which failed to shoot and later died.

Possible methods of improving early root initiation and the later phase of shoot development are discussed.

Introduction

Adenanthos cygnorum (Woolly bush) occurs as a dwarf shrub of 0.5 to 1m height in the climax kwongan of the Eneabba district. When free of competition, as along road verges or on cleared land, it is an effective pioneer species and may grow rapidly as a shrub up to 2m high.

This potential to lead vegetation recovery does not show up well in heavy mineral sand mining rehabilitation where topsoil has been layered over mine tailings fill. The species may, however, contribute significantly to cover after about the sixth year from topsoiling.

Current practice to protect the topsoil from wind erosion utilises very light sowing and fertilizing of a grass cover crop, such as cereal rye or Sudax. These are effective for the first two years from topsoiling. This leaves an erosion risk period until suitable soil-binding native species become established. The filling of the erosion risk period with native plants possessing suitable nurse crop characteristics has always posed a difficult problem at Eneabba. Here strong easterly winds may severely erode topsoil containing young slow-growing native seedlings, or bury them with sand accretions.

Direct seeding of fast-growing native species with the grass cover crop and the planting of nursery-raised transplants have both been used to fill this erosion risk period. Successful species used so far have been **Acacia blakelyi** Maiden and **A. pulchella** R.Br. as shrubs, and **Tersonia cyathiflora** (Fenzl) A.S. George as a ground cover. Although these species occur in the Eneabba district on disturbed soil, they do not contribute as members of the climax kwongan; their use may thus pose later problems. Another system used is the surface application of a chopped mulch from native kwongan after the second year when the soil has firmed. This treatment by itself helps to control erosion (Allied Eneabba Interim Report 1981, Section 5.2) and also aids the establishment of some **Adenanthos cygnorum** plants (Allied Eneabba Triennial Report 1979, Table 8).

A study reported by Lamont and Grey (1984) helps to explain the success of **A. cygnorum** as a pioneer species in terms of the dispersal of its seeds by ants to their nests at soil depths probably often below the depth to which topsoil is collected. This feature, to which is attributed the "mass regeneration of **A. cygnorum** after disturbance", is apparently not effective in topsoil-treated tailings. Although plants of **A. cygnorum** can be readily raised in a nursery from collected seed, a corollary of the Lamont and Grey (1984) study is that seed supplies are difficult and uneconomic to collect. This limitation is accentuated by the inconspicuous appearance of the flowers and fruit of this species.

The objective of the present project was to utilise the pioneer potential of **A. cygnorum** more fully in the Eneabba minesite rehabilitation programme by propagating from cuttings. A number of earlier attempts to strike cuttings at a site nursery failed, probably mainly because of the difficulties in maintaining water pressure for misting combined with the severe dehydrating climate.

Materials and Methods

Shoots of **A. cygnorum** were cut from the Allied Eneabba rehabilitation block 79B on 29th March 1985. These were wrapped in moist paper and stored over ice in an insulated container. Six days later shoots were divided into 240 tip cuttings. These were sterilised in 0.5 percent chlorine (a 1 to 25 dilution of commercial sodium hypochlorite solution) for 10 to 20 minutes. After a triple washing in tap water, the cuttings were divided evenly according to size into four trays containing 60 cuttings each. Two sets of 60 received auxin treatment (see below), two did not (control). The medium in the trays consisted of a 1:1 volume mix of polystyrene grit and **Sphagnum** peat. No sand was used in the mix to avoid having to sterilise the medium or use fungicides (Aitken 1983). The experiment was conducted in a glasshouse at Curtin University.

One tray each of treated and control cuttings was randomly assigned to one of two mist benches. One bench had a clear plastic cover and effective bottom heat. The other was an open bench with no cover or bottom heat.

An indication of the temperature and relative humidity regimes of the two benches is presented in Table 1. These data do not show full diurnal trends and the bed heater of the covered bench was set higher on 3rd June. The removal of the first rooted cuttings (Table 2) occurred on 25th June.

The temperature data indicate that radiation and air heating of the tray media could occasionally produce a higher temperature on the open bench, particularly in the afternoon. An important aim was to produce a higher rooting medium temperature on the covered bench. The mean data temperature difference of 4.7°C was probably a conservative estimate of this difference.

The misting frequency under the clear plastic cover was controlled by a Thermomister unit operating on relative humidity. A timer unit, set to the average diurnal relative humidity changes as shown by the glasshouse screen mounted chart recorder, controlled the mister frequency of the open bench. The relative humidity on the benches was measured between mists by a Lambrecht hygrometer (Table 1).

Auxin treatments of native cuttings carried out previously using indole butyric acid (IBA) in commercial talc mixtures showed burning at the base of many cuttings. It was decided in this experiment to try the concentrations of IBA mineral nutrients used in the standard culture rooting medium of Murashige and Skoog (1962). The IBA concentration was 5ppm and the organics, sucrose and agar were omitted. The auxin and minerals were applied weekly with watering.

Successful cuttings were potted on and grown in a shadehouse at Curtin University.

TABLE 1. Some winter temperatures and relative humidities associated with the mister beds used for **Adenanthos cygnorum** cuttings.

		COVERED BENCH				OPEN BENCH			
		Temperature °C			RH%	Temperature °C			RH%
Date	Time	2.5cm below medium surface	Tray medium	Air at cutting height	Cutting height	2.5cm below medium surface	Tray medium	Air at cutting height	Cutting height
23.5.85	0830	17.0	-	16.4	100	13.3	-	15.2	-
23.5.85	1420	20.2	24.0	20.2	62	18.6	21.0	24.6	-
24.5.85	0825	16.9	15.4	14.2	100	10.9	10.1	10.0	-
24.5.85	0930	17.0	17.8	18.0	63	11.5	12.8	14.0	-
24.5.85	1030	17.0	18.8	18.0	66	13.7	18.0	19.3	-
24.5.85	1525	22.7	21.2	23.5	76	21.1	23.4	26.2	25
25.5.85	0900	17.1	11.5	15.9	80	11.5	11.9	15.1	-
26.5.85	0845	18.3	15.9	18.2	100	16.5	16.2	17.0	-
27.5.85	0930	16.8	13.0	14.6	100	12.0	12.2	12.3	-
31.5.85	0910	16.6	14.8	13.2	100	8.8	9.2	9.0	70
03.6.85	1000	17.0	18.0	16.5	96	8.8	11.5	14.8	-
03.6.85	1200	18.1	21.6	21.0	85	12.5	17.8	18.2	36
03.6.85	1420	20.3	22.7	22.5	-	15.3	19.0	19.7	-
05.6.85	1000	32.6	29.9	24.8	100	14.1	17.0	17.2	-
05.6.85	1200	33.0	32.1	28.7	100	16.2	21.1	21.0	58
10.6.85	1200	27.7	28.6	26.7	86	16.0	19.8	21.0	-
20.6.85	1415	27.0	27.6	29.8	88	15.8	-	24.2	-
	MEAN	20.9	20.8	20.1	88	13.9	16.1	17.6	47

Results

At 12 weeks from setting out, the cuttings in the warmer covered bench showed dark, heavy callusing. Those from the open bench possessed calluses lighter in both weight and colour. In both benches the callusing was slightly more advanced in the weekly auxin plus nutrient treatment. No shoot growth was evident in any treatment.

All rooted cuttings (Table 2) were removed and potted on in the same medium as for the trays. These were placed on a third bench with light automatic misting for two weeks. They were then removed to a standard glasshouse bench and hand watered. About every three weeks, a one tenth strength full nutrient solution was used.

The remaining unrooted cuttings were returned to the original treatments. At 27 weeks from setting out, the residual cuttings under treatment were finally assessed (Table 3). Again, the surviving unrooted cuttings showed much heavier callusing in the covered bench and this development was favoured in the auxin plus nutrient treatment of both benches. However, the auxin benefit to rooting shown at 12 weeks (Table 2) was lost over the additional 15 weeks period (Table 3). The second selection rooted cuttings did show apparent benefits from the mineral nutrients in shoot growth and general greenness of foliage.

TABLE 2. Response of **Adenanthos cygnorum** cuttings at 12 weeks. Each treatment contained 60 cuttings.

	Covered Bench Bottom Heat		Open Bench	
Percent	Survival	Rooted	Survival	Rooted
5 ppm IBA plus nutrients	98.3	46.7	100	5.0
Control	98.3	33.3	98.3	3.3

TABLE 3. Response of residual **Adenanthos cygnorum** cuttings at 27 weeks. Numbers of cuttings involved indicated.

Percent	Covered Bench Bottom Heat (No.)	Survival	Rooted	Open Bench (No.)	Survival	Rooted*
5 ppm IBA plus nutrients	(31)	87.1	38.7 (half with shoot growth)	(57)	84.2	47.4 (green +)
Control	(39)	89.7	43.6 (no shoot growth)	(57)	94.7	54.4 (green -)

* Only one cutting of each of IBA and control treatments showed new shoot growth.

After this second assessment, all rooted cuttings (including those collected at 12 weeks) were potted or repotted to a 1:1:1 volume mix of **Sphagnum** peat, fine mortar sand and washed coarse river sand. All these cuttings in labelled batches were then placed in a shadehouse provided with automatic spray irrigation. They were also watered with one tenth strength full nutrient solution at approximately monthly intervals.

It became apparent that many of the rooted cuttings from the open bench were not shooting, in spite of warm summer conditions and vigorous shoot growth in the successful plants. Also, approximately one half of these non-shooting cuttings from the open bench were dying, although in possession of a root system. After 19 weeks in the shadehouse, it was decided to assess the ability of these rooted cuttings to produce a new shoot system. This was carried out on 20th February 1986 (Table 4).

Of the 12 weeks rooted cuttings from the open bench, there were only three from the IBA + nutrients treatment and two from the control treatment. The percentages of 0 and 50 (Table 4) are considered to be insignificant. The remaining six sets can be divided into a group of three successful outcomes:

a) 12 weeks, covered bench, IBA + nutrients
b) 12 weeks, covered bench, control, and
c) 27 weeks, covered bench, IBA + nutrients,

where the production of vigorously shooting plants from rooted cuttings was 60 percent or more, and the remaining three sets:

d) 27 weeks, covered bench, control
e) 27 weeks, open bench, IBA + nutrients, and
f) 27 weeks, open bench, control,

where the production of less vigorously shooting plants from rooted cuttings was 22 percent or less.

Plant deaths of rooted cuttings were common to all treatments and at the final assessment stage (Table 4) for the first group of successful outcomes, were 39, 30 and 17 percent respectively. For the second group, plant deaths were 53, 52 and 48 percent respectively. However, the syndromes for the two groups were different. For the first group, many of the plants collapsed suddenly after having earlier produced new shoot growth. In contrast, almost all the dead rooted cuttings of the second group had very slowly dried out, leaf by leaf, and without any sign of shoot-bud development.

TABLE 4. Performance of rooted **Adenanthos cygnorum** cuttings at 46 weeks as percent shooted and number of final plants.

		Rooted at 12 weeks		Residuals rooted at 27 weeks		Total Plants
		Covered Bench Bottom Heat	Open Bench	Covered Bench Bottom Heat	Open Bench	
5 ppm IBA plus nutrients	%	61	0	67	22	
	No	17	0	8	6	31
Control	%	60	50	18	16	
	No	12	1	3	5	21
Total plants		29	1	11	11	52

Discussion and Conclusions

The methods used point the way to the large scale production of **Adenanthos cygnorum** plants for rehabilitation purposes, thus avoiding the difficulties of seed collection for a kwongan species with undoubted pioneer characteristics. Callus production over winter in a covered bench with bottom heat was very vigorous and in the order of 90 percent of cuttings. The first phase limitation was the initiation of roots and this appeared to be partly overcome by weekly watering with a dilute solution of 5ppm IBA during at least the first three months.

Rooting auxins, such as IBA, can be important in initiating roots, but may inhibit subsequent root elongation in some plants (White 1986). A higher concentration of IBA applied for a shorter period may have induced a higher percentage of rooting than that shown in Table 2. The question remains on how soon such applications should be made. With slow developing native cuttings such as **A. cygnorum** it might be an advantage to wait until callusing has commenced.

The supply of mineral nutrients in solution is common in tissue culture work on natives (McComb 1983), but tends not to be recommended for cuttings (Aitken 1983). Much depends on the rate of leaching of nutrients from the cuttings and, especially in slow developing cuttings, there should be less leaching if a high pressure fog system were used rather than a mist system (White 1986). In this work, the second stage of rooting from 12 to 27 weeks (Table 3) showed an apparent benefit from the applied nutrients in shoot growth and general greenness of the cuttings. There was a little trouble from algal development on the trays; thus in future work it is recommended that the nutrient concentrations be reduced to half strength or less (McComb 1983).

With adjustments of the bottom heat of the covered bench, favourable tray medium temperatures were eventually obtained (Table 1). However, care had to be taken that radiation and air heating of the tray medium during the day did not raise this temperature too high. Aitken (1983) states that the desirable temperature should lie between 25 and 27°C, but should never exceed 28°C. Wrigley (1979) considers the root zone temperature should be held at approximately 27°C but for this to be effective, the leaf temperature must be maintained at at least 4 to 5°C below the root zone temperature. Air temperature at cutting height (Table 1) fluctuates widely diurnally and between mists, but does not reflect such a drop in temperature. However, as the leaf surfaces are continually moistened, the actual leaf temperature should remain below the air temperature.

The second phase limitation on the production of viable plants was the very limited shoot production in the second group of treatments involving rooted cuttings collected at twenty seven weeks (Table 4). The most obvious method of reducing this loss would be the acceleration of root initiation along the lines already discussed, thus reducing the average age of the cuttings when potted out.

The conditions in the shadehouse used for plant establishment were clearly not ideal for the purpose. Although probably warm enough, light intensity was low and there was overwatering. This probably accounted for the sudden collapse of many plants that had shooted; this was the most common form of death among the plants of the most successful first group of treatments (Table 4). The unhealthy root environment for **A. cygnorum** in the overwatered pots may have also partly accounted for the common absence of shoot initiation in the rooted cuttings of the second group of treatments.

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GROWTH OF ACACIA SPECIES IN COAL MINE INTERBURDEN MATERIALS

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Summary

Growth and survival of **Acacia** species in fertilized and unfertilized coal mine interburden materials were compared. The species used were: **Acacia saligna, A. extensa** and **A. pulchella**. For the latter species two ecotypes were used. Plants were from two seed sources: a) ex Yalgorup (coastal sand), and b) ex Harvey (lateritic gravel).

Soil materials from the Ate-Bellona (pH 4.6) and Ceres-Diana (pH 6.1) interburden layers were used in controlled pot trials. 'Osmocote' fertilizer was added as a nutrient source to half the pots for each set.

After 78 days plants had grown best in Ceres-Diana with fertilizer. Superior growth in this medium was shown in significantly greater height and dry matter production. Plants in Ate-Bellona with fertilizer showed better growth than plants in both unfertilized interburdens, for which responses were generally equally poor. On the basis of dry weight (total and root) production in fertilized Ceres-Diana, **Acacia extensa** and **Acacia pulchella** (ex Harvey) would appear to be the most suitable for use in field trials.

Introduction

Previous studies on the revegetation of dump material from Collie, W.A. coal mine operations, indicate that regrowth is sparse on soils of low pH values (less than about 5), probably due to either unavailability of nutrients or metal toxicity (Bartle and Riches 1978). In addition, nitrogen fixing rhizobia are generally less active in soils with low pH. Liming of spoils to increase the pH coupled with studies to contrast the performance of different plant species have been reported by Fox and Mathie (1982), and for **Acacia pulchella** by Koch and Bell (1985).

Species able to tolerate low acidity are clearly of interest. Their persistence may lead to amelioration of conditions such that other species may follow them. Species which can fix some nitrogen are desirable. In a previous study (Fox, O'Dea and Patroni 1985), **Acacia extensa** showed early promise for revegetation in unimproved mixed interburden materials. It was the only one of 5 **Acacia** species which showed better growth in height as a seedling on material of low pH and deficient nutrient status compared with amended materials.

This earlier study suggested that both **A. extensa** and **A. pulchella** merited further testing in relation to enhanced nutrient availability. These two (with two sources of seed for **A. pulchella**) and **A. saligna** were selected for testing in pot trials with contrasting interburden materials. **A. saligna** was included as this species shows some characteristics of a pioneer species and will grow rapidly on open, wasteland sites. A slow release NPK fertilizer was used as a nutrient source.

These three **Acacia** species all occur naturally in the Collie area. It was anticipated that the most successful species would not only germinate and survive, but also bind the soil with an extensive root system, fix adequate atmospheric nitrogen and tolerate acidic conditions.

The performance of each type of **Acacia** in the different materials was assessed in terms of height, growth rate, dry matter production and root nodulation.

Materials and Methods

Two types of interburden materials were used. Black interburden material from between the Ate and Bellona coal seams had an average pH of 4.6. It tended to be clay-like with a mean nitrogen concentration of 0.03 percent. The whiter material from between the Ceres and Diana coal seams was less acidic (average pH of 6.1) with no available nitrogen. This was a sandy soil with larger pore size and lower field capacity than the Ate-Bellona material. Consequently it had better drainage characteristics with less surface runoff, but poorer moisture retention. In addition to poor nitrogen status, both materials had very low levels of other essential minerals, with potassium about 5ppm and phosphorus present as a trace only (Dames and Moore 1983).

Both "soils" were tested with and without fertilizer. The fertilizer used was osmocote (90 day release) applied at a rate equivalent to 50kg ha^{-1} of nitrogen. This fertilizer contains 18 percent nitrogen, 10 percent potassium and 2.6 percent phosphorus.

Seedlings of the following species were grown from seed in seed trays: **Acacia saligna, A. extensa,** and **A. pulchella** a) ex Yalgorup, and b) ex Harvey.

Prior to sowing into germination trays, seeds were placed in boiling water for a few minutes. Six weeks later five representative plants of each type were harvested (initial harvest). At that time plants of the same stage of development were transplanted into plastic pots (7 x 7 x 10cm) lined with vermiculite and filled with soil. Fifteen **Acacia** plants of each type were grown in each soil preparation, that is Ceres-Diana with fertilizer, Ceres-Diana without fertilizer, Ate-Bellona with fertilizer and Ate-Bellona without fertilizer. Five plants per treatment were randomly selected for harvest at each of 30, 56 and 78 days from potting.

Measurements of seed weight, plant height and dry weights at harvest were taken. Heights were also measured at 7, 20, 42 and 70 days from potting. Relative growth rates (RGR) were calculated according to the equation

$$RGR = \frac{\log_e W2 - \log_e W1}{t2 - t1} \qquad g\ g^{-1}\ day^{-1}$$

where W1, W2 are plant dry weights at times t1 and t2.

Standard deviations were obtained for each set of measurements and dry weights were subjected to analysis of variance. The presence or absence of nodules on roots was noted and shoot nitrogen content was determined using the Kjeldahl method.

Results

Seed

Mean seed weights and standard deviations are given in Table 1.

TABLE 1. Weight of **Acacia** seed used.

Species	Mean Weight of 10 seeds (g)	Standard Deviation (95% Confidence Level)
Acacia saligna	0.0162	0.0026
A. extensa	0 0095	0.0006
A. pulchella (Yalgorup)	0.0045	0.0004
A. pulchella (Harvey)	0.0083	0.0006

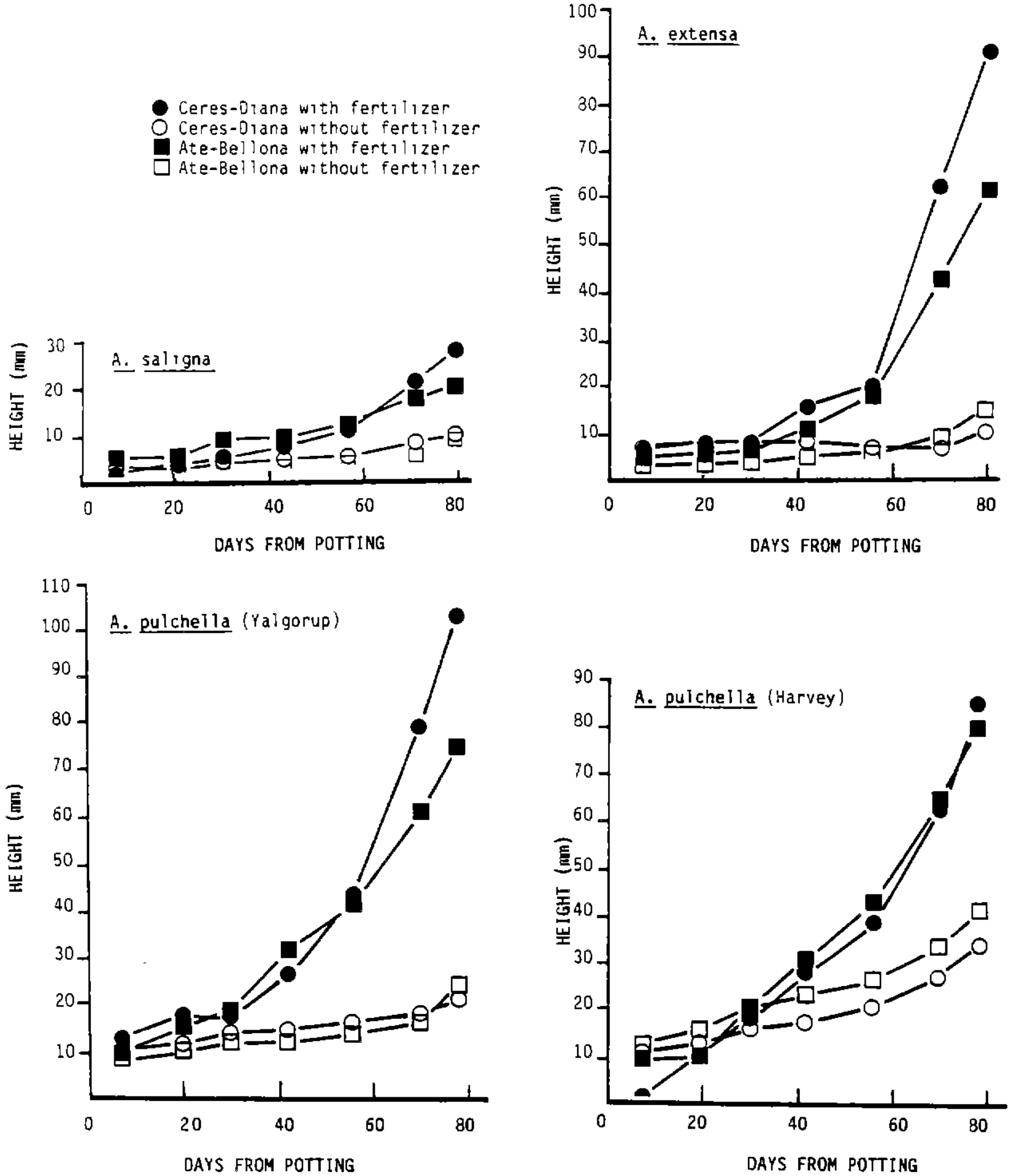

FIGURE 1. Heights (mm) in different interburden materials after potting.

Germination levels were good for all species. Nineteen days after sowing some 80 percent of the seeds of each batch had germinated.

Height Measurements

In all cases plants growing in the fertilized soils grew significantly taller in 78 days than those in the unfertilized soils (Figure 1). Plants in fertilized Ceres-Diana all performed better than those in fertilized Ate-Bellona although the difference was not significant in the case of **Acacia saligna** and **A. pulchella** (Harvey). At the termination of the experiment, best height growth in Ceres-Diana fertilized material was **A. pulchella** (Yalgorup) (104mm). This was followed by **A. extensa** (94mm), **A. pulchella** (Harvey) (86mm) with **A. saligna** (29mm) the poorest.

Relative Growth Rate (RGR)

RGR for each plant species was calculated from four sets of dry weights corresponding to the initial harvest and sequential harvests of potted plants (Table 2). The fertilized plants all showed a higher RGR than the unfertilized plants with those in Ceres-Diana performing better than those in Ate-Bellona (Figure 2). RGR for fertilized **A. saligna** and **A. extensa** plants increased for about 40 days. Thereafter the RGR decreased. This decrease may have been associated with high seed weights and exhaustion of seed food materials. In contrast the RGR's of **A. pulchella** varieties in fertilized soils (except **A. pulchella** (Yalgorup) in Ate-Bellona) were still increasing at the termination of the experiment.

TABLE 2. Mean total dry weights from successive harvests for **Acacia** plants grown in different soil types

Species/Soil Medium	Mean Total Dry Weights (g) & Standard Deviations (in brackets) ($p<0.05$)			
	Initial (n = 5 throughout)	1st Harvest	2nd Harvest	3rd Harvest
Acacia saligna				
C-D + fertilizer	0.017(0.002)	0.061(0.021)a	0.190(0.077)a	0.390(0.080)a
C-D		0.031(0.001)a	0.053(0.008)b	0.047(0.008)b
A-B + fertilizer		0.051(0.020)a	0.105(0.053)a,b	0.149(0.072)b
A-B		0.028(0.016)a	0.036(0.010)b	0.047(0.014)b
Acacia extensa				
C-D + fertilizer	0.013(0.002)	0.043(0.007)a	0.228(0.060)a	0.552(0.088)a
C-D		0.030(0.004)b	0.051(0.010)c	0.114(0.083)b
A-B + fertilizer		0.034(0.003)b	0.149(0.028)b	0.391(0.142)a
A-B		0.029(0.004)b	0.041(0.006)c	0.049(0.017)b
Acacia pulchella (Yalgorup)				
C-D + fertilizer	0.004(0.002)	0.020(0.004)a	0.067(0.004)a	0.284(0.074)a
C-D		0.009(0.003)a	0.027(0.026)a	0.024(0.004)b
A-B + fertilizer		0.013(0.010)a	0.058(0.025)a	0.099(0.039)b
A-B		0.012(0.003)a	0.012(0.006)a	0.012(0.007)b
Acacia pulchella (Harvey)				
C-D + fertilizer	0.011(0.004)	0.046(0.018)a	0.122(0.064)a	0.645(0.241)a
C-D		0.021(0.008)b	0.028(0.021)b	0.034(0.012)b
A-B + fertilizer		0.030(0.007)a,b	0.065(0.053)a,b	0.229(0.062)b
A-B		0.029(0.009)a,b	0.025(0.004)b	0.037(0.025)b

C-D = Ceres-Diana and A-B = Ate-Bellona interburdens, harvest weights do not differ significantly where superscripts are the same

Dry Matter Production

Dry weights of plants were recorded at the commencement of the trial (seedlings six weeks old) and at three subsequent harvests. Detailed analytical results are summarised in Table 2.

Harvest 1 (30 days)

Acacia saligna and **A. pulchella** (Yalgorup) showed no significant difference in dry matter production between the treatments. **A. extensa** and **A. pulchella** (Harvey) showed significantly greater dry matter production in Ceres-Diana with fertilizer. There were no significant differences between the other three treatments.

Harvest 2 (56 days)

Fertilized **A. saligna** and **A. extensa** treatments produced plants with greater dry weight than the unfertilized treatments. Fertilized Ceres-Diana gave better growth than fertilized Ate-Bellona for both species. **A. pulchella** (Yalgorup) and **A. pulchella** (Harvey) showed greater mean dry matter production with fertilized soils compared with unfertilized soils although the differences were not all significant ($p < 0.05$).

Harvest 3 (78 days)

A. saligna showed significantly better growth in Ceres-Diana with fertilizer compared to the other three treatments which were not significantly different. **A. extensa** showed significantly better growth in the fertilized soils compared to the unfertilized soils which gave similar results. Both varieties of **A. pulchella** gave similar results with best growth (dry weight production) being achieved in Ceres-Diana with fertilizer treatment.

In all cases plants growing in Ceres-Diana with fertilizer showed the greatest dry matter production after 78 days growth. The type of soil did not appear to affect growth in unfertilized treatments: growth was poor in all cases.

Comparisons of total dry weights for each **Acacia** grown in Ceres-Diana with fertilizer (Table 3) show that after 78 days (harvest 3), **A. pulchella** (Yalgorup) gave the least total dry matter production followed by **A. saligna, A. extensa** and **A. pulchella** (Harvey). Root dry weight ratios followed the same order. **A. pulchella** (Harvey) showed the lowest top/root ratio.

Root Nodulation

No attempt at rhizobium inoculation was made and at the initial harvest none of the seedlings planted had nitrogen fixing nodules on their roots. After 30 days (Harvest 1) all plant types except **A. pulchella** (Harvey) showed signs of nodulation. At the second (56 days) and third (78 days) harvests all species possessed nodules.

Nitrogen

Results of nitrogen analyses on dried combined stem and foliage of plants grown in Ceres-Diana with fertilizer from the third harvest (78 days) are presented in Table 4. Insufficient dry matter was available from plants grown on Ate-Bellona.

Discussion

In a previous experiment (Fox, O'Dea and Patroni 1985) early height growth of **A. pulchella** was generally greater

TABLE 3. Mean dry weights of plants harvested after 78 days (harvest 3) growth on Ceres-Diana with fertilizer (g).

Species	Total	Dry Weights Tops	Roots	Top/Root Ratio
Acacia saligna	0.390	0.223	0.168	1.452
Acacia extensa	0.552	0.360	0.192	2.060
Acacia pulchella (Yalgorup)	0.284	0.132	0.152	0.952
Acacia pulchella (Harvey)	0.645	0.216	0.430	0.672

than **A. extensa**. Height growth in this experiment was greatest in the Yalgorup source grown in Ceres-Diana with fertilizer whereas the Harvey **A. pulchella** had shorter plants than **A. extensa**. The Harvey **A. pulchella** attained greatest heights in unfertilized Ceres-Diana. This pattern may be related to the source environments of sand for the Yalgorup population and lateritic gravel for the Harvey set. At the final measurement (78 days) differences in height due to fertilizer were less with the Harvey plants and these produced the tallest plants in Ate-Bellona.

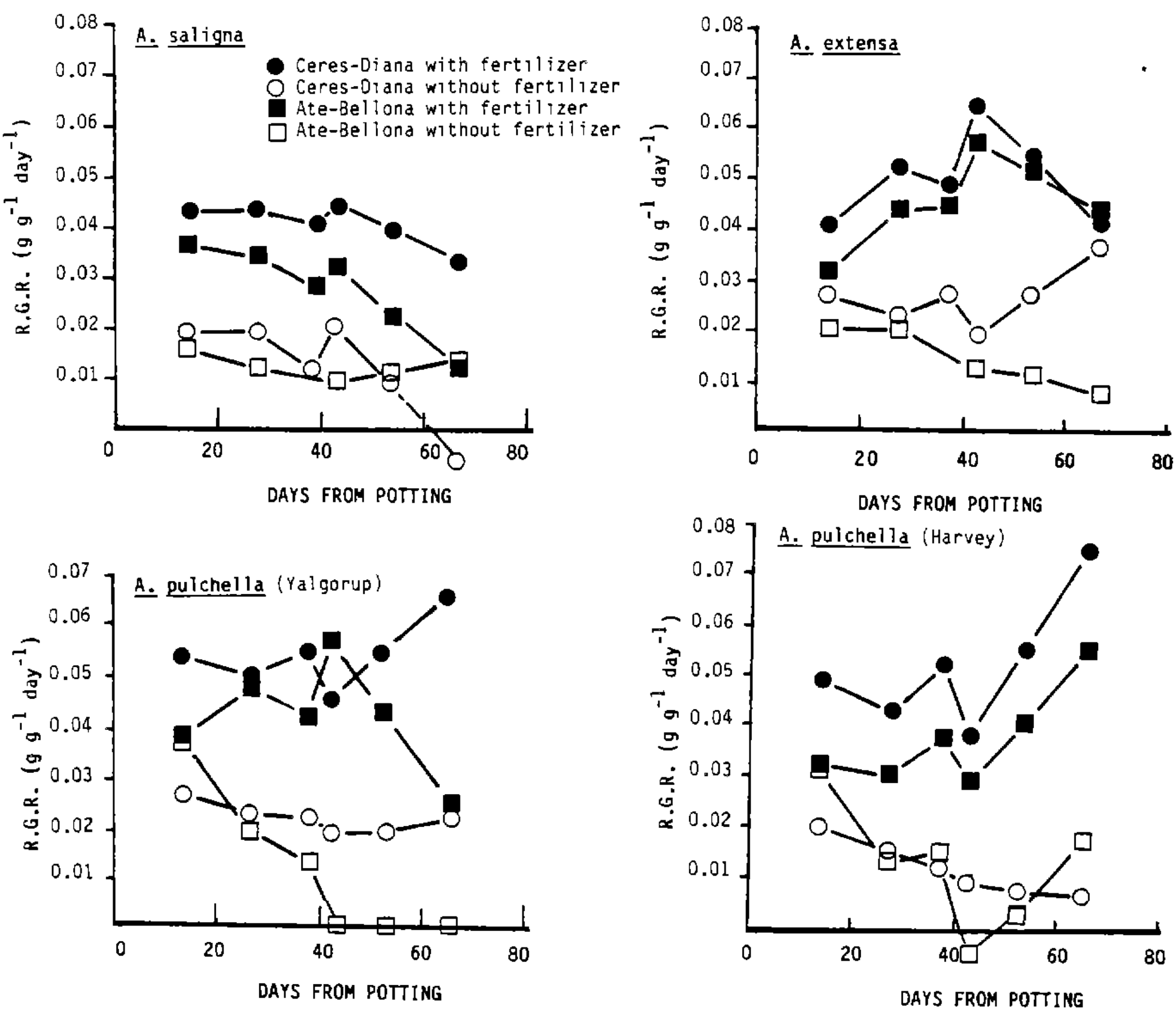

FIGURE 2. Relative growth rates (g g^{-1} day^{-1}) over the trial period.

Differences between the three species were more pronounced in final dry weights with Yalgorup **A. pulchella** producing least dry weight in all four treatments, and also lower yield than **Acacia saligna**. In the earlier experiment there was little difference between **A. extensa** and **A. pulchella** in dry matter production, although **A. extensa** showed both a lower response to liming and higher mean dry weights at 62 days on unamended material than **A. pulchella** (Fox, O'Dea and Patroni 1985). In the present case **A. extensa** showed the lowest response to fertilizer with Ceres-Diana (< 5 x increase in yield at 78 days) coincident with highest yields on both unfertilized materials. It outperformed all others in fertilized Ate-Bellona and was only outyielded by Harvey **A. pulchella** in fertilized Ceres-Diana. However, final yield for this ecotype of **A. pulchella** was extremely variable with a high standard deviation (Table 2).

A. extensa relative growth rate in unfertilized Ceres-Diana was still increasing at the end of the experiment. This species appears to carry higher moisture contents than **A. pulchella** and to have a higher top:root ratio than **A. pulchella** (Fox, O'Dea and Patroni 1985). On fertilized Ceres-Diana both **A. pulchella** types maintained an increasing relative growth rate to the 78 day harvest (Figure 2) and the Harvey set also did well, using this measure, on fertilized Ate-Bellona. In the longer run a greater allocation of production to roots by **A. pulchella** suggests this species should survive longer than **A. extensa**. It must be noted that liming (with no added nitrogen) and fertilizing, of very acidic material produced **A. pulchella** plants with comparatively high top:root ratios over a 9 month pot trial (Koch and Bell 1985). Preliminary field observations indicate that **A. extensa** has a very leggy appearance on dump material and may have a shorter life span. Top:root ratios taken in the field should assist in confirming the relative strategies open to the two species.

Despite the seed weight advantage for **A. saligna** this species performed poorly. It took longer to put on height growth than the other species tested but this was not compensated for by greater root growth. The patterns of relative growth rate for **A. saligna** suggest that this species is unlikely to persist well. In the presence of fertilizer tissue nitrogen accumulation was good (Table 4) but this feature may not be sufficient to allow better growth in the longer run. Total weight of contained nitrogen in tops was highest

TABLE 4. Nitrogen content of **Acacia** stems and leaves growing on Ceres-Diana with fertilizer at harvest 3.

Species	N (%)
Acacia saligna	2.81
Acacia extensa	2.24
Acacia pulchella (Yalgorup)	2.19
Acacia pulchella (Harvey)	2.04

in **A. extensa** (8.06mg) suggesting either more efficient nodulation activity or ability to take up nitrogen from the fertilizer source.

The next stage should be to examine comparative growth over a longer period, under field conditions. It is clear that there is little to be gained from using extremely acidic overburden materials as dressings when materials of higher pH are available.

Conclusions

This study suggests that unfertilized Ceres-Diana and Ate-Bellona interburden materials from the Collie district are not conducive to sustainable growth of **Acacia saligna, Acacia extensa, Acacia pulchella** (Yalgorup) and **Acacia pulchella** (Harvey). When amended with osmocote slow release fertilizer at a rate corresponding to 50kg ha^{-1} of nitrogen however, the Ceres-Diana material supports good growth of all species tested. Fertilized Ate-Bellona failed to give consistent responses. The superior growth in fertilized Ceres-Diana was shown in significantly increased dry weight production and in significantly greater plant height. The relative growth rates did not provide conclusive information possibly due to initial differences arising from differing seed weights. However, plants growing in fertilized soils tended to show better relative growth rates.

At the termination of the most successful treatment (Ceres-Diana with fertilizer), trends of increasing total dry weight and root dry weight were:

A. pulchella (Yalgorup) < **A. saligna** < **A. extensa** < **A. pulchella** (Harvey)

and of increasing plant height:

A. saligna < **A. pulchella** (Harvey) < **A. extensa** < **A. pulchella** (Yalgorup).

Nodulation had occurred on roots of all species by the end of the experiment. Nitrogen levels in all shoots grown in Ceres-Diana with fertilizer were good (between 2 and 3 percent).

It is not possible to determine from the results presented which species would be the most successful coloniser on Ceres-Diana material with fertilizer. All species survived well over the duration of the experiment. They all showed some tolerance of acidic conditions and were able to fix nitrogen. **A. extensa** and **A. pulchella** (Harvey) which produced highest dry matter (total and root) may be the most suitable for field use. It is possible that **A. extensa** would persist less well than the **A. pulchella** over the longer term.

Acknowledgements

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GROWTH OF ACACIA AND EUCALYPTUS SEEDLINGS IN POTENTIAL OVERBURDEN MATERIALS FROM THE WEST ANGELAS IRON ORE PROSPECT

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Summary

Should an iron ore mine be developed at West Angelas, Pilbara, eventual rehabilitation of the site will be necessary. Overburden material from depth will be brought up and dumped. Particular strata may be used as the main superficial dressing or alternatively, top soil could be placed over the depth materials as the primary growth stratum. Growth of a range of locally occurring **Acacia** and **Eucalyptus** species in fertilized and unfertilized materials from different depths was assessed. Records were obtained for seedling plant height, leaf numbers, plant dry weight and relative growth rate over a 75 day growing period.

Each material was ranked according to growth promoted in each species. The performance of the **Acacia** and **Eucalyptus** species was ranked for each material in which the species was tested. Unfertilized plants, except for **Acacia citrinoviridis** and **A. victoriae** in material 2 (shale, row 5, no. 4), did not produce as much dry matter as plants in fertilized soil materials.

Fertilized materials 3 (shale, row 5, no. 15) and 5 (clay, row 10, no. 4) promoted best growth overall in the pot trials. Of the species tested in any particular soil **Acacia ancistrocarpa, Eucalyptus leucophloia, E. patellaris, A. hamersleyensis** and **A. tetragonophylla** grew particularly well in fertilized shale; **A. hamersleyensis, A. tetragonophylla** and **E. patellaris** grew best in fertilized clay. If unamended overburden material were to be used as a rehabilitation surface then of those strata examined the shale material no. 2 would be most suitable.

Introduction

Subsequent to mining ecosystem restoration is obligatory under the Mining Act. More recently the Environmental Protection Authority Act has also laid down requirements for rehabilitation. To achieve revegetation of disturbed areas and unfavourable dumped overburden the surface material conditions can be altered in various ways and use can be made of plant species tolerant of the imposed conditions.

At the West Angelas iron ore prospect one or more of the waste materials may eventually be used to provide the basis for the main superficial soil dressing for rehabilitation. Alternatively, topsoil may be placed over the depth materials to serve as a primary growth medium. Natural restoration of soil fertility can be a very lengthy process without intervention. Fertilizer treatments often restore fertility and initiate a return to natural cycles broken by mining. Whatever the long term outcome desired, pioneer species able to withstand harsh post-mining conditions, may be used as initial colonisers.

The investigation reported here was undertaken to compare which of four depth materials would provide suitable media for plant growth. The four different iron ore overburden materials, from varying depths within the prospect, were compared with an artificial potting mix, in which the species under consideration would be assumed able to grow, with no major physical or chemical limitations to growth. These 5 media were used to contrast growth from among nine **Acacia** and three **Eucalyptus** species. Each material was used unamended and amended with a slow release fertilizer.

Methods

Four different materials from the trial shaft at West Angelas were available for testing. It had been planned to use local top soil (desert red earth-sandy loam) in the experiment as a control medium. Unfortunately this could not be supplied. For comparison with the depth materials, an artificial sandy loam potting mix (material 1) was made up from one part desert red earth and two parts by volume of fine washed white sand. This dilution with fine sand was necessary to provide sufficient material for eight of the twelve species to be used. The desert soil was taken from the surface 10cm around mulga trees at Leinster Downs in the eastern goldfields.

Overburden materials (nos. 2-5) were supplied in forty four gallon drums by the operators of the mine prospect and described by them as:

2. Row 5, No. 4, dark reddish-brown shale, mullock 30-40m depth
3. Row 5, No. 15, yellowish-brown shale, mullock 30-40m depth
4. Row 12, No. 4, dark red gravelly mudstone from close to surface
5. Row 10, No. 4, yellow clay.

Materials 2 and 4 contained much coarse matter. This necessitated some correction prior to pot preparation. Aggregations of shale were crushed in material 2. Material 4 was put through a 4mm mesh sieve to remove gravel. Field capacity of each of the soils together with pH, organic matter content and partial chemical analysis (N, K, Fe, SiO_2, Al_2O_3, P, TiO_2, S, Mn) were determined. N (Kjeldahl method) and K (flame photometric method) were analysed at Curtin. Other chemical analyses were supplied by Cliffs Robe River Iron Associates.

Comparative estimates of soil acidity (pH) were determined by agitating 10g samples in 50ml deionised water, filtering and testing the filtrate with a pH meter. This method usually gives a pH reading of up to one pH unit greater than the slurry method (Allen **et al.** 1974).

The plant species used were **Acacia ancistrocarpa, A. aneura, A. citrinoviridis, A. coriacea, A. hamersleyensis, A. pachyacra, A. tenuissima, A. tetragonophylla, A. victoriae, Eucalyptus leucophloia, E. striaticalyx** and **E. patellaris.**

Sets of twenty seedlings of each species were grown in test, unamended, materials and twenty in the same material amended with Osmocote 90 day slow release fertilizer* at a rate equivalent to 50kg N ha^{-1}.

The experiment was undertaken by five final year Biology undergraduate students. In order to provide a reasonable task for each student, not all 12 species were tested in each material. Eight species were compared in each material. These were as follows: **Acacia hamersleyensis, A. tenuissima, Eucalyptus patellaris** and **E. striaticalyx** were grown in all five materials. **E. leucophloia** and **A. ancistrocarpa** were grown in all but soil 5. Two species were used in 3 materials: **A. tetragonophylla** in 3, 4 and 5, and **A. victoriae** in materials 1, 2 and 4. **A. citrinoviridis** was grown in soils 1 and 2, **A. pachyacra** in 3 and 5. Both **A. aneura** and **A. coriacea** were only grown in material number 5.

Seedlings were raised from seed sown in coarse sand in June 1982 and transplanted to the different soil materials in 70 x 70 x 100mm square topped plastic pots six weeks later. Five plants from each treatment were harvested randomly at transplanting and at approximately 25 day intervals thereafter for seventy five days. At each harvest

* N 14% (8.2% ammonium N, 5.8% nitrate N); P 6.1% (4.8% water soluble, 1.3% citrate soluble); K 11.6%; S 4.5%

a record of root and shoot length, fresh and dry weights of roots and shoots, and leaf numbers were made. Seed weights were also recorded, to determine whether seed reserves affected subsequent growth.

The soil was brought to field capacity with distilled water twice weekly in cool weather and three times a week in hotter weather.

Analyses of variance or t-tests were used to estimate the significance of differences between growth in fertilized and unfertilized materials. Differences between the soil materials (nos. 1-5) were tested using Least Significant Difference Tests.

Results

Analyses of overburden materials are presented in Table 1. A complete analysis was not available for material 1, but pH and field capacity are given for comparison with the mine materials.

All soils were markedly nutrient deficient. Levels of K and N were undetectable or present at very low levels. There was very little organic matter in any soils. Material no. 4 had a very high Mn level and the SiO_2 level was higher than in other materials in this study. Materials no. 5 and no. 1 were slightly more acidic than the others. The Osmocote fertilizer increased the levels of NPK and S in all soils.

Mean seed weights are given in Table 2. Mean dry weights of plants at each harvest are given in Table 3. Initial harvest weights, as may be anticipated, reflected seed weights. For example, fertilized material 1 25 day weights gave a Spearman Rank Correlation Coefficient of 0.81 with seed weight (ranking in agreement at p 0.05). For the final harvest in unfertilized materials yields were correlated with seed weights in materials 1, 4 and 5, suggesting that these materials least affected plant growth. Materials 2 and 3 (r_s 0.55 and 0.62 respectively, r_s 0.05 = 0.74) presumably either benefited some species, e.g. **E. patens** in both materials, and **A. victoriae** in material 2; or disbenefited some species, e.g. **A. tenuissima** in both and **A. ancistrocarpa** in material 2. Correlation of dry matter production with seed weight was lost in all fertilized materials, except no. 4 (r_s 0.89, r_s 0 05 = 0.89). In fertilized materials **A. tenuissima**, with higher seed weight than the **Eucalyptus** species was outperformed by **E. patens** in all except material 4 and by both the other **Eucalyptus** species Both **E. leucophloia** and **E. striaticalyx** failed in material 4. These were the smallest seedlings and most susceptible to transplant shock.

In material 1 (control) at first harvest only **A. citrinoviridis** and **A. hamersleyensis** exhibited statistically significant differences between unfertilized and fertilized material. There was a progressive increase in total dry weight until at the last harvest all species except **A. tenuissima**, showed a significant response to fertilizer.

TABLE 2. Mean weights (g) of dry seed of species used.

Species	Weight (g)
A. ancistrocarpa	0.0404
A. aneura	0.0364
A. citrinoviridis	0.0393
A. coriaceae	0.0955
A. hamersleyensis	0.0163
A. pachyacra	0.0313
A. tenuissima	0.0073
A. tetragonophylla	0.0170
A. victoriae	0.0150
E. leucophloia	0.0004
E. striaticalyx	0.0005
E. patellaris	0.0006

TABLE 1. Properties of soil materials used.

Properties	Soil Material				
Number	1	2	3	4	5
Location	Potting Mix	Row 5 No. 4	Row 5 No. 18	Row 12 No. 4	Row 10 No. 4
Colour	red	dark red-brown	yellow-ish brown	dark red-brown	yellow
Material	sandy loam	shale	shale	mudstone	clay
pH	6.3	6.8	6.2	6.8	6.1
Field capacity (mg/200g)	75	80	80	70	80
Percentage					
Loss on ignition		11.80	11.50	7.99	6.68
N	U.D.	0.008	U.D.	U.D.	0.015
Fe		43.50	25.70	20.50	63.80
SiO_2		13 20	27.00	41.00	1.40
Al_2O_3		8.10	19.50	16.00	0 70
P		0.156	0.067	0.086	0.070
TiO_2		0.41	1.30	0.68	0.01
S		0.012	0.002	0.007	0 003
Parts per million					
Mn		1.03	4.68	51.00	3.56
K	U.D.	U.D.	U.D.	U.D.	0.74

U.D. undetectable.

TABLE 3 Mean dry weights (+ S.D.) of plants at each harvest for each soil material

* denotes that the unfertilized and fertilized values are significantly different ($p < 0.05$)

Material 1

HARVEST	1 (25 days)		2 (50 days)		3 (75 days)	
Fertilizer	-	+	-	+	-	+
A. ancistrocarpa	0.0184 ±0.0066	0.0165 ±0.0043	0.0830 ±0.0207	0.1047 ±0.0392	0.0390 ±0.0109	*0.1651 ±0.0608
A. citrinoviridis	0.0391 ±0.0029	*0.0583 ±0.0182	0.0752 ±0.0101	*0.2551 ±0.0273	0.0964 ±0.0141	*0.2434 ±0.0575
A. hamersleyensis	0.0158 ±0.0031	*0.0227 ±0.0038	0.0249 ±0.0040	*0.0603 ±0.0225	0.0316 ±0.0091	*0.1278 ±0.0529
A. tenuissima	0.0064 ±0.0010	0.0064 ±0.0016	0.0099 ±0.0028	*0.0238 ±0.0070	0.0106 ±0.0025	0.0496 ±0.0369
A. victoriae	0.0176 ±0.0028	0.0268 ±0.0142	0.0396 ±0.0059	*0.0652 ±0.0349	0.0278 ±0.0094	*0.1331 ±0.0468
E. leucophloia	0.0020 ±0.0015	0.0035 ±0.0017	0.0052 ±0.0007	0.0371 ±0.0259	0.0063 ±0.0021	*0.1371 ±0.0735
E. striaticalyx	0.0027 ±0.0016	0.0049 ±0.0003	0.0043 ±0.0016	*0.0303 ±0.0025	0.0062 ±0.0030	*0.2221 ±0.0658
E. patellaris	0.0080 ±0.0011	0.0116 ±0.0075	0.0090 ±0.0046	0.0514 ±0.0468	0.0190 ±0.0102	*0.1999 ±0.1132

Material 2

Species	1 -	1 +	2 -	2 +	3 -	3 +
A. ancistrocarpa	0.0541 ±0.0238	0.0344 ±0.0140	0.0850 ±0.0233	0.1004 ±0.0208	0.1264 ±0.0558	0.1888 ±0.0736
A. citrinoviridis	0.0527 ±0.0130	0.0634 ±0.0173	0.1808 ±0.0357	0.1984 ±0.0987	0.2458 ±0.0288	0.2904 ±0.1231
A. hamersleyensis	0.0283 ±0.0098	0.0266 ±0.0071	0.0594 ±0.0240	0.0904 ±0.0416	0.1021 ±0.0306	0.1547 ±0.0681
A. tenuissima	0.0060 ±0.0024	0.0531 ±0.0106	0.0140 ±0.0073	0.0196 ±0.0098	0.0259 ±0.0078	0.0339 ±0.0209
A. victoriae	0.0332 ±0.0126	0.0324 ±0.0069	0.0796 ±0.0142	0.1056 ±0.0922	0.1361 ±0.0280	0.1562 ±0.0273
E. leucophloia	0.0031 ±0.0006	0.0034 ±0.0013	0.0139 ±0.0065	0.0158 ±0.0074	0.0312 ±0.0241	0.0425 ±0.0231
E. striaticalyx	0.0050 ±0.0030	0.0047 ±0.0015	0.0246 ±0.0199	0.0261 ±0.0338	0.0733 ±0.0631	0.1231 ±0.1124
E. patellaris	0.0161 ±0.0032	0.0162 ±0.0123	0.0668 ±0.0497	0.1341 ±0.1019	0.1348 ±0.0510	*0.4256 ±0.2359

Material 3

HARVEST	1 (25 days)		2 (50 days)		3 (75 days)	
Fertilizer	-	+	-	+	-	+
A. ancistrocarpa	0.0350 ±0.0121	0.0380 ±0.0107	0.0836 ±0.0278	0.1373 ±0.1042	0.1149 ±0.0087	*0.3678 ±0.1168
A. hamersleyensis	0.0325 ±0.0102	0.0235 ±0.0094	0.0381 ±0.0093	*0.1715 ±0.0894	0.0590 ±0.0283	*0.2663 ±0.0868
A. pachyacra	0.0174 ±0.0076	0.0225 ±0.0068	0.0540 ±0.0164	0.0658 ±0.0119	0.0675 ±0.0127	*0.1110 ±0.0426
A. tenuissima	0.0079 ±0.0027	0.0074 ±0.0023	0.0132 ±0.0019	0.0358 ±0.0129	0.0258 ±0.0058	*0.0680 ±0.0039
A. tetragonophylla	0.0258 ±0.0086	0.0403 ±0.0177	0.0564 ±0.0317	*0.1565 ±0.0622	0.0862 ±0.0232	*0.2601 ±0.0794
E. leucophloia	0.0052 ±0.0014	*0.0102 ±0.0030	0.0144 ±0.0074	*0.0688 ±0.0518	0.0362 ±0.0255	*0.2767 ±0.1170
E. striaticalyx	0.0079 ±0.0034	0.0073 ±0.0021	0.0193 ±0.0158	0.0774 ±0.0594	0.0519 ±0.0313	*0.1887 ±0.1172
E. patellaris	0.0096 ±0.0034	*0.0186 ±0.0099	0.2849 ±0.0570	0.2562 ±0.1472	0.0921 ±0.0786	*0.6353 ±0.2864

Material 4

Species	1 -	1 +	2 -	2 +	3 -	3 +
A. ancistrocarpa	0.0234 ±0.0099	0.0264 ±0.0048	0.0492 ±0.0051	0.0433 ±0.0083	0.0617 ±0.0086	0.0761 ±0.0240
A. hamersleyensis	0.0179 ±0.0057	0.0222 ±0.0034	0.0338 ±0.0079	0.0437 ±0.0262	0.0498 ±0.0164	0.0600 ±0.0110
A. tenuissima	0.0058 ±0.0024	0.0071 ±0.0009	0.0087 ±0.0029	0.0168 ±0.0070	0.0088 ±0.0034	*0.0272 ±0.0102
A. tetragonophylla	0.0177 ±0.0057	0.0287 ±0.0122	0.0446 ±0.0117	*0.0752 ±0.0262	0.0688 ±0.0260	*0.1211 ±0.0193
A. victoriae	0.0250 ±0.0037	0.0221 ±0.0035	0.0304 ±0.0112	0.0490 ±0.0151	0.0362 ±0.0076	*0.0684 ±0.0076
E. patellaris	0.0066 ±0.0023	0.0096 ±0.0024	0.0127 ±0.0034	*0.0316 ±0.0115	0.0155 ±0.0038	0.0211 ±0.0075

Material 5

Species	1 -	1 +	2 -	2 +	3 -	3 +
A. aneura	0.0273 ±0.0058	0.0244 ±0.0022	0.0524 ±0.0117	0.0561 ±0.0262	0.0728 ±0.0141	*0.1552 ±0.0774
A. coriaceae	0.1464 ±0.0068	0.1271 ±0.0200	0.2862 ±0.0797	0.3642 ±0.1440	0.2081 ±0.0698	0.4337 ±0.2404
A. hamersleyensis	0.0219 ±0.0053	0.0215 ±0.0020	0.0468 ±0.0157	*0.0977 ±0.0238	0.0506 ±0.0174	*0.4660 ±0.1630
A. pachyacra	0.0171 ±0.0052	0.0226 ±0.0089	0.0585 ±0.0198	0.0880 ±0.0267	0.0760 ±0.0221	*0.1488 ±0.0553
A. tenuissima	0.0055 ±0.0018	0.0091 ±0.0038	0.0138 ±0.0017	*0.0241 ±0.0086	0.0236 ±0.0047	*0.0641 ±0.0266
A. tetragonophylla	0.0359 ±0.0033	0.0495 ±0.0195	0.0941 ±0.0553	0.1388 ±0.0323	0.1399 ±0.0842	*0.4541 ±0.1100
E. striaticalyx	0.0074 ±0.0032	0.0062 ±0.0021	0.0252 ±0.0114	0.0198 ±0.0018	0.0293 ±0.0115	0.1086 ±0.0137
E. patellaris	0.0094 ±0.0022	*0.0168 ±0.0031	0.0180 ±0.0055	0.1039 ±0.1110	0.0230 ±0.0090	0.2665 ±0.0284

TABLE 4. Mean dry weights (g) of unfertilized plants at final harvest in different soil materials. Scoring beside species growing in the material which promoted most growth (2) indicates means which do not differ at $\alpha = 0.05$ (Least Significant Difference Test)

Ranking	Material 1	Material 2	Material 3	Material 4	Material 5
1	**A. citrinoviridis** 0.0964	**A. citrinoviridis** 0.2458	**A. ancistrocarpa** 0.1149	**A. tetragonophylla** 0.0688	**A. coriacea** 0.2081
2	**A. ancistrocarpa** 0.0390	**A. victoriae** 0 1361	**E. patellaris** 0.0921	**A. ancistrocarpa** 0 0617	**A. tetragonophylla** 0 1399
3	**A. hamersleyensis** 0.0316	**E. patellaris** 0 1348	**A. tetragonophylla** 0.0862	**A. hamersleyensis** 0 0498	**A. pachyacra** 0.0760
4	**A. victoriae** 0 0278	**A. ancistrocarpa** 0.1264	**A. pachyacra** 0.0675	**A. victoriae** 0.0362	**A. aneura** 0.0728
5	**E. patellaris** 0.0190	**A. hamersleyensis** 0.1021	**A. hamersleyensis** 0.0590	**E. patellaris** 0.0155	**A. hamersleyensis** 0 0506
6	**A. tenuissima** 0 0106	**E. striaticalyx** 0.0733	**E. striaticalyx** 0.0519	**A. tenuissima** 0.0088	**E. striaticalyx** 0 0293
7	**E. leucophloia** 0.0063	**E. leucophloia** 0.0312	**E. leucophloia** 0.0362		**A. tenuissima** 0.0236
8	**E. striaticalyx** 0.0062	**A. tenuissima** 0.0259	**A. tenuissima** 0 0258		**E. patellaris** 0 0230

TABLE 5. Mean dry weights (g) of fertilized plants at final harvest in different soil materials. Scoring beside species growing in materials which promoted most growth (2, 3 and 5) indicates means which do not differ at $\alpha = 0.05$ (Least Significant Difference Test).

Ranking	Material 1	Material 2	Material 3	Material 4	Material 5
1	**A. citrinoviridis** 0 2434	**E. patellaris** 0.4256	**E. patellaris** 0.6353	**A. tetragonophylla** 0.1211	**A. hamersleyensis** 0.4660
2	**E. striaticalyx** 0.2221	**A. citrinoviridis** 0 2904	**A. ancistrocarpa** 0.3678	**A. ancistrocarpa** 0.0761	**A. tetragonophylla** 0.4541
3	**E. patellaris** 0.1999	**A. ancistrocarpa** 0 1888	**E. leucophloia** 0.2767	**A. victoriae** 0 0684	**A. coriacea** 0.4337
4	**A. ancistrocarpa** 0.1651	**A. victoriae** 0.1562	**A. hamersleyensis** 0 2663	**A. hamersleyensis** 0.0600	**E. patellaris** 0 2665
5	**E. leucophloia** 0.1371	**A. hamersleyensis** 0.1547	**A. tetragonophylla** 0.2601	**A. tenuissima** 0.0272	**A. aneura** 0.1552
6	**A. victoriae** 0.1331	**E. striaticalyx** 0.1231	**E. striaticalyx** 0.1887	**E. patellaris** 0 0211	**A. pachyacra** 0.1488
7	**A. hamersleyensis** 0.1278	**E. leucophloia** 0.0425	**A. pachyacra** 0.1110		**E. striaticalyx** 0.1086
8	**A. tenuissima** 0.0496	**A. tenuissima** 0 0339	**A. tenuissima** 0.0680		**A. tenuissima** 0 0641

At the first harvest of the 8 species grown in material 2 only **A. tenuissima** showed a significant dry weight response to fertilizer. Analysis of variance of mean dry weights at the time of final harvest between fertilized and unfertilized plants of the same species showed height differences to be significant only in the case of **E. patellaris**. All other plants grew similarly in material 2 with or without fertilizer. The greatest growth was found in **E. patellaris, A. citrinoviridis, A. ancistrocarpa** and **A. victoriae** in both amended and unamended soil materials.

In the case of material 3 at all harvests there was an increase in mean dry weight for plants in fertilized materials compared with those in unfertilized materials. These differences were significant at first harvest for **E. leucophloia** and **E. patellaris**; at second harvest for **A. hamersleyensis, A. tenuissima, A. tetragonophylla**; and **E. leucophloia**; and at the final harvest for all plants. **E. patellaris** produced significantly greater dry weight than other species in material 3 at final harvest.

At the first harvest of plants grown in material 4 there was a trend for greater dry matter production with fertilized plants, in all species, although these differences were not significant. At the second harvest fertilized **A. tetragonophylla** and **E. patellaris** produced significantly more dry matter and at the final harvest, **A. victoriae, A. tenuissima** and **A. tetragonophylla** produced significantly greater dry weights than other species tested.

In material 5 in all cases dry matter production was greater in fertilized compared with unfertilized plants. The differences were significant in the following: first harvest for **E. patellaris**; second harvest for **A. tenuissima** and **A. hamersleyensis**; third harvest for **A. pachyacra, A. tenuissima, A. hamersleyensis, A. aneura** and **A. tetragonophylla**. The dry weights of the three species which grew best, **A. hamersleyensis, A. tetragonophylla** and **E. patellaris** in fertilized material 5, were not significantly different at the final harvest.

Discussion

Osmocote fertilizer was beneficial in most cases in promoting growth in the different soil materials. Unfertilized and fertilized plants are shown ranked in order of dry weight production at the final harvest (Tables 4 & 5) to emphasise the differences. Species growing in materials which produced best overall growth (material 2 fertilized and unfertilized, material 3 fertilized, material 5 fertilized) were tested for levels of significant differences in dry weight at the final harvest. Dilution of red earth with twice the quantity of more or less barren fine sand resulted in comparatively poor growth in unfertilized material no. 1.

Tables 6 and 7 rank the materials in which different species grew best. Except in the case of **A. citrinoviridis** and **A. victoriae** for which there were no significant differences between dry weights produced in unfertilized and fertilized soils, significantly less dry matter was produced by plants grown in unfertilized material. Both **A. citrinoviridis** and **A. victoriae** appeared to grow equally well in unfertilized and fertilized material 2. With fertilizer application the ranking of materials changed. Material 3 followed by material 5 promoted greatest dry matter production in most species. Materials 4 and 1 were least supportive of good growth in both unfertilized and fertilized treatments.

Analysis of material 4 revealed that this had a high manganese (Mn) concentration. The poor performance of plants in this material even when fertilized is likely to have been associated with manganese toxicity. Amounts as low as 0.0028ppm in the soil are known to affect growth adversely (Horst & Marshner 1978). Repeated attempts to establish **E. leucophloia** and **E. striaticalyx** in material 4 failed. Both **A. tenuissima** and **A. ancistrocarpa** proved difficult to sustain although enough plants survived to enable three harvests to be taken.

The performance of each species in the materials in which it was tested, is given in Tables 6 and 7.

TABLE 6. Ranked mean dry weights of plants grown in two or more unfertilized materials 1-5. Underscoring indicates means which do not differ at α = 0.05 (Least Significant Difference Test).

Ranking	1	2	3	4	5
A. ancistrocarpa	2 0.1264	3 0.1149	4 0.0617	1 0.0390	
A. citrinoviridis	2 0.2458	1 0.0964			
A. hamersleyensis	2 0.1021	3 0.0590	5 0.0506	4 0.0498	1 0.0316
A. pachyacra	5 0.0760	3 0.0675			
A. tenuissima	2 0.0259	3 0.0258	5 0.0236	1 0.0106	4 0.0088
A. tetragonophylla	5 0.1399	3 0.0862	4 0.0688		
A. victoriae	2 0.1361	4 0.0362	1 0.0278		
E. leucophloia	3 0.0362	2 0.0312	1 0.0063		
E. striaticalyx	2 0.0733	3 0.0519	5 0.0293	1 0.0062	
E. patellaris	2 0.1348	3 0.0921	5 0.0230	1 0.0190	4 0.0155

TABLE 7. Ranked mean dry weights of plants grown in two or more fertilized materials 1-5 Underscoring indicates means which do not differ at $\alpha = 0.05$ (Least Significant Difference Test).

Ranking	1	2	3	4	5
A. ancistrocarpa	3 0.3678	2 0.1888	1 0.1651	4 0.0761	
A. citrinoviridis	2 0.2904	1 0.2434			
A. hamersleyensis	5 0.4660	3 0.2663	2 0.1547	1 0.1278	4 0.0600
A. pachyacra	5 0.1488	3 0.1110			
A. tenuissima	3 0.0680	5 0.0641	1 0.0496	2 0.0339	4 0.0272
A. tetragonophylla	5 0.4541	3 0.2601	4 0.1211		
A. victoriae	2 0.1562	1 0.1331	4 0.0684		
E. leucophloia	3 0.2767	1 0.1371	2 0.0425		
E. striaticalyx	1 0.2221	3 0.1887	2 0.1231	5 0.1086	
E. patellaris	3 0.6353	2 0.4256	5 0.2665	1 0.1999	4 0.0211

A. ancistrocarpa. Fertilized material 3 produced significantly better growth than other fertilized or unfertilized materials. Material 4 was least suitable as a growth medium for this species.

A. aneura. This species was grown only in material 5. Fertilized soil provided better growth.

A. citrinoviridis. There were no significant differences between dry matter production in fertilized materials 2 and 1 and unfertilized material 2.

A. coriacea. This species was grown only in material 5. Fertilized soil promoted better growth than unfertilized soil at the 3rd harvest.

A. hamersleyensis. Best growth occurred in fertilized material 5 followed by fertilized soil 3. Materials 3 and 5 produced better growth when fertilized than when unfertilized.

A. pachyacra. There was no difference between growth of this species in fertilized materials 5 and 3. However, both produced better growth than unamended materials.

A. tenuissima. Growth was equally poor in all fertilized soil materials but worse in unfertilized materials.

A. tetragonophylla. Amended material 5 produced significantly better growth than amended material 3 which in turn was better than growth in material 4 and unfertilized soils.

A. victoriae. Fertilized soils 1 and 2 did not differ with respect to dry matter production: both produced better growth than fertilized material 4. In unfertilized materials no. 2 was responsible for better growth than materials 4 and 1. Comparison of growth in unfertilized and fertilized materials revealed significantly better growth in fertilized material 2, unfertilized material 2 and fertilized material 1.

E. leucophloia. All fertilized materials promoted significantly greater growth than unfertilized material: the best growth was recorded in material 3 with fertilizer.

E. striaticalyx. All unfertilized materials promoted less dry matter production than all fertilized materials. There were no significant differences between any of the fertilized materials.

E. patellaris. Best growth was recorded in fertilized materials 3 and 2 both of which materials were better promoters of growth than all unfertilized materials.

Positive identification of the presence of root nodules was observed on only two species of **Acacia**, namely **A. citrinoviridis** and **A. victoriae.** These plants were growing in unamended soil material 1 providing further evidence of the low N content of this material.

It might be expected that fertilizing of the unamended soil which generally produced best growth, material 2 (Table 6) would produce the best fertilized soil material. Unfertilized no. 2 material had more N, P, S and less Mn than unfertilized nos. 3 or 5, both of which gave best growth when fertilized. Other factors such as soil structure, texture, microbial content or porosity may become important in controlling growth once the mineral requirements are satisfied.

Relative Growth Rates

In general the relative growth rate between harvests was higher in fertilized than in unfertilized plants. In some cases rates were similar (e.g. **A. citrinoviridis** in soil 2); in other cases the unfertilized plants grew faster (e.g. **A. tenuissima** second and third harvests, material 2) and other rates were negative (e.g. **A. ancistrocarpa**, first and third harvests, soil 1). Although these growth rate fluctuations between harvests were noted, the overall growth rate from seed until harvest 117 days later was always greater in fertilized soils. A ranking of plants in the different soil types is given in Table 8.

Leaf/Phyllode Numbers and Mean Shoot Length

At the time of the final harvest the number of leaves/phyllodes (Table 9) was greater for fertilized plants than for unfertilized plants in all cases except for **A. ancistrocarpa** in material 4. The mean shoot lengths (Table 10) of fertilized plants were greater than those of unfertilized plants. However neither the increase in leaf/phyllode number nor the increase in shoot length could be related to increases in total dry weight.

TABLE 8. Relative growth rates (seed to final harvest gg^{-1} day^{-1}) of fertilized plants in different soil materials.

Ranking	Soil 1	Soil 2	Soil 3	Soil 4	Soil 5
1	**E. striaticalyx** 0.0521	**E. patellaris** 0.0560	**E. patellaris** 0.0594	**E. patellaris** 0.0303	**E. patellaris** 0.0520
2	**E. leucophloia** 0.0503	**E. striaticalyx** 0.0471	**E. leucophloia** 0.0563	**A. tenuissima** 0.0186	**E. striaticalyx** 0.0460
3	**E. patellaris** 0.0495	**E. leucophloia** 0.0403	**E. striaticalyx** 0.0507	**A. tetragonophylla** 0.0168	**A. hamersleyensis** 0.0287
4	**A. victoriae** 0.0182	**A. victoriae** 0.0195	**A. hamersleyensis** 0.0239	**A. victoriae** 0.0125	**A. tetragonophylla** 0.0281
5	**A. hamersleyensis** 0.0176	**A. hamersleyensis** 0.0192	**A. tetragonophylla** 0.0233	**A. hamersleyensis** 0.0111	**A. pachyacra** 0.0133
6	**A. tenuissima** 0.0164	**A. citrinoviridis** 0.0171	**A. tenuissima** 0.0191	**A. ancistrocarpa** 0.0054	**A. coriacea** 0.0129
7	**A. citrinoviridis** 0.0156	**A. ancistrocarpa** 0.0132	**A. ancistrocarpa** 0.0189		**A. aneura** 0.0124
8	**A. ancistrocarpa** 0.0120	**A. tenuissima** 0.0131	**A. pachyacra** 0.0108		

TABLE 9. Mean number of leaves/phyllodes per plant at the final harvest for plants grown in different soil materials. * denotes values significantly different ($p < 0.05$), between fertilizer treatments.

Material	1		2		3		4		5	
Fertilizer	-	+	-	+	-	+	-	+	-	+
A. ancistrocarpa	25	37	7.6	9	4	9	54	33	-	
A. aneura	-	-	-	-	-	-	-	-	4	14
A. citrinoviridis	24	*35	6.6	7	-	-	-	-	-	-
A. coriaceae	-	-	-	-	-	-	-	-	5	9
A. hamersleyensis	18	*43	7	8	4	6	27	28	-	-
A. pachyacra	-	-	-	-	5	7	-	-	1	3
A. tenuissima	11	*27	6	7.6	4	5	16	28	4	9
A.tetragonophylla	-	-	-	-	13	22	20	45	17	80
A. victoriae	36	44	14	16	-	-	28	50	-	-
E. leucophloia	6	*9	8.2	10.5	9	13	-	-	-	-
E. striaticalyx	6	*12	7.8	9	6	9	-	-	5	9
E. patellaris	9.5	*12.5	10	13	9	12	5	7	6	10

TABLE 10. Mean length of shoots (mm) of plants growing in different materials at final harvest. * denotes values significantly different ($p < 0.05$) between fertilizer treatments.

Ranking	1		2		3		4		5	
Fertilizer	-	+	-	+	-	+	-	+	-	+
A. ancistrocarpa	44	*74	40	47	26	*68	64	*81	-	-
A. aneura	-	-	-	-	-	-	-	-	41	53
A.citrinoviridis	62	*113	63	75	-	-	-	-	-	-
A. coriaceae	-	-	-	-	-	-	-	-	59	63
A.hamersleyensis	36	*52	24	23	10	*18	36	43	25	28
A. pachyacra	-	-	-	-	16	24	-	-	35	36
A. tenuissima	28	*71	23	22	15	20	39	44	31	33
A.tetragonophylla	-	-	-	-	40	*98	67	84	63	138
A. victoriae	38	*59	44	43	-	-	42	*51	-	-
E. leucophloia	23	*40	32	36	34	*65	-	-	-	-
E. striaticalyx	19	*67	46	53	25	*39	-	-	32	39
E. patellaris	38	46	43	*76	40	59	29	36	24	51

Conclusions

With the exception of **A. citrinoviridis** and **A. victoriae**, all fertilized plants produced significantly better growth in terms of dry weight than unfertilized plants. Relative growth rates, leaf numbers and shoot heights were also greater in fertilized plants. However, there were no clear relationships between dry weight values, relative growth rate values, leaf numbers and shoot heights.

In terms of dry matter production, best growth occurred in material no. 3 (row 5, no. 18, shale) and in material 5 (row 10, no. 4, yellow clay). **A. ancistrocarpa, E. leucophloia, E. patellaris**, **A. hamersleyensis** and **A. tetragonophylla** grew particularly well in the fertilized shale; **A. hamersleyensis**, **A. tetragonophylla** and **E. patellaris** grew best in the fertilized clay. The gravelly mudstone 4 (row 12, no. 4, overburden) generally produced least growth even when fertilized, probably because of toxicity induced by the high level of manganese in this material. Removal of gravel from this material is unlikely to have enhanced toxicity. When unamended, material 2 (row 5, no. 4, shale) produced the best growth in most species. However after fertilization, when all soils were equally amended, material 2 no longer promoted best growth except in **A. citrinoviridis** and **A. victoriae**. If these two species were grown in material 2, fertilizer of the level tested would not be advantageous: dry weights were not significantly increased in amended soils. If material 2 were to be used as surface dressing then some treatment may be required to break up the coarser fragments. Once soil nutrient levels have been adequately provided by fertilization other factors - physical or microbial may determine the degree of growth.

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