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MULGA
RESEARCH
CENTRE

VOLUME NUMBER 8

PREFACE

The Mulga Research Centre was formed at the Western Australian Institute of Technology in 1977. Report number seven published on 18th September 1984 foreshadowed the change in designation of the major medium of communication of the Mulga Research Centre to journal format. The present volume is the first for which all communications included have been reviewed by an external panel of referees.

SPONSORSHIP

Number 8 has been sponsored by Cliffs International Incorporated.

EDITORIAL PANEL

EDITORIAL POLICY

Contributions are welcomed which bear on the objectives of the Mulga Research Centre. It is anticipated that the main emphasis will continue to be in terms of acting as a publication medium for work undertaken by staff and students at WAIT. Studies of a preliminary nature will be preferred. Although some scope exists for review articles, it is anticipated that most items will be research notes and descriptive papers.

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 of a volume. A limited number of reprints will be supplied.

AVAILABILITY

Copies may be purchased from WAIT Bookshop, Kent Street, Bentley, W.A. 6102.

CONSTITUTION OF THE MULGA RESEARCH CENTRE

NAME

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

OBJECTIVES

1. To promote field and laboratory studies in the biology and ecology of Western Australian trees and shrubs, with emphasis where appropriate on those of the Mulga Zone.
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 a three member external review panel, on an approximately annual basis.
3. To assist scholars engaged in appropriate related studies.
4. To raise funds from appropriate sponsors to enable 1, 2 and 3 above to be undertaken.
5. To report work undertaken in journal format.

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).

SUBSCRIPTIONS

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

OFFICE BEARERS

Office bearers shall consist of a President, a Secretary, and a Treasurer.

COMMITTEE

The appointed Office Bearers shall constitute the Committee. The 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.

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.

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 appoint proxies (in writing) to the Secretary.

QUORUM

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

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.

GENERAL ADMINISTRATION

1. Location

The address of the Mulga Research Centre is C/- School of Biology, Western Australian Institute of Technology, Kent Street, Bentley, W.A. 6102.

2. Bank Account

An account will be opened at the South Bentley branch of the R & I Bank. Signatories shall be the President 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.

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.

OFFICE BEARERS

President	Dr J.E.D. Fox
Secretary	Mrs J.M. Osborne
Treasurer	Dr J.D. Majer
Honorary Auditor	Mr J.B. Burling

MULGA RESEARCH CENTRE JOURNAL VOLUME NUMBER 8

CONTENTS

Pages

This manuscript was prepared at the School of Biology, Western Australian Institute of Technology by Miss Sallie Palmer.

The following persons are thanked for reviewing papers in Volume 8: I. Abbott, B.A. Carbon, D.R. Fox, L.E. Koch, F.J. McKinnell, B.G. Muir and J.R.H. Riches.

AN ACCOUNT OF EDAPHIC FACTORS IN RELATION TO THE DISTRIBUTION OF PERENNIAL WOODY SPECIES IN A TROPICAL MULGA COMMUNITY

S.J. Van Leeuwen and J.E.D. Fox, School of Biology, Western Australian Institute of Technology.

Introduction

The Hamersley Plateau of Western Australia's Pilbara Region is endowed with ranges of mountains. Between the areas of high country broad valley systems are vegetated with open to closed woodland vegetation systems. Hummock grasslands occur throughout the region. In much of the woodlands mulga, **Acacia aneura**, predominates. This species occupies a number of sites in addition to the valley systems and, under some circumstances, is able to persist well up into the higher country. It is not, however, universally present and there are stands of **Eucalyptus** and local occurrences of other **Acacia** species interspersed through the area.

Moisture regimes appear to be the most significant of the environmental factors affecting the density and distribution of plant species. Moisture regimes are a complex function of climatic, physiogeomorphic and edaphic attributes (Boyland 1973). Undoubtedly climatic factors are of major importance to the overall level of biomass attained by the plant formations. We find in the region that hummock grasslands of **Triodia** species are frequent, and often carry few large, woody, perennial species of tree or shrub form. Physiogeomorphic factors in arid regions are of importance by virtue of their water-controlling attributes. Run-off, surface drainage and redistribution of water are all influenced by physiogeomorphic factors. There are possible effects on sunlight, and indirectly on drying properties, due to the effects of aspect (Hadley 1962; Toy 1979).

In conjunction with long-term investigations into the dynamics of ecosystems in the eastern Pilbara (Fox 1981, Fox et al. 1983), a study was undertaken to determine whether edaphic factors could be responsible for some differences in the structure, floristics and density of **Acacia aneura** associations.

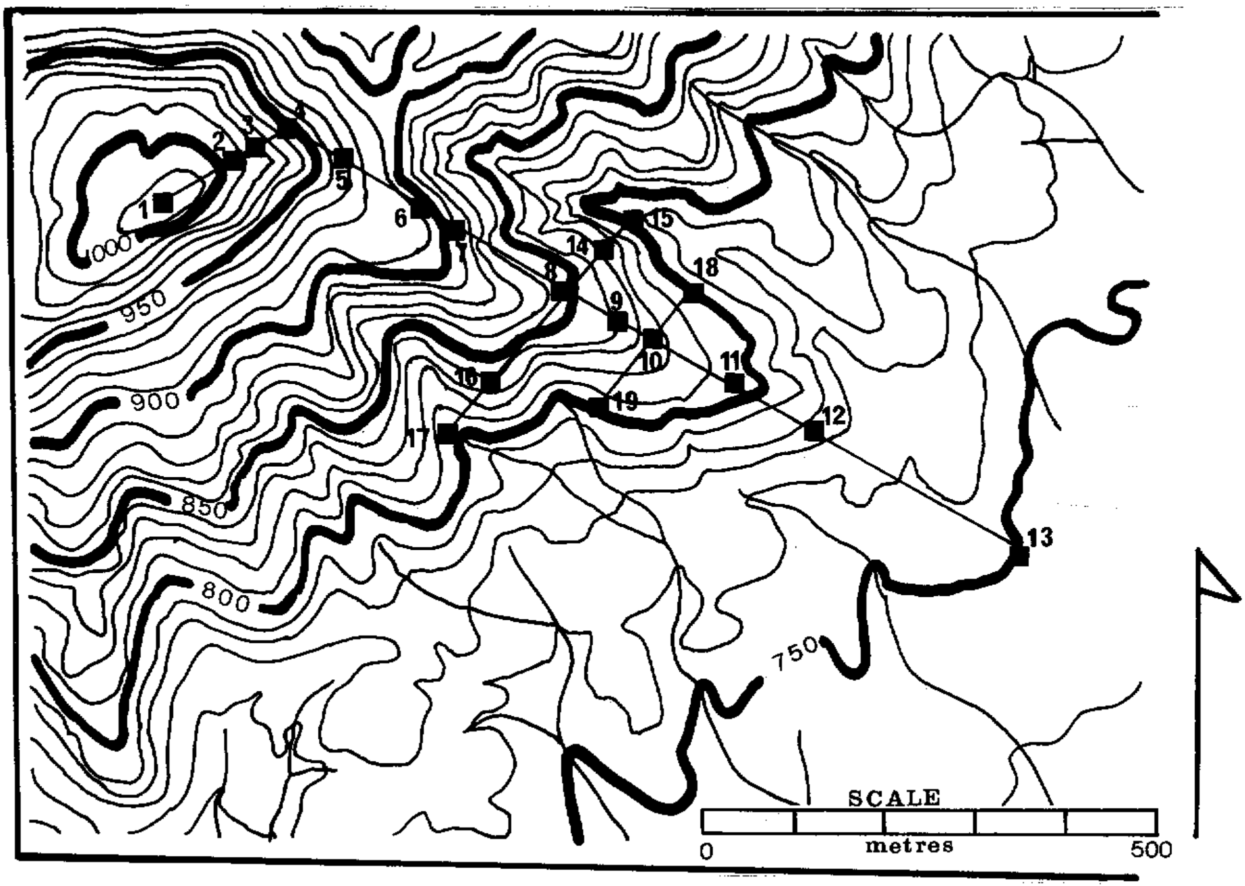

FIGURE 1. Location of transects on hill sites. Transect A 1-13, Transect B 14-17, Transect C 18, 19. This figure is extracted from Cliffs International Inc. West Angelas Project Map DRL BB with contour intervals of 10m.

Mulga Research Centre Journal No. 8
Published November 1st 1985, 1-12.

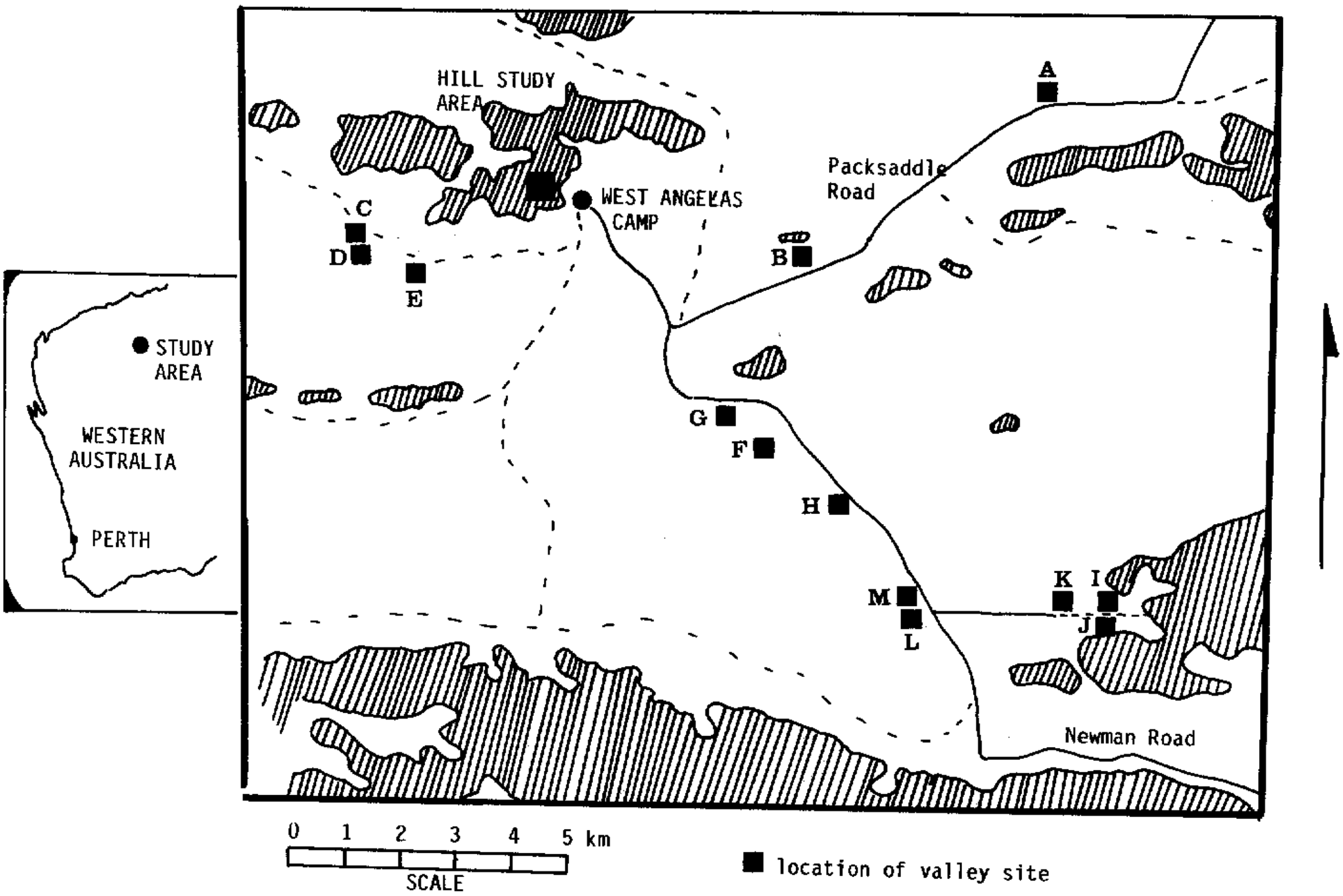

FIGURE 2. Valley site locations A-M inclusive. Shading indicates country above 800m altitude. This figure is based on sheet 2651 of National Topographic Map Series at 1: 100,000.

The soils of mulga communities are typically low in available nutrients, especially nitrogen and phosphorus (Keay & Bettenay 1969). The soils are often characterised by low porosity, with poor physical properties, low water holding capacity and extreme hardness when dry (Perry 1983). Texture and depth of soil are the main factors considered to govern plant distribution, density and size within mulga communities (Boyland 1973). These factors control the distribution of moisture in the soil and the amount available to the plant (Perry 1973).

In the investigation reported herein soil characteristics of depth, texture, moisture relations, organic matter, pH and nutrient status, were recorded from defined sites where perennial woody shrubs were recorded. Measurements of **Acacia aneura** trees were taken. Correlations are examined between these factors in an effort to elucidate those of importance.

Study Location

A hill at 23°05'S, 118°40'E known locally as 'Twin Peaks' was selected for placement of hill study sites. A number of long-term study plots are located within a 15 km radius of this hill in the West Angelas area.

A set of 19 sites were located on the hill at intervals of c 25 m elevation along the main southeastern spur. Transect A contained sites 1-13. It ran at 60° from the highest peak at 1017 m to the fourth site at 950 m, thence at 120° to the 13th site at 750 m elevation (Figure 1). This transect was 1.18 km in length. Transect B contained sites 14-17 and ran at 40° through site 8 on transect A, for a total of 0.4 km. Transect C was 0.23 km in length, it ran through site 10 at 40° and contained sites 18 and 19 to the north and south respectively. There was no evidence of recent fire in any of these sites.

A set of 13 sites was selected from plots located at less than 750 m elevation. These are labelled as sites A-M in Figure 2. Relative elevations in metres above sea level are illustrated in Figure 3.

Sample Collection

At each site all perennial plant species were measured within a 10 m radius. An air-tight sample of soil from the top 10 cm was taken at the centre of the site. In addition soil depth, penetrability, percentage stone cover and pH were recorded in the field. Soil depth was obtained by hammering a sharpened steel rod into the ground at 3 points one metre apart. Penetrability was also expressed in cm, and was obtained by dropping the same rod into the ground from a height of 15m. Stone cover was visually estimated, and pH was determined with the use of a CSIRO portable kit, using powder and liquid.

Laboratory Analysis

In the laboratory field soil moisture was obtained as the percentage of oven dry weight. Saturation percentage and field capacity were also determined for each sample of soil. Approximately 200 g of soil was sieved through the range 2.36 mm down to 75 um to obtain particle size distribution. Percentage organic matter was determined from a 2 g sample ignited at 750° for 30 min. A 1:5 soil water extract was used to determine total soluble salts by electrical conductivity, and pH with a glass electrode pH meter. The conductivity was expressed in millisiemens per centimetre (mS/cm) (Bear 1964). Total soluble salts were then estimated from electrical conductance readings using the factor suggested by Piper (1942):

$$\text{TSS ppm} = \text{E.C. mS/cm} \times 3360$$

This factor is an approximation, particularly in respect of arid zone soils high in bicarbonate, sulphate or calcium salts.

For soil chemical analyses samples were sieved to give soil material with particles of 0.5 mm or less. Nitrogen was determined by the Kjeldahl method using sulphuric acid and hydrogen peroxide. Further samples of 0.5 mm or less were digested using nitric/perchloric acid. Total phosphorus was determined by colorimetry using molybdenum blue (Allen 1974). The cations of calcium, potassium and sodium were determined by flame photometry. Magnesium was determined by emission spectrophotometry (Allen 1974).

Results

A summary of soil physical properties for each of the 32 sites is given in Table 1. Hill sites tended to have coarse blocky or platey development in contrast to less strongly developed medium, sphaerodial structure on valley sites. Particle analysis resulted in classification of the majority of sites as sandy loam in texture, with one silty loam, 5 loams and 2 sands.

TABLE 1. Physical soil characteristics and pH.

Site	Soil Description	Transect	% Particle Size			Textural Classification	Stoniness (%)	Depth (cm)	Penetrability (cm)	Soil pH	
			Sand	Silt	Clay					Field	Laboratory
HILL											
1	Strong, coarse, blocky	A	54.3	31.5	14.2	Sandy loam	100	1.5	1.5	4.5	4.2
2	Strong, medium, sphaeroidal	A	80.1	13.8	6.1	Sandy loam	100	20.0	3.5	4.0	4.6
3	Strong, medium, sphaeroidal	A	72.4	20.8	6.8	Sandy loam	100	67.0	4.0	3.5	5.0
4	Strong, coarse, blocky	A	48.0	44.1	7.9	Loam	100	25.0	3.0	5.5	5.4
5	Strong, coarse, blocky	A	83.7	12.5	3.8	Sand	100	100.0	2.9	9.0	8.6
6	Strong, coarse, prismatic	A	68.5	23.1	8.4	Sandy loam	100	6.5	1.5	6.0	6.7
7	Strong, coarse, prismatic	A	70.5	22.0	7.5	Sandy loam	100	24.0	3.0	6.0	7.3
8	Strong, coarse, platey	A/B	73.6	18.9	7.6	Sandy loam	90	11.0	4.8	6.0	5.5
9	Strong, coarse, platey	A	75.2	15.7	9.1	Sandy loam	100	13.1	3.8	6.0	5.9
10	Strong, coarse, blocky	A/C	79.3	14.9	5.8	Sandy loam	95	16.5	3.1	6.0	6.2
11	Strong, medium, platey	A	49.0	31.4	19.6	Loam	100	5.5	7.5	8.0	7.5
12	Strong, medium, platey	A	48.6	32.7	18.7	Loam	95	7.5	4.3	8.0	7.4
13	Strong, medium, platey	A	55.9	28.9	15.3	Sandy loam	90	15.8	4.8	6.0	6.9
14	Moderate, coarse, prismatic	B	63.5	27.4	9.1	Sandy loam	95	13.6	4.8	6.0	6.0
15	Moderate, coarse, platey	B	55.9	30.5	13.6	Sandy loam	100	11.0	3.3	8.5	7.5
16	Moderate, medium, blocky	B	70.0	21.7	8.3	Sandy loam	100	17.5	1.6	7.5	6.9
17	Strong, coarse, platey	B	72.9	18.0	9.1	Sandy loam	100	16.8	4.5	6.5	6.3
18	Strong, coarse, prismatic	C	73.6	19.7	6.7	Sandy loam	95	17.6	3.3	6.0	5.8
19	Strong, coarse, blocky	C	72.9	19.5	7.6	Sandy loam	100	10.0	3.1	7.5	6.9
VALLEY											
A	Strong, medium, prismatic		58.8	29.3	11.9	Sandy loam	10	23.0	5.7	6.5	5.0
B	Weak, fine, sphaeroidal		45.3	37.3	17.4	Loam	70	21.6	5.7	6.0	4.8
C	Moderate, coarse, sphaeroidal		63.6	25.3	11.1	Sandy loam	80	14.7	6.0	6.0	4.7
D	Moderate, medium, blocky		64.6	25.0	10.4	Sandy loam	90	20.0	4.7	5.5	5.0
E	Weak, medium, sphaeroidal		61.2	30.5	8.3	Sandy loam	100	20.3	2.6	6.0	5.0
F	Moderate, medium, sphaeroidal		60.4	28.1	11.5	Sandy loam	5	12.6	5.7	7.5	6.3
G	Moderate, fine, sphaeroidal		35.7	49.1	15.2	Loam	30	34.3	6.0	8.0	7.2
H	Weak, medium, sphaeroidal		58.2	30.4	11.4	Sandy loam	70	18.0	4.6	6.5	5.5
I	Moderate, medium, sphaeroidal		91.1	5.8	3.1	Sand	80	14.0	4.3	5.5	5.8
J	Moderate, medium, sphaeroidal		52.0	30.5	17.5	Sandy loam	90	21.0	4.6	5.5	4.7
K	Moderate, medium, sphaeroidal		77.5	16.5	6.0	Sandy loam	100	21.0	3.6	5.5	6.1
L	Moderate, medium, sphaeroidal		50.8	36.8	12.3	Sandy loam	100	31.0	3.3	6.5	5.5
M	Weak, fine, sphaeroidal		37.2	56.0	18.8	Silty loam	40	24.0	6.3	6.0	5.0

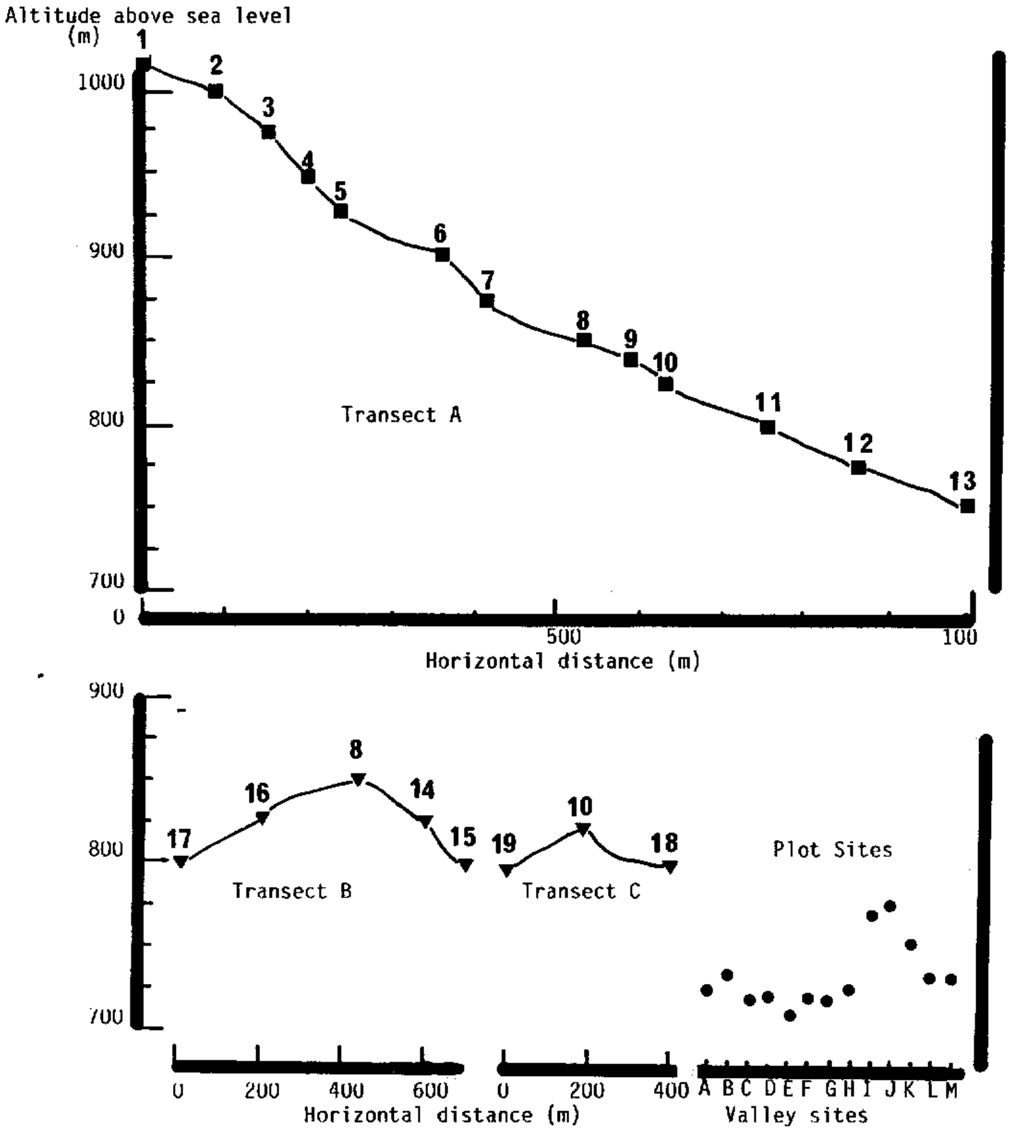

FIGURE 3. Comparative elevation of study sites with sectional representation of hill transects.

Most sites were stony with a mean value of 85% surface stone cover. The hill sites were much more stony than the valley sites where the mean value was 66%. Depth to hardpan or subsurface rock was very variable, with little difference in mean values for hill and valley sites. However the variability was much greater on hill sites (mean 21 cm, SD 23) than in the valley sites (mean 21, SD 6). The valley sites had generally higher values for penetrability (mean 4.9 cm, SD 1.2) than the hill sites (mean 3.6, SD 1.4).

Field pH proved to be a good general guide to the levels measured in the laboratory. The two were strongly correlated (r = 0.79***). There were a few extremes of difference with sites 3 and A differing by 3 half units each. Site 3 was underestimated with the field kit, whereas A was overestimated. The majority of valley sites were overestimated such that the mean for field values was 6.2 and for laboratory values 5.4. Laboratory values are used subsequently in this paper. Hill sites 1 and 2 had the most acidic soils recorded and hills sites 5, 11, 15 and 12 had the most alkaline soils recorded. The range for valley sites was much less at 4.7-7.2, compared with 4.2-8.6 for the hill sites where standard deviation was also higher at 1.1 versus 0.8 for valley soils. The majority of samples analysed were characteristically acidic (65%), a finding in agreement with Keay and Bettenay (1969).

The sandy loams were strong to medium acid in reaction, ranging from very strongly acid to very slightly alkaline. The loams ranged from strongly acid to neutral in reaction.

Table 2 summarises the results of chemical analyses, and also gives the moisture characteristics and organic matter contents, for samples taken from each site. Site 5 with the highest pH (8.6) was saturated with bases, more so than other samples analysed.

Dimensions of **Acacia aneura** from each site and the total numbers of species (and plants) of woody perennial species are tabulated in Table 3. Table 4 records the distribution of perennial woody species and **Triodia** hummock grasses by site.

A description of each of the 32 sites examined is given in the Appendix in terms of slope position, species present and dimensions. These dimensions are summarised here.

Along the catena transects eleven woody perennial plant species were recorded. The most frequent and dominant species was **A. aneura** represented in its two phyllode forms in three of the study sites. It was present in fourteen sites altogether. On those sites where it was absent **A. bivenosa** was the dominant species, except for site 5 where **E. oleosa** was dominant.

The mean height of mulga on the transects of the catena was 3.6 m (SD = 0.9), with a maximum height of 4.9 m (SD = 1.3), a mean stem diameter of 4.9 cm (SD = 2.8), and a mean crown size of 3.4 m (SD = 1.5).

The mean number of plants per site was 11 with mean number of **A. aneura** plants of 8. The mean number of species per site was 3. The two dominant ground cover species were **T. wiseana** and **T. pungens.**

On transects B and C the values for mean mulga height were, on the northern facing slopes, 3.96 m and 4.97 m respectively, while on the southern facing slopes mulga was absent with the exception of study site 16 in transect B, which had a mean mulga height value of 2.51 m. The mean numbers of plants, mulga, and species per site on the northern facing slopes of transect B and C were 9 and 9, 6 and 9, and 3 and 1 respectively. On the southern facing slopes of these transects the values for plants, mulga, and species per site were 11 and 8, 2 and 0, and 2 and 1 respectively. Thus while numbers present were slightly greater on the southern slopes, the number of mulga present was considerably less. The number of species present per site was similar on both aspects.

In the valley study sites twenty plant species were recorded. The most frequently occurring, dominant, species was **A. aneura** followed by **A. pruinocarpa** and **Eremophila leucophylla. A. aneura** was recorded in all thirteen sites with both forms of the plant present. The mean height of the **A. aneura** plants in the valley sites was 3.1 m (SD = 0.9), with a mean maximum height of 5.6 m (SD = 1.4), a mean stem diameter of 4.9 cm (SD = 2.1), and a mean crown size of 3.1 m (SD = 1.0).

The mean number of plants per site was 23, with mean number of **A. aneura** plants of 15. The mean number of species per site was 4.

TABLE 2. Chemical characteristics, moisture and organic matter.

	MOISTURE PROPERTIES (%)			Organic matter	CHEMICAL ANALYSIS (All values in parts per million)						
Site	Moisture Content	Satur-ation	Field Capacity	% loss on ignition	Total Soluble Salts	N	P	Mg	Ca	K	Na
HILL											
1	1.4	28.3	22.0	12.8	1075	1351	40.8	3398	4543	1022	102
2	1.3	16.3	12.0	12.1	504	1560	37.4	2854	7734	6986	411
3	0.9	21.5	17.1	8.7	268	48	6.4	1981	11578	3752	611
4	0.8	31.9	23.9	9.7	1310	610	14.5	1521	11821	2626	1225
5	1.8	26.4	14.1	8.3	168	819	15.3	52824	16135	10180	922
6	2.0	18.9	12.3	7.4	604	1106	1.6	11533	7098	8501	165
7	2.4	25.5	20.0	8.6	1377	1290	36.0	7857	11761	1440	552
8	1.5	23.6	12.0	6.5	1881	942	41.3	15548	8949	6154	355
9	1.7	15.9	11.3	6.4	873	777	35.5	10480	2621	5149	196
10	1.5	15.0	11.9	6.5	739	759	18.9	6263	6169	5102	557
11	1.3	22.3	16.4	4.9	773	508	9.0	17958	6334	5090	588
12	1.9	29.2	19.7	6.8	168	1455	15.0	37195	7715	8743	1034
13	1.9	21.6	16.8	4.4	1444	1759	32.0	16299	8620	7635	431
14	2.2	21.5	14.0	6.5	1747	805	32.8	14679	6348	6239	339
15	2.2	23.9	16.9	5.8	2419	784	31.2	30461	7211	8413	360
16	4.8	21.4	13.5	7.1	2419	949	30.5	15003	6819	6999	296
17	1.3	21.4	12.9	6.0	2116	821	34.5	7038	5404	3782	183
18	1.9	12.0	11.6	7.2	4116	799	19.8	7142	5050	4599	216
19	1.8	21.1	14.7	5.3	2822	580	18.3	14007	7560	5173	209
VALLEY											
A	2.5	16.9	14.1	3.1	1881	301	1.7	2688	14957	1388	277
B	2.9	23.8	18.0	5.9	873	823	1.8	3225	10373	1844	218
C	2.5	17.5	13.5	4.8	604	555	5.1	2694	18139	4302	604
D	2.8	17.6	13.4	5.0	1209	537	26.9	8186	6859	2572	257
E	2.7	20.1	15.5	4.7	1276	499	37.8	3875	8759	2840	331
F	3.2	27.6	22.0	5.7	638	286	43.5	47869	5666	2266	170
G	3.7	21.9	16.3	4.8	268	416	2.3	22523	5827	3263	454
H	1.4	16.9	12.7	4.3	940	556	5.8	8079	8780	2926	353
I	1.2	12.1	9.0	5.3	638	359	1.8	1551	10440	1392	417
J	2.3	22.4	17.4	8.1	705	1309	0.4	2632	6364	1909	222
K	2.4	14.3	8.9	7.7	604	1048	0.2	5518	4347	1304	173
L	1.2	26.5	19.6	6.2	705	122	0.2	2436	8283	4141	390
M	2.1	25.5	16.7	4.7	1579	299	0.2	3046	10109	1648	296

TABLE 3. Acacia aneura representation in sites and dimensions.

	Numbers of			Dimensions of Acacia aneura stems					
Site	Species	Plants	Acacia aneura	Mean Ht (m)	Max. Ht (m)	Mean Crown (m)	Mean Stem Diam. (cm)	Mean Stem Area (m2)	Relative Density
HILL									
1	1	19	18	2.75	4.94	2.35	3.6		95
2	2	39	38	4.18	5.40	4.99	5.1	.0326	97
3	1	12	12	3.92	5.03	2.89	4.8	.0488	100
4	4	12	5	2.16	3.20	2.24	2.6	.0026	42
5	1	3	0	-	-	-	-	-	-
6	3	16	14	3.55	7.10	2.43	4.7	.0360	89
7	3	15	13	3.39	5.87	3.39	4.8	.0488	88
8	2	7	5	3.45	4.56	3.17	4.2	.0048	78
9	3	14	10	4.87	4.99	4.95	4.9	.0301	78
10	3	10	6	2.43	4.21	2.71	4.1	.0237	60
11	6	11	6	3.80	4.61	2.27	3.8	.0088	55
12	5	9	0	-	-	-	-	-	-
13	4	8	0	-	-	-	-	-	-
14	3	6	4	5.20	5.50	7.45	13.8	.2393	36
15	3	13	8	2.73	4.08	2.25	3.5	.0096	61
16	3	12	3	2.51	2.87	2.15	2.3	.0013	25
17	1	11	0	-	-	-	-	-	-
18	1	9	9	4.97	7.30	4.06	6.2	.0353	100
19	1	8	0	-	-	-	-	-	-
VALLEY									
A	4	16	5	4.05	4.45	3.52	3.8	.0204	31
B	5	34	17	2.48	7.30	1.87	1.1	.1292	54
C	3	21	15	3.56	5.20	2.53	3.8	.0102	71
D	4	13	6	3.35	5.15	3.65	4.7	.0104	86
E	5	12	5	2.54	4.80	4.85	5.1	.0020	42
F	2	34	33	5.00	6.20	2.16	4.9	.1011	97
G	5	19	11	3.22	7.90	1.51	8.7	.0330	58
H	3	33	15	1.87	3.60	1.50	2.2	.0041	44
I	7	24	13	2.82	7.40	3.63	-	-	54
J	5	45	29	3.01	4.70	1.53	-	-	64
K	5	17	14	3.07	6.80	-	-	-	82
L	3	18	16	2.75	3.60	7.65	-	-	89
M	2	14	13	3.05	5.30	2.30	4.9	.0490	93

TABLE 4. Distribution of species by sites.

	SITES																															
SPECIES	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	A	B	C	D	E	F	G	H	I	J	K	L	M
Acacia aneura (B)	*	*	*	*	-	*	*	*	*	*	*	*	*	*	*	*	-	*	-	*	*	*	*	*	*	*	*	*	*	*	*	*
A. aneura (N)	*	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	*	-	-	*	-	*	-	-	-	-	-	-
A. bivenosa	-	-	-	-	-	-	-	-	-	-	-	*	*	-	-	*	*	-	*	-	-	-	-	*	-	-	-	-	-	-	-	-
A. inaequilatera	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-
A. kempeana	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-
A. marramamba	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	*	-
A. pruinocarpa	-	-	-	*	-	-	*	-	*	-	*	-	-	*	-	*	-	-	-	*	-	*	-	-	-	-	-	*	*	*	-	*
A stowardii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-
A. tetragonophylla	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
Canthium lineare	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-	*	-	-	-	*
Cassia glutinosa	-	-	-	-	-	-	-	-	-	*	-	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
C. helmsii	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	*	-	-	*	-	-	*	-	-
C. nemophila	-	*	-	*	-	*	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Eremophila leucophylla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	*	*	-	-	*	-	*	-	-	*
Eremophila indet	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-
Eucalyptus dichromophloia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-
E. gamophylla	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-
E. leucophloia	-	-	-	-	-	-	-	*	*	*	*	*	*	-	-	-	-	-	-	*	-	*	-	-	-	-	-	*	-	-	-	-
E. oleosa	-	-	-	*	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E. patellaris	-	-	-	-	-	-	-	-	-	-	-	*	*	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-
E. setosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-
Grevillea berryana	-	-	-	-	-	*	-	-	-	-	-	-	-	-	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	*	-
Hakea lorea	-	-	-	-	-	-	*	-	-	-	*	*	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Triodia pungens	*	*	-	-	-	*	*	*	*	*	*	-	-	-	*	*	*	-	-	*	*	-	*	*	*	*	*	*	*	*	*	*
T. wiseana	*	*	*	*	*	*	-	*	-	-	-	*	*	*	-	-	-	*	*	-	-	-	-	-	-	-	-	-	-	-	-	-

NOTE: Numbers of species reported in Table 3 is for woody perennials i.e. excluding Triodia species, and a value of 1 for Acacia aneura.

Taking the hill and valley sites together, in total twenty two different woody species were recorded. The most frequently occurring plant species was **A. aneura**. The mean dimensions for this species were height 3.35 m (SD = 0.90); maximum height 5.25 m (SD = 1.35); stem diameter 4.9 cm (SD = 2.4); crown diameter 3.23 m (SD = 1.62), and stem area 0.0343 m2 (SD = 0.0502), per site.

The mean values over all sites were: number of species 4.65; number of individuals 17; and number of **A. aneura** plants 12, per site. On the hill sites the values for mean height of **A. aneura**, size of the crown and stem area per site were higher than those in the valley. In the valley sites maximum height and crown area were higher than for the catena hill sites. The values for stem diameter were similar in both the hill and valley sets. The means for number of species, individual plants, and **A. aneura** plants per site, were greatest in the valley.

There was a tendency for **Acacia aneura** on the hill sites to have more than 1 stem per plant (mean 1.5) in contrast with the valley sites where the plants were usually single-stemmed.

Moisture Characteristics

At the time of sampling moisture in soil was low (0.8 to 4.8%). The mean value for soil moisture throughout the study area was 2.1% (SD = 0.9), ranging from 0.9-4.9%. The highest mean values for moisture content of the soil were obtained from the valley sites. These had a mean of 2.4% (SD = 0.8), whereas hill sites had a mean moisture content of 1.9% (SD = 0.8). The largest range in moisture content values was experienced on the catena sites from 0.9 to 4.9%, whereas for the valley the range was from 1.2 to 3.8%. Transect A had a mean moisture content of 1.6% (SD = 0.4), with a range of 0.9 to 2.4. Transect B had a mean moisture content of 2.4% (SD = 1.4), with a range of 1.3 to 4.9% and transect C had a mean moisture content of 1.7% (SD = 0.2), with a range of 1.5 to 1.9%. The southern facing slopes of transects B and C had a mean moisture content of 1.6%, whereas northern facing slopes had a mean moisture content of 1.3%.

Mean saturation percentage for the study area was 20.9 (SD = 5.4). On the hill the mean was 20.1% (SD = 7.8), while in the valley it was 20.3 (SD = 7.8). Transects A, B and C had mean values of 22.8 (SD = 5.3), 22.4 (SD = 1.3) and 16.1% (SD = 3.8) respectively. These mean values are very similar to the value calculated by Keay and Bettenay (1969), of 20%.

The mean value for field capacity throughout the study area was 15.5% (SD = 4.3), with a range of 9.0 to 28.9%. The mean value for the catena was 16.2% (SD = 3.4), with a range of 11.6 to 28.9%, while in the valley the mean value was 15.2% (SD = 3.8), with a range of 9.0 to 22.1%. Transects A, B and C had mean field capacity values of 16.1 (SD = 4.3), 13.9 (SD = 1.8), and 12.8% (SD = 1.7), respectively.

The mean level for total soluble salts in the study area was 1100 ppm (SD = 1250), with a range of 170 to 4170 ppm. On the hill sites the mean value was 1320 ppm (SD = 110), with a range of 170 to 4170 ppm. Valley sites had a mean of 760 ppm (SD = 390), with a range of 540 to 1580 ppm. For transects A, B and C the mean values for T.S.S. were 860 (SD = 530), 2120 (SD = 310), and 2580 ppm (SD = 1730), respectively.

Organic Matter

The mean organic matter content for the study area was 6.6% (SD = 2.1), with a range from 3.1 to 12.8%. For hill sites the mean organic matter content was 7.4% (SD = 2.2), with a range from 4.4 to 12.8% and for the valley the mean was 5.5% (SD = 1.4), with a range from 3.1 to 8.2%. In transects A, B and C the mean values were 7.9 (SD = 2.4), 6.4 (SD = 0.5) and 6.3% (SD = 0.9) respectively.

Nitrogen

Nitrogen levels were considerably higher than those obtained by Boyland (1973), who suggested a mean nitrogen level of 400 ppm in mulga soils. In the study area the mean nitrogen level was 776 ppm (SD = 421). On the catena sites the mean value for nitrogen was 932 ppm (SD = 409), with a range of 580 to 1759 ppm, while in the valley the mean nitrogen value was 546 ppm (SD = 333), with a range of 122 ppm to 1309 ppm. The mean nitrogen values for transects A, B and C were 998 (SD = 479), 860 (SD = 79) and 713 ppm (SD = 117) respectively.

Phosphorus

Phosphorus levels were low. P is probably the main nutrient limiting factor in these mulga soils (Christie 1970).

The mean level of phosphorus for the study area was 18.7 ppm (SD = 15.4), with a range from 0.2 to 43.5 ppm. On hill sites the mean value was 24.8 ppm (SD = 12.3), with a range from 1.7 to 41.3 ppm, and in the valley the mean was 9.8 (SD = 15.8), with a range from 0.2 to 43.5 ppm. In transects A, B and C the mean values for phosphorus were 23.4 (SD = 14.2), 34.1 (SD = 4.3) and 19.0 ppm (SD = 0.8) respectively. These values are extremely low when compared to the mean values obtained by Wild (1958) and Keay and Bettenay (1969) for mulga community soils, of 200 ppm phosphorus.

Exchangeable Cations

Magnesium was the dominant exchangeable cation in the study area, although in some sites calcium was dominant. Calcium was the second most dominant cation, followed by potassium and then sodium. On the hill sites magnesium was the dominant exchangeable cation, whereas in the valley the dominant exchangeable cation was calcium.

Magnesium had a mean value of 12 140 ppm (SD = 13 140), with a range of 1520 to 52 800 ppm in the study area. On hill sites the mean value was 14 420 ppm (SD = 13 040), with a range of 1520 to 52 800 ppm. In the valley the mean was 8790 ppm (SD = 13 000) with a range of 1550 to 47 900 ppm. In transects A, B and C the mean values for magnesium were 14 285 (SD = 15 060), 16 550 (SD = 8530) and 9140 ppm (SD = 4240) respectively.

The mean value for calcium was 8390 ppm (SD = 3450), with a range from 2620 to 18 140 ppm. For hill sites the mean value was 7870 ppm (SD = 3140), with a range from 2620 to 16 140 ppm, while in the valley the mean value was 9150 (SD = 3860), with a range of 4350 to 18 140 ppm. Transects A, B and C had mean calcium levels of 8540 (SD = 3570), 6950 (SD = 1370) and 6260 ppm (SD = 1260) respectively.

Potassium levels varied considerably between the study sites with a mean level of 4370 ppm (SD = 2580) and a range from 1020 to 10 200 ppm. On the hill potassium mean value was 5690 ppm (SD = 2500), with a range from 1020 to 10 200 ppm, whereas in the valley the mean value for potassium was 2450 ppm (SD = 1000), with a range from 1300 to 4140 ppm. Transects A, B and C had mean potassium levels of 6130 (SD = 2300), 6420 (SD = 1700) and 5000 ppm (SD = 300) respectively.

The mean level of sodium throughout the study area was 403 ppm (SD = 258), with a range from 102 to 1225 ppm. For the hill sites the mean sodium level was 460 ppm (SD = 310), with a range from 102 to 1225 ppm, while in the valley the mean was 320 ppm (SD = 124), with a range of 170 to 604 ppm. Transects A, B and C had mean sodium levels of 549 (SD = 339), 306 (SD = 73) and 327 (SD = 199) respectively.

Discussion

Both species and numbers of perennial woody shrubs increased down the hill. The decrease in altitude coincided with decreased slope. In total the hill sites carried an average of 3 species in contrast with valley sites with four. There was also an increased number of individual plants recorded in valley sites. **Acacia aneura** on the hill sites tended to be more shrubby in habit, in that many plants had more than one measured stem at 1.3 m.

There was a general tendency for **Acacia bivenosa** to dominate the more neutral to alkaline soils on the hill sites. Lack of mulga on southern slopes is not believed to be a general feature of the Hamersley Plateau region and is probably associated with the edaphic differences enumerated herein. Note that moisture was marginally higher for south facing slopes, an anticipated result (Hadley 1962; Troy 1979).

Spearman's rank correlation analysis was applied to the data sets obtained for the 32 sites. The following discussion draws on this analysis to emphasise correlated factors. The 10 percent probability level (p 0.10) is included in this discussion to emphasise the relative strengths of the correlations.

Acacia aneura Height

Mean mulga height for all sites was most strongly correlated with low soil pH (p 0.05) and also, less strongly, (p 0.10) with low levels of sodium and saturation percentage. On the hill sites both pH and saturation percentage followed the same trend, at p 0.05, and a low level of magnesium was also correlated with mean mulga height (p 0.05). Within the 3 individual transects the strongest correlations with mulga height were with low magnesium (p 0.05, transect A), low sodium (p 0.10, transects A,B), and low calcium and phosphorus (p 0.10, transect C). Valley sites separately showed the reverse to hill sites in respect of magnesium (p 0.05) and the only other variable nearly reaching significance with mulga height was soil moisture content (p 0.10).

Soil Depth

Deeper soils tended to have more calcium (p 0.01), sodium (p 0.05) and lower total soluble salts (p 0.05). Similar trends were evident for hill sites taken separately, with calcium and soil depth correlation being stronger (p 0.001) but sodium and low T.S.S. were less strongly correlated at p 0.05, as also was magnesium. There were no significant correlations between soil depth and any other soil characteristic for the valley sites considered separately. In transect B nitrogen was negatively correlated with soil depth at p 0.05.

Soil pH and Total Soluble Salts

The laboratory calculated pH values were strongly correlated with magnesium and potassium (p 0.001), and less strongly with sodium (p 0.10). Low pH was associated with taller mulga, and on the hill with organic matter (p 0.01). In transect A higher pH was also correlated with moisture content (p 0.05).

Throughout shallower soils tended to have higher levels of total soluble salts (p 0.05), but this was largely due to hill sites, especially transect A. In valley sites total soluble salts was most strongly correlated with nitrogen level (p 0.10).

Soil Moisture, Field Capacity and Saturation Percentage

In transect A a higher soil moisture level was associated with higher pH and nitrogen levels (p 0.05). In transect C there was a weak correlation between soil moisture and low total soluble salts (p 0.10).

For all sites field capacity was correlated only with saturation percentage. On hill sites there was a weak correlation with sodium and in transect A with low levels of potassium (p 0.10).

Saturation percentage was strongly correlated with field capacity (p 0.001), both sodium and magnesium (p 0.05), and less strongly with mulga height (p 0.10). The valley sites showed the field capacity/saturation percentage correlation more strongly (p 0.001) than hill sites (p 0.05).

Organic Matter, Nitrogen and Phosphorus

Overall there was significant correlation between organic matter and nitrogen, especially in valley sites (p 0.01) and transect B (p 0.10). On hill sites organic matter was strongly correlated with low pH levels (p 0.01), especially so for transect A. There was a negative correlation between calcium and organic matter in valley sites and also in transect C.

In addition to organic matter, nitrogen was also correlated with phosphorus (p 0.05) (particularly on hill sites), potassium (p 0.05) and in valley sites there was a slight correlation with total soluble salts (p 0.10). In transect A nitrogen was correlated with high soil moisture content.

Phosphorus had a less significant correlation with low levels of calcium (p 0.10) than with high nitrogen content. On the hill sites, in addition to nitrogen, phosphorus was correlated with low sodium (p 0.10). In valley sites phosphorus was correlated with magnesium (p 0.05).

Nitrogen levels were higher and phosphorus levels lower than other recorded values (Wild 1958; Keay and Bettenay 1969). The correlations suggest that nitrogen and phosphorus are related and influenced by organic matter levels. Similar correlations between nitrogen and phosphorus for mulga soils are reported in Jackson (1962).

Exchangeable Cations

Magnesium was significantly correlated with high pH (p 0.001) and also potassium (p 0.001) and to a lesser extent with saturation percentage (p 0.05). On the hill sites magnesium was negatively correlated with mulga height (p 0.05) whereas the correlation was positive, also at p 0.05, for valley sites. Magnesium showed a weak correlation with calcium on the hill (p 0.10), and a rather stronger correlation with phosphorus in valley sites (p 0.05), where it was also higher with higher soil moisture level (p 0.10).

Throughout calcium was correlated positively with sodium and soil depth (p 0.01), and less strongly with low phosphorus content (p 0.10). For hill sites the correlation of calcium with soil depth was highly significant (p 0.001), less so with sodium (p 0.01), saturation percentage (p 0.05) and magnesium (p 0.10). In valley sites there was a positive association between calcium and sodium (p 0.05) whereas calcium was associated with low organic matter (p 0.05) and low pH (p 0.10).

Potassium was significantly correlated with pH, magnesium (both 0.001), nitrogen and sodium (both p 0.05). The correlations were stronger with magnesium on hill sites and with sodium (p 0.01) in valley sites. In transect A there was a weak correlation of potassium with low field capacity (p 0.10).

Throughout sodium levels were correlated most strongly with calcium (p 0.01) and then saturation percentage, soil depth, low height of mulga, pH and potassium (all p 0.05). The strongest correlation on the hill sites was with calcium (p 0.01) and in the valley with potassium (p 0.01).

Cation levels varied considerably between sites. Such variation is largely due to clay content (Dawson & Ahern 1973). Magnesium was the dominant exchangeable cation, with calcium the next. Calcium was particularly important on top of the hill and in some valley sites, whereas magnesium was particularly abundant on some of the higher pH soils particularly on the hill slopes.

In these locations the magnesium levels are most influential on species representation, and contribute to the high pH levels found. The exchangeable cations are also related to the amount of phosphorus present, which is probably the overriding nutrient limitation to plant development.

Conclusions

This study provides an exhaustive account of perennial species dimensions and edaphic properties of two sets of sites, one down a steep hillside, the other representing a number of valley locations. In both areas **Acacia aneura** occurs as the main dominant. Hill slope sites provide a harsher environment for plant growth in that the surfaces tend to be stonier, soil moisture content is lower and the depth of soil is variable. However valley sites tended to have lower proportions of the main plant nutrients nitrogen, phosphorus and potassium. This may be a reflection of higher standing woody biomass in valley sites where there were twice as many **Acacia aneura** trees, with taller maximum heights than on the hill sites. Mean values for height, crown size and stem diameter were similar, suggesting that the hill slopes, though harsher, still allow mulga to reach reasonable dimensions. The main influence on development of woody perennial biomass is likely to be moisture availability.

Acacia aneura is more abundant on soils with an acidic reaction trend. Our pH and soil nutrient analyses imply that soil chemical composition (based on the underlying rocks) appears to have some effect on species distributions among the sites examined. Elsewhere in the region sharp boundaries between species distribution have been observed to be correlated with soil boundaries. Soil chemical composition may also influence the density and size of perennial species even though, in a general floristic sense, the species may belong to the same or similar associations. The presence of patches high in magnesium on the hillside suggest soil development over underlying dolomitic parent material. These soils tend to be characterised by the presence of mallee **Eucalyptus** (but not **Eucalyptus** gamophylla a common species of lower sites, with acidic soils), **Acacia bivenosa** and Triodia **wiseana**. The latter, common on high ground or steep slopes, appears lower down the hillside on the basic soils.

It must be emphasised that sites examined were not selected on floristic grounds, or to specifically discriminate between apparently discrete associations. There are denser valley stands of **Acacia aneura**, in the general area, than those included. If the hill sites had been confined to pre-determined species sets, then it is likely that higher correlations of magnesium-rich material would have been attained with the presence of loamy textured soil and virtual exclusion of **Acacia aneura**. The study suggests that it would be instructive to contrast germination and seedling development on a range of differing pH media for **A. aneura** and **A.** bivenosa.

Elsewhere in the Hamersley Plateau we have noted a tendency for compact stands of **A. aneura** to persist on south-facing slopes in areas which have been subject to Triodia based fires. We assume this to be associated with the possible higher soil moisture to be anticipated on south-facing slopes. This requires further examination.

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APPENDIX

Description of Sites Examined

Hill Sites

Transect A Site 1. This site was close to the summit of the hill and the only woody perennial species was Acacia **aneura**, with two forms. One was of the terete, narrow phyllode type and the other of a broader phyllode type. The ground cover was a mixture of **Triodia pungens** and T. wiseana. The measured attributes of the plants in this plot are not very reliable because many of the larger trees and shrubs had been removed for surveying purposes.

Site 2. This study site was located on a seepage slope and contained two species of woody plants totalling thirty nine individuals. The dominant species was **A. aneura**. All measured characteristics of this species were larger than at site 1 with the exception of crown area, which was slightly smaller. The ground cover was a mixture of **T. pungens** and **T. wiseana**.

Site 3. This site was located on a fall face and only held one woody perennial species with twelve individuals. This was **A. aneura**. All the measurements taken (except relative density and stem area) were lower than at site 2. T. wiseana was the main ground cover species.

Site 4. This study site was located on a midslope and carried four species of woody plants totalling twelve individuals. The dominant species was **A. pyrifolia** (Relative Density of 49). The **A. aneura** plants in the study site were of low dominance and had considerably smaller sizes compared to sites 2 and 3. The ground cover was mainly **T. wiseana**.

Site 5. This site was located at the base of a transportational midslope and contained three individuals named as **Eucalyptus oleosa**. The pH here was high. The ground cover was **Triodia** wiseana.

Site 6. This site fell on a seepage slope and contained three species of plant totalling sixteen individuals. The dominant species was A. aneura. All measured characteristics were higher than those in site 4 but lower than at site 3. However, maximum height was higher than sites of higher altitude. The ground cover was T. wiseana and T. pungens.

Site 7. This was located at the base of a fall face and carried three species of plant totalling fifteen individuals. The dominant species was A. aneura. The measurements taken suggest that structurally this site was very similar to site 6, with the exception of maximum height which was slightly lower. The crown cover was greater than in higher sites. The ground cover species was **T. pungens**.

Site 8. This site occurred on a colluvial footslope and held two species of plant totalling seven individuals. The dominant species was A. aneura with measurements similar to those of site 7 with the exceptions of maximum height and crown area, both smaller. T. pungens was the only ground cover species.

Site 9. This study site was on a colluvial footslope and contained three species of woody perennial totalling fourteen individuals. A. **aneura** was the dominant species with measured attributes being slightly greater than those in site 8 with the exception of crown area which gave the highest value down to this altitude. The ground cover was T. **wiseana** and T. **pungens**.

Site 10. This site was located on a transportational midslope and held three species of plant totalling ten individuals. **A. aneura** was again the dominant species with all measured characteristics being lower than those in site 9. The ground cover species was T. **pungens**.

Site 11. This site was at the base of a transportational midslope and contained six species totalling eleven individuals. The dominant species was **A. aneura** with measurements similar to those for site 8. The dominant ground cover species was T. **pungens**.

Site 12. This was located on a colluvial footslope and held five species of perennial woody plants, totalling nine individuals. The pH here was relatively high, with the dominant species being **A. bivenosa** (RD = 45). **A. aneura** was not present in this site. **T. wiseana** was the dominant ground cover species.

Site 13. This site was also on a colluvial footslope and contained four species totalling eight individuals. The dominant species was again **A. bivenosa** (RD = 63). **A. aneura** was also not present in this site. **T. wiseana** was the dominant ground cover species again.

Altogether transect A included representatives of eleven different species of woody plants. The dominant ground cover species were T. pungens and T. **wiseana**. Through the transect **A. aneura** was the dominant species followed by E. **oleosa** and **A. bivenosa** on more alkaline soils. Measured characteristics for **A. aneura** remained reasonably constant. Maximum height values were similar to mean height values. The tallest plants were located in site 9 but maximum height was recorded in site 6. The measurements for crown size and stem diameter were also reasonably constant throughout with the maxima occurring in sites 2 and 9. Crown and stem areas were greatest in sites 9 and 3 respectively.

Transect B Site 14. This was on a fall face and contained four species of tree or shrub, totalling six individuals. **A. aneura** was the dominant species, present in both forms seen in site 1. The measured attributes of the plants were extremely high in comparison to all sites of higher elevation. This site had large crowns and stem diameters. The dominant ground cover species was T. **wiseana**.

Site 15. This study site was located on a transportational midslope and held three species of plants totalling thirteen individuals. A. **aneura** was found in both forms and was the dominant species. The measurements of **A. aneura** were similar to those in sites 1 and 10. The dominant ground cover species was T. **pungens**.

Principal Components Analysis - Centred and Standardised ordinations expressed variation in the data more accurately than any other ordination technique (Table 8). Principal Components Analysis - Centred ordinations were the next most efficient, followed by Reciprocal Averaging, Principal Components Analysis - Non-Centred and finally Polar Ordination. It appears that the higher axes ordinations (i.e. Axes 1/2) provided more efficient ordinations than lower axes (Table 8).

Using the most efficient ordination (Principal Components Analysis - Centred and Standardised, Axis 1 with Axis 2 ordination) four species associations can be identified from the ordination (Figure 3). The general description of vegetation types of Yalgorup National Park (Table 1), has been included in Table 9 to provide a measure of the ordinations' ability to demonstrate differences.

The typical plot characteristics were determined for each species using SPSS.

The physical and species characteristics of the association can be determined by grouping plot characteristics of species in each association. Analysis of the association characteristics (Table 10) indicated the following:

(i) percentage of organic matter differed between associations.

(ii) minimum and maximum distance from the ocean varied between associations.

(iii) association 4 had a significantly lower percentage of species growing in soils containing limestone ($P < 0.05$).

(iv) tree and shrub species growing in association 4 were significantly taller ($P < 0.05$).

(v) **Xanthorrhoea preissii** and **Eucalyptus gomphocephala** are two well distributed species in Yalgorup National Park.

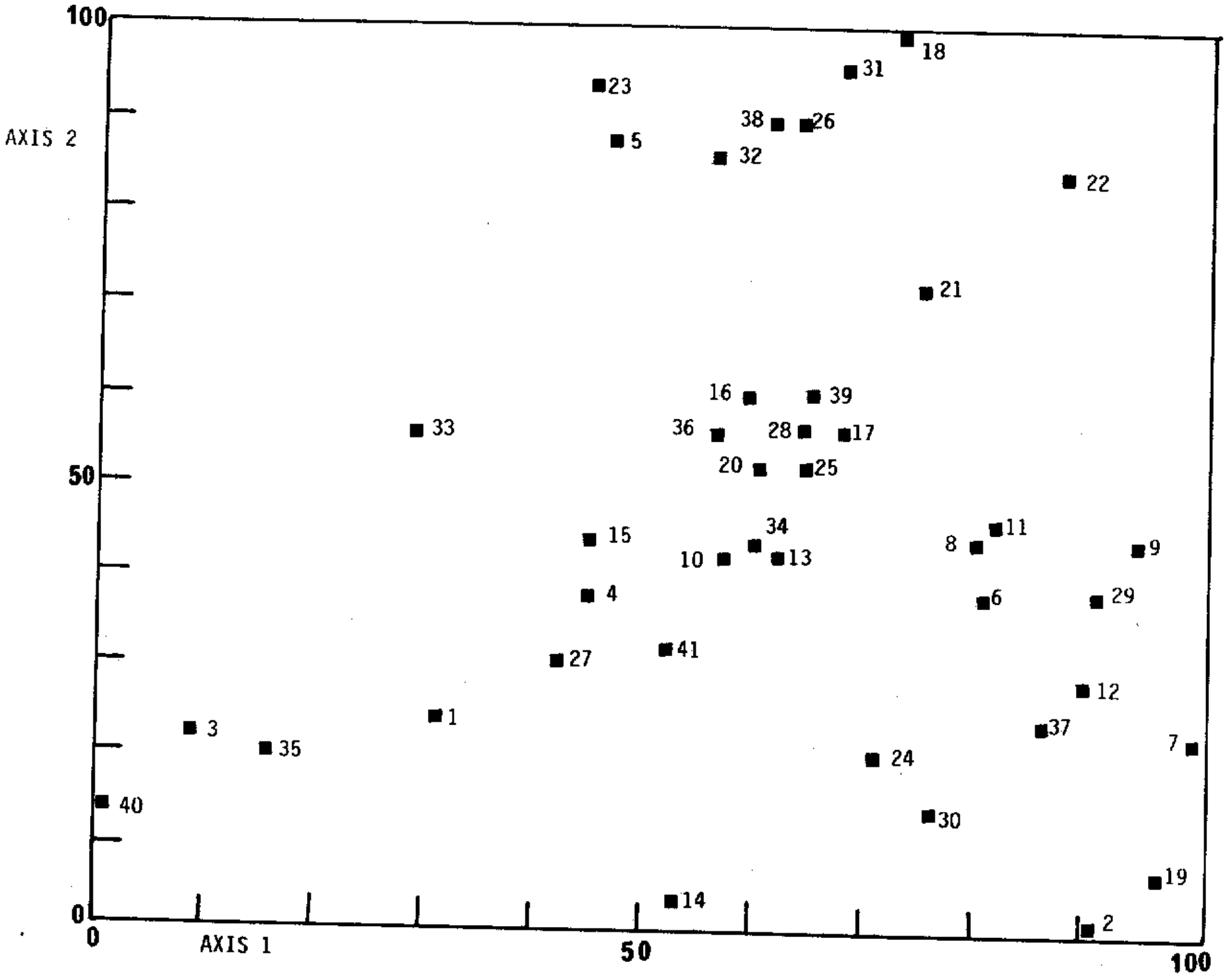

FIGURE 2. PCA (centred and standardised). Axis 1 with Axis 2.

TABLE 7. Chi-Square significance values for cross tabulations between selected tree and shrub species.

Species No.*	1	3	13	19	21	23	26	35	40	41
1	0	0	1.0	1.0	1.0	1.0	1.0	0	0	0.072
3	0	0	1.0	1.0	1.0	1.0	1.0	0	0	0.195
13	1.0	1.0	0	0.284	0.009	1.0	1.0	0	1.0	0.512
19	1.0	1.0	0.284	0	0.527	1.0	1.0	1.0	1.0	1.0
21	1.0	1.0	0.009	0.527	0	0	1.0	1.0	1.0	0.102
23	1.0	1.0	1.0	1.0	0	0	0.199	0.865	0.001	0.012
26	1.0	1.0	1.0	1.0	1.0	0.199	0	1.0	1.0	1.0
35	0	0	0	1.0	1.0	0.865	1.0	0	0	0.328
40	0	0	1.0	1.0	1.0	0.001	1.0	0	0	0
41	0.072	0.195	0.512	1.0	0.102	0.012	1.0	0.328	0	0

* Species numbers as in Tables 2 and 6.

TABLE 8. Ranking of ordination techniques according to efficiency.

Ordination Technique	Axis	Similarity Between Species ($P < 0.05$)*	No Similarity Between Species ($P = 1.0$)*	Overall Rank
Polar	1/2	41	107	11
PCA (Non-centred)	1/2	84	63	10
	1/3	89	64	13
	2/3	82	43	6
PCA (Centred)	1/2	76	39	2.5
	1/3	83	56	8
	2/3	76	66	9
PCA (Centred and Standardised)	1/2	71	31	1
	1/3	56	64	4
	2/3	53	62	2.5
Reciprocal Averaging	1/2	23	101	5
	1/3	51	85	7
	2/3	32	117	12

* Ranking measure.

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A PRELIMINARY ASSESSMENT OF MINESITE REHABILITATION IN THE PILBARA IRON ORE PROVINCE USING ANT COMMUNITIES AS ECOLOGICAL INDICATORS

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Introduction

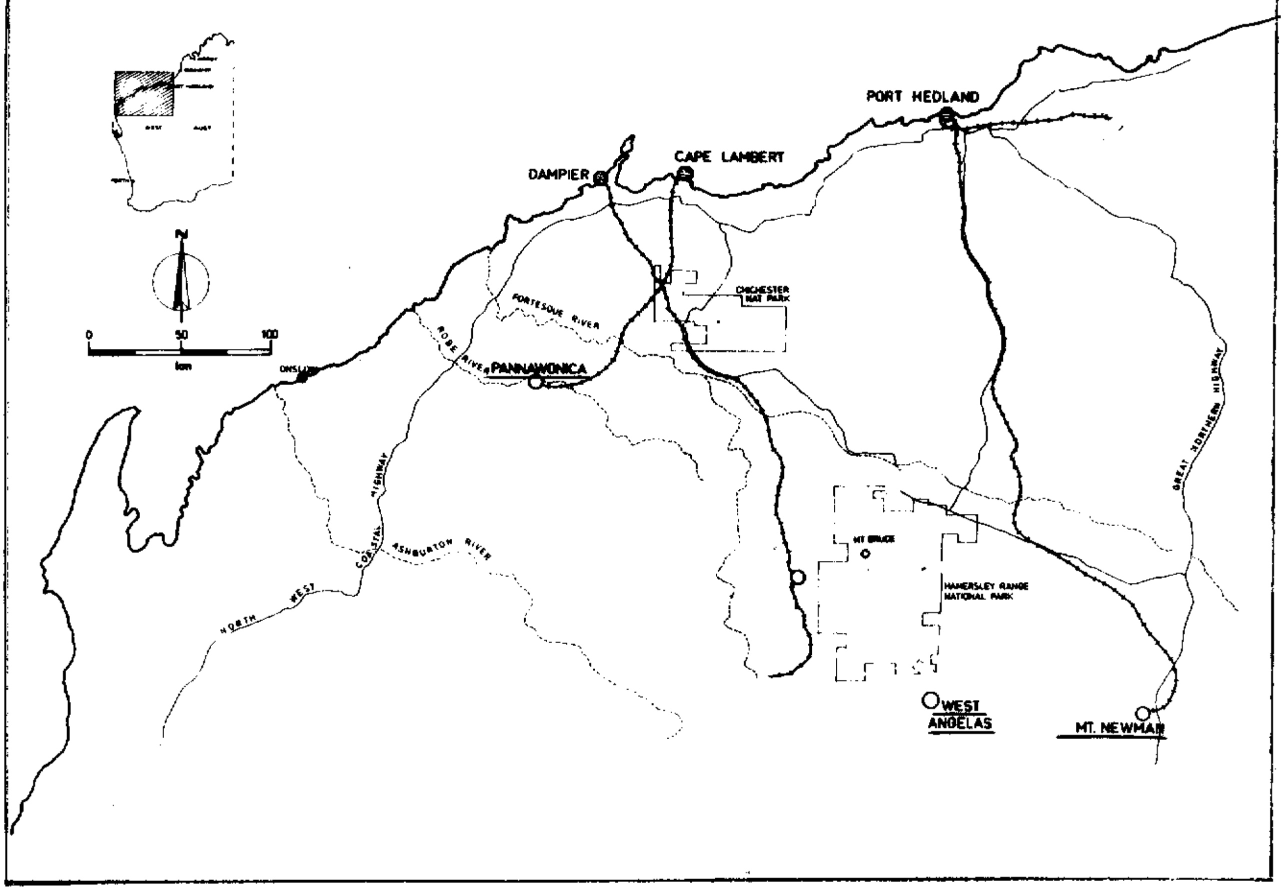
None of the existing iron ore mining operations in the Pilbara district of Western Australia have in their Agreement Acts any provision requiring ecosystem recovery on affected areas. Some companies, in particular Mt Newman Mining since 1975, Cliffs Robe River since 1981 and recently Hamersley Iron Pty Ltd, have attempted rehabilitation on a limited scale. These efforts are likely to increase in the future as more mined-out areas and completed waste dumps become available. An assessment of ecosystem recovery on the treated sites is now of some importance, because provision for ecologically defined rehabilitation will almost certainly be contained in subsequent agreements for currently proposed mines in the region. Studies of these early experiments in rehabilitation should provide essential information on the potential for ecosystem development on mined lands in the region and on the efficacy of various rehabilitation techniques. They should also lead to the development of environmental assessment criteria based on the monitoring of ecological indicators.

To this end a preliminary investigation was carried out in January 1984 at Pannawonica on the Robe River Mesas and at Mt Whaleback, Newman (Figure 1). The study involved sampling treated (rehabilitating) and untreated mined mesa tops and an overburden dump at the Robe River, and a treated waste dump at Mt Whaleback.

Methods

Ants were sampled by pitfall trapping at each study site using 20 (42 mm internal diameter) plastic jars set out at 5-m intervals along a 100 m transect. Each jar contained about 30 ml of alcohol/glycerol (70/30v/v) preservative. Traps were set for 48 hours at each site with all Pannawonica sites sampled simultaneously.

FIGURE 1. A map showing study and mine sites in the Pilbara Iron Ore Province.



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At Pannawonica each study site was searched for one half hour in daylight during the cooler parts of the day and again for the same period in darkness. During the search all ant species detected were collected and notes made on the species behaviour and microhabitats. No hand collecting was undertaken at Mt Whaleback.

Ants from pitfall traps were sorted by species and counted, and a species list for each site compiled. Hand collections were examined and any species not recorded in the traps were added to the species lists for the sites.

Description of Study Sites

Robe River Mesas

At the Robe River, pisolitic iron ore was stripped from the tops of mesas, leaving at the termination of mining, a compacted pavement of underlying bedrock. On the edge of the mined mesas there is normally a wall of rock rubble or unmined residual faces. The slopes of the mesas are covered with blasted rubble to at least 1/3 of their height. Five study sites were established on two closely adjacent mined mesas. These are described below. Vegetation description follows the life-form density classes of Muir (1977).

Site 1An: Mining ceased at this 10 ha site 12 years prior to the study and no rehabilitation treatments had been attempted. The sampling transect was over bare ground, mostly compacted, although with some pockets scattered with fine scree. There was no vegetation on the site, the nearest appearing on the edge of an overburden dump (Site 1Ao) about 40 m away.

Site 1At: This site of about 2 ha was mined until 12 years before the study. It was treated in 1979 by ripping at 10 m x 10 m intervals to a depth of 0.5 m. Then in November 1982 the rip lines were sown with local legumes, principally **Petalostyles labicheoides**. Vegetation cover was confined to rip-lines and consisted of **Acacia pachyacra** and **Petalostyles labicheoides** shrubs to 1.5 m, but contributing less than 5% cover over the site. Also established in the rip lines were **Ptilotus** spp. and clumps of the bunch grass **Cymbopogon ambiguus**. Along the rip lines were the only pockets of friable soil and stoney mullock. Deposits of leaf litter occurred under the shrubs. Between the rip lines the surface was bare and compacted.

Site 1Ao: This was an overburden dump covering about 3 ha on which the last layers of blasted and scraped material would have been deposited more than 12 years ago. The dump was not treated in any way, but vegetation has become established apparently due to the friable substrate, stoney mullock surface and the presence of stored seed in the overburden. The shrub stratum resembles that of adjacent unmined mesa tops (Site 1Au) consisting of sparse to mid-dense low scrub A (Muir 1977) of **Acacia pachyacra** and **Petalostyles** sp. The sub-stratum, unlike unmined mesa tops, consisted of open short bunch grassland of **Cymbopogon ambiguus** and **Themeda australis** and some short-lived herb species including **Ptilotus** spp. and **Corchorus walcottii**. There was little regeneration of **Triodia**. Vegetation cover was patchy by comparison with unmined mesa top vegetation.

Site 2At: This was an entire mesa top of about 20 ha on which mining ceased 10 years prior to the study. Almost the entire area was ripped to a depth of 0.5 m and at 1.0 m intervals in November 1981 and was immediately sown with seed collected using a vacuum cleaner from adjacent unmined mesa top vegetation. The area sampled was vegetated with sparse herbs, **Ptilotus** spp., **Cleome viscosa**, **Corchorus walcottii** and sparse grasses principally, **Themeda australis** and **Cymbopogon ambiguus**. There were occasional shrubs from 1.0 m to 1.5 m of **Acacia pachyacra**, **Grevillea wickhamii** and **Acacia** aff. **"clementii"**. Most of the ground surface was friable due to ripping and was scattered with stoney mullock.

Site 1Au: This was an unmined area of mesa top of about 15 ha. The area sampled was about 120 m from a mine face. Mining ceased on the mesa 12 years before the study. The area was vegetated with **Acacia pachyacra** dwarf scrub C (Muir 1977) over **Triodia wiseana** hummock grassland and mid-dense hummock grassland. The substrate consisted of weathered bedrock with some surface scree. Leaf litter deposits occurred under the shrubs and there was some sparse deadwood. There was no evidence of recent fire.

Mt Whaleback Waste Dump

Sampling at Mt Whaleback was undertaken on waste dump W06A, an area of 4.4 ha. This site is illustrated in Figure 2. W06 has 3 sections (A, B, C) totalling 7.3 ha, it is the most intensively managed rehabilitation site on the Pilbara iron ore mines. It was treated in November 1978, 5 years before the present study.

The surface of the dump was ripped to a depth of 1.0 m and at 1.0 m spacing. Over the area sampled fresh topsoil had been spread and seed of local legumes and chenopods broadcast. The site was then irrigated for six weeks with the amount of watering diminishing progressively until it was terminated.

FIGURE 2. Area W06-A used to trap ant species.

The sampling transect passed through patchy vegetation. Most of the line was in **Acacia** bivenosa scrub over mid-dense **Triodia wiseana** hummock grassland, but some jars were in open grassy areas or patches of chenopod open low scrub. The substrate throughout was friable and strongly hummocked by the ripping process. Many large stones were scattered across the surface. Deposits of leaf litter were associated with A. bivenosa shrubs and the larger Triodia hummocks. The areas which have now been colonised with hummock grassland resemble unmined hilltops although the shrub cover tends to be of higher density.

Results and Discussion

Species Richness

Table 1 shows the ants collected at five of the sampling sites in January 1984. No ants were collected from the fallow, mined mesa top (site 1An). Thirty species were collected during the survey from the control site, overburden dump, two treated mine surfaces and the treated waste dump.

Species richness was highest on the undisturbed control and the 5-year treated waste dump at Mt Whaleback, both with 16 species. After 12 years the overburden dump on mesa 1A had accumulated 15 species.

The recently treated mine surfaces, sites 1At and 2At, had lower numbers of species. Although of similar age since seeding, site 1At was richer than 2At. This may be attributable to the larger size and greater concentration of shrubs here. These perennials would provide a more stable environment by supplying a continuous source of honeydew and leaf litter. Site 2At was dominated by short-lived or ephemeral dwarf shrubs, herbs and grasses.

Dominance Index

The apportionment of individuals (from pitfall trap captures) amongst the various species at each site was measured using the dominance index:

$$C = \sum \left(\frac{n_i}{N}\right)^2$$

where:

n_i is the number of individuals of the i species captured at each site, and

N is the total number of ants captured at the site.

Values range between 1 and 0, where higher figures indicate a concentration of one or a few dominant species thus giving a low evenness. Whilst ant communities in stable environments are usually dominated by an **Iridomyrmex** sp., these communities often show greater evenness than communities in disturbed systems. Thus the dominance index can be used as an indicator of stability. Community evenness varies however with season, so comparisons should only be made between sites sampled at the same time.

The control site (1Au) in undisturbed vegetation had the most even ant community, whilst the 12 years overburden regeneration (1Ao) and the 5-year waste dump rehabilitation (W06) showed similar values. Community evenness was low on the 2 year treated minesites (1At and 2At) which were strongly dominated by one species of **Iridomyrmex** able to utilise honeydew.

TABLE 1. Ants collected on Pilbara Mine environments in January 1984.

+ indicates species collected only by hand.

Ant Species	Robe River Sites				Mt Whaleback
	1Au	1Ao	1At	2At	W06
PONERINAE					
Rhytidoponera sp. JDM 248	20				
Rhytidoponera sp. JDM 65	8				
MYRMICINAE					
Chelaner sp. nov.		88		53	
Monomorium sp. 2 (ANIC)	3	29	6		44
Monomorium sp. JDM 274	1				
Monomorium sp. JDM 276		833	32	86	
Pheidole sp. JDM 306		8	20		
Tetramorium sp. JDM 142					3
Tetramorium sp. JDM 305		1	5		
DOLICHODERINAE					
Iridomyrmex purpureus	19				
Iridomyrmex sp. JDM 9		2			211
Iridomyrmex sp. JDM 327	73	32	8	10	16
Iridomyrmex sp. JDM 463		65			
Iridomyrmex sp. JDM 464	202	84	326	361	43
Iridomyrmex sp. JDM 466	5				
Iridomyrmex sp. JDM 467					5
Iridomyrmex sp. JDM 595	11	267	15		
Iridomyrmex sp. JDM 596		3	74	1	2
Iridomyrmex sp. nov.	66				
FORMICINAE					
Prolasius sp. JDM 471					1
Prolasius sp. nov.					2
Camponotus sp. JDM 184	4	+	3		1
Camponotus sp. nov.	8				24
Melophorus sp. 1 (ANIC)	4	52	2	4	12
Melophorus sp. JDM 24		22	7	8	14
Melophorus sp. JDM 221					1
Melophorus sp. JDM 304	43	9			
Melophorus sp. JDM 472	34				5
Melophorus sp. JDM 474	37				
Melophorus sp. nov.					1
Total pitfall catch	538	1495	498	523	385
Total species richness	16	15	11	7	16
Dominance Index	0.194	0.353	0.474	0.515	0.334

ANIC - Australian National Insect Collection species number.

JDM - Western Australian Institute of Technology species number.

sp. nov. - Not in W.A.I.T. state collection.

Community Structure

In Figure 3 the community species richness and evenness values for each study site are plotted on parallel scales. Values for four additional control sites from hill top, hummock grassland control sites from West Angelas are also plotted for comparison.

The values for species richness and dominance index obtained for the Pannawonica control site, both fall within the ranges recorded from West Angelas. Natural summer undisturbed hummock grassland values for ant richness fall between 10 and 18 species, although four of the five values lie between 16 and 18 species. Dominance index values for control sites were between 0.25 and 0.19. These values would indicate complete ecosystem recovery at a rehabilitation site following summer sampling, provided the species compositions are similar.

None of the mine sites studied has achieved complete recovery, although site W06 after 5 years and the overburden dump site (1Ao) after 12 years appear to be approaching recovery. However, an analysis of the types of ants which have colonised the overburden dump site indicates that a normal ant community structure has not developed.

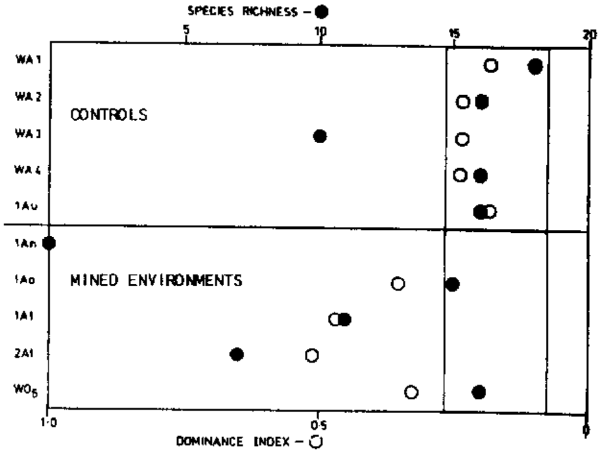

FIGURE 3. Species richness (●) and dominance index (○) values for five undisturbed hummock grassland sites and five hilltop iron ore minesite environments in the Pilbara.

Figure 4 shows the proportion of individuals captured in pitfall traps at each site in each of seven ecological groups defined by Greenslade and Thompson (1981). These are described below:

ANT ECOLOGICAL GROUPS

Group	Taxonomy and Ecology
1.	Dominant **Iridomyrmex** active on ground. Over the greater part of Australia, competing colonies of dominant Iridomyrmex set up a mosaic pattern with which the rest of the ant community conforms.
2.	Subordinate camponotine formicinae Members of the genera **Camponotus**, Polyrhachis, Calomyrmex and **Opisthopsis** commonly co-exist with **Iridomyrmex** due to differences in worker size, foraging time, evasive behaviour and mimicry.
3.	Taxa whose occurrence depends on physical properties of climate and soil type. **Melophorus** is particularly conspicuous during the hot season in the Pilbara. Tolerance of extremely high ground temperatures allows these ants to forage when **Iridomyrmex** is inactive.
4.	Cryptic soil and litter ants This group is not well represented in Pilbara hummock grasslands.
5.	Opportunists These species, best represented by **Rhytidoponera** in the Pilbara, have wide physical tolerances, generalised diets, and are ubiquitous although rarely abundant in undisturbed habitat.
6.	Generalised myrmicines Members of the genera **Crematogaster**, **Pheidole**, **Monomorium**, **Chelaner** and **Tetramorium** are mostly small ants which are ecologically generalised. Some are important harvesters of small seed.
7.	Large, solitary foragers Species which, as a result of their large size, are insulated from interaction with many other ants.

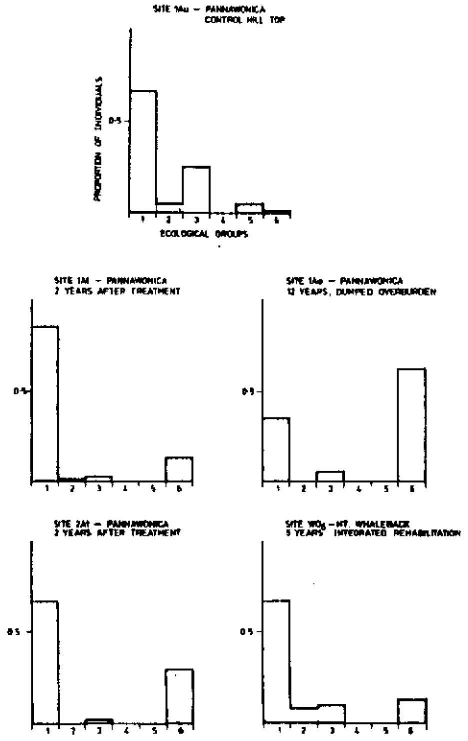

FIGURE 4. Histograms showing the abundance of ants in six ecological classes at a control site and four minesites in January 1984.

The normal summer ant community (1Au) in an undisturbed hummock-grassland was dominated by **Iridomyrmex** (class 1), but **Camponotus** (class 2), **Melophorus** (class 3) and **Rhytidoponera** (class 5) were also well represented. Generalised myrmicines (class 6) were scarce although they became more conspicuous during winter.

The generalised myrmicines were fairly abundant on all the rehabilitation sites and the **Iridomyrmex** sp. (class 1) were generally more dominant than in undisturbed vegetation. Interestingly, **Rhytidoponera** spp. which are ubiquitous in undisturbed vegetation in the Pilbara, were absent from all the mined areas.

The ant community structure of the 12-year overburden site was anomalous when compared to controls in that it was dominated by the myrmicines (class 6). Site W06 on the waste dump at Mt Whaleback most resembles a natural hummock-grassland community structure. The principal difference between site 1Ao and site W06 has been the successful establishment of Triodia hummock-grassland at Mt Whaleback. This is probably essential for the development of stable hill top habitats on mined areas.

Community Similarity

Similarity in ant species composition between the sites sampled in January 1984 was measured using Sorenson's Similarity Index:

$$I = \frac{2j}{a + b} \times 100$$

where j is the number of species common to sites a and b,

a is the number of species at site a, and

b is the number of species at site b.

The similarity values for each pair of sites are given in Table 2.

TABLE 2. Sorenson's Similarity Indices for each pair of sites sampled in January 1984.

	1Au	1Ao	1At	2At	W06
1Au	-	32.0	44.0	26.0	43.7
1Ao	-	-	84.6	54.5	51.6
1At	-	-	-	66.6	44.0
2At	-	-	-	-	43.4
W06	-	-	-	-	-

These values reflect two trends - higher similarity with proximity of sites, and the nature of the habitat. Thus control site 1Au shows highest similarity with site 1At (a rehabilitation area of the same mesa) and site W06 (a rehabilitation area in an advanced stage of recovery about 400 km away). Interestingly, similarity is low between the control site and site 1Ao which were both on the same mesa and each with 12 years regeneration. This again reflects the anomalous ecological development on this site.

Like all other rehabilitation areas, site 1Ao contained many opportunistic species, particularly myrmicines. The adjacent site, 1At, treated only 2 years prior to the study, had the highest similarity to 1Ao, no doubt having received many colonising species from it.

The remaining comparisons also showed high similarities between rehabilitation sites due to the presence on all sites of colonising opportunists.

Ecosystem Recovery Rates

Two factors influence mine rehabilitation rates. These are the climatic characteristics (temperature and rainfall which control biological productivity), and rehabilitation effort and techniques. In some extreme mine environments such as site 1An without any rehabilitation measures, there has been no measurable ecosystem recovery after 12 years.

When appropriate rehabilitation techniques are employed the recovery rates in the first 3 years correlate with rainfall. From the work of Majer **et al.** (1982), Majer **et al.** (1984), Fox & Fox (1982), Majer (1984a & b), a species richness of less than 6 species in 3 years might be predicted in the Pilbara. However, the data from this survey plotted in Figure 5 predict a richness value twice as high after 3 years for this region. This may be related to the association of rainfall with higher temperatures and hence greater productivity, but this might be more than offset by the unreliability of the rainfall. It is possible that this semi-arid region has more ants adapted to survive in rather open habitats, similar to those on rehabilitating mines.

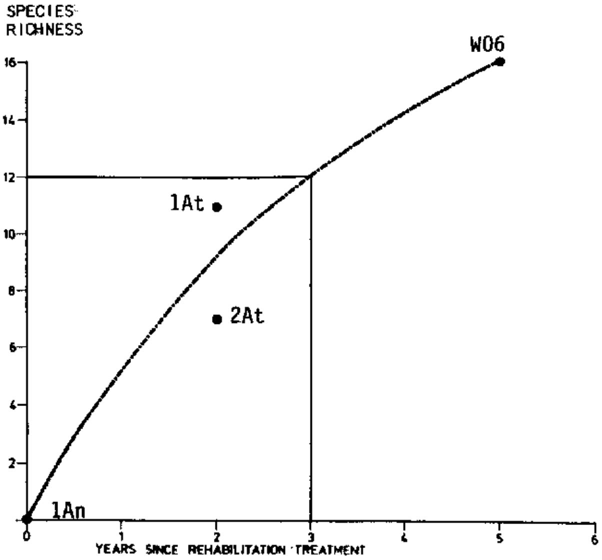

FIGURE 5. The relationship between species richness and years since rehabilitation treatment as indicated by sites sampled in January 1984.

The importance of rehabilitation technique is exemplified by the 12 year old overburden dump. Although not in itself a rehabilitation attempt, it does represent the results of not spreading topsoil. This site has seen 12 years of regeneration but has not recovered. Whether the site reached maximum species richness and then collapsed or has simply been retarded in development is unknown. The high proportion of short-lived plants in the sub-stratum and the absence of hummock grass may make this mine environment unstable. Absence of hummock grass may be a consequence of deep burial of the seed following mine stripping and the dumping of the over-burden.

By contrast, the rehabilitation on waste dump W06 at Mt Whaleback is approaching ecological recovery. It is therefore not surprising that some of the regional vertebrate ground fauna, including two species of marsupial mice (Dasyuridae) **Planigale maculatus** and **Ningaui timealeyi**, have colonised the site.

The results of the present study indicate that, using appropriate rehabilitation techniques, significant ecological recovery can take place on sterile waste dumps within 6-7 years.

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GROWTH AND NUTRIENT CONCENTRATION OF SANDALWOOD SEEDLINGS GROWN IN DIFFERENT POTTING MIXTURES

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Introduction

The Western Australian Sandalwood, **Santalum spicatum** (R.Br.) DC., is a slow-growing obligate hemi-parasite. The aromatic wood of this shrub is of commercial value and has been exported from W.A. since the mid-19th century. Reserves of sandalwood are becoming severely depleted, and attempts are therefore being made to commercially cultivate this species. The main problem in cultivation is the inability of seedlings to survive without hosts. Although some plants have been grown in pots for up to 3 years without a host, the first 6-12 months growth is poor in the absence of hosts. Following host attachment plants generally thrive, and it is believed that subsequent growth rate is determined by the capacity of the host to support the parasite. The critical phase is the 6-12 month stage, prior to and during the period of initial host contact. A very high mortality rate is observed during this period.

External nutrient supplies are needed as early as three weeks from germination. This requirement was demonstrated in a hydroponic nutrient omission study (Struthers **et al.** 1985) in which plants died within 3 weeks in the absence of calcium. Growth was depressed in the absence of other nutrients. It is generally accepted that the sandalwood requires only a part of its nutrients from hosts. A comparative study of hosts of sandalwood (**A. acuminata**) and non-parasitised trees of the same species found differences in levels of K, Ca and Cu in the host trees (Struthers **et al.** submitted 1985), indicating loss of nutrients from the acacias to the sandalwood. Increasing levels of K and Ca supply to seedlings in the absence of hosts were found to produce higher growth rates and to increase the levels of these nutrients in the seedlings. Nutrient uptake from soil is therefore clearly established.

Sandalwood seedlings have also been observed to demonstrate a response to changes in the composition of growth medium. Considering the ability of sandalwood seedlings to take up nutrients and responses to the composition of the growth medium, it was hypothesised that seedlings should respond differently to various potting mixes. An experiment was designed using five soil mixes (Table 1). The fine sand, coarse sand and peat mixture normally used to raise sandalwood seedlings acted as the control. The other soil mixes contained peat, jarrah sawdust or pine bark in various proportions to coarse and/or fine sand and different levels of fertilisers. Growth responses of seedlings in these mixes were expected to indicate a preferred medium to cater for early growth requirements of sandalwood seedlings.

TABLE 1. Composition of five potting mixes used to grow sandalwood seedlings.

Designation (abbreviation*)	Composition
Control (C)	One part peat: one part fine sand: one part coarse sand
Extra Sand (ES)	One part peat: 1.5 parts fine sand: 1.5 parts coarse sand. Plus 740mg/litre of mixture of Osmocote
Native Mix 1 (NM1)	3.1-3.2 parts jarrah sawdust: 1-1.5 parts washed cream sand (fine sand): 2.3-3 parts river sand (coarse sand). Plus the following in mg/litre: nitrogen 1.5; lime 1.67; dolomite 0.46; potassium nitrate 0.3; iron 0.76; osomocote 1.08; and trace elements 0.1
Native Mix 2 (NM2)	2 parts jarrah sawdust: 2 parts pine bark: 1 part washed cream sand: 1 part river sand. Plus the following in mg/litre: nitrogen 1.96; lime 2.63; dolomite 0.46; potassium nitrate 0.33; iron 0.79; osmocote 1.3; traces 0.1
University of California Mix (UC)	1 part peat: 1 part fine sand. Plus the following in mg/litre: urea formaldehyde 1.5; lime 3.5; magnesium carbonate 2.0; potassium nitrate 0.15; potassium sulphate 0.15; superphosphate 1.5

* The abbreviations C, ES, etc. are used to designate potting mixes throughout this paper.

Materials and Methods

A shallow cut was made in the endocarp with a bandsaw, according to standard germination methods for sandalwood seeds (Crossland 1982). The seeds were then sown directly into 2.5 litre black plastic bags. 30 bags were set up in each treatment, and the seeds were sown 2 per bag on the 30th April 1984. Artificial irrigation was necessary due to lack of rain.

Mulga Research Centre Journal No. 8
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Germination reached 93 percent and seedlings were thinned to 1 per bag in mid July.

Pots were kept weed free and were irrigated daily in summer. Plant growth was observed at intervals from September 1984. Three plants from each treatment were harvested periodically to determine dry matter production and nutrient levels. Plant material was dried for 24 hr in a 60°C oven. Whole plant material was analysed for nitrogen content using the Kjeldahl technique at 3, 4 and 5 months from germination. At 6, 7 and 10 months shoot and root materials were taken separately. Phosphorus was determined using mixed acid digest, and the cations potassium, calcium, magnesium and sodium were determined by flame photometry.

For calcium, potassium and sodium whole plant material was analysed at 3 months, and whole plant material was also used to determine phosphorus at 5 months. At 7 and 10 months from germination shoot and root materials were analysed separately for Ca, K, Na, Mg and P.

Three plants from each treatment were transplanted in June 1985 to a site at Bentley with Acacia aneura as prospective host plants.

Results

Germination commenced during mid-May and continued into mid-June. Germination rates were not affected by soil treatments. June 1st was taken as the reference point for germination time.

Mean plant heights at 3, 4, 6, 7, 9, 12 and 15 months from germination are illustrated in Figure 1. Only in the case of UC was mean height consistently significantly greater than control (p 0.05) over the period 3-9 months from germination.

TABLE 2. Shoot/root ratios for dry matter production over the period 3-10 months from germination.

Soil Mixture	Time from Germination (months)					
	3	4	5	6	7	10
Control	0.3	2.1	2.6	2.1	2.3	2.1
ES	0.5	2.0	2.7	2.5	1.9	2.5
NM1	0.5	1.8	2.6	2.1	1.8	1.6
NM2	0.4	1.5	1.8	2.0	1.4	1.3
UC	0.6	2.7	3.6	2.9	2.6	4.3

At each harvest shoot and root materials were dried and weighed separately. Figures 2 and 3 illustrate shoot and root mean weights respectively, for plants harvested at 3, 4, 5, 6, 7 and 10 months from germination. At 3 months root weights were much greater than shoot weights in all treatments, such that shoot/root ratio was less than 0.7 in all treatments (Table 2). Thereafter shoot growth was rapid, such that all subsequent harvests had shoot/root ratios of 1.3 or greater. Highest mean shoot weight was attained by UC plants at 7 months with 1.86 g, and greatest mean root weight was recorded at 10 months for NM2 plants at 0.84 g.

Mean plant nitrogen concentrations are illustrated in Figure 4. At 3 months plants contained 22-33 mg/g N, by 10 months levels had fallen to around 10 mg g-1. For harvests 6, 7 and 10 where roots and shoots were analysed separately control plants had slightly higher N concentrations in roots. This pattern held for the ES treatment but NM1 had similar concentrations in both roots and shoots, and the other two mixes tended to give higher nitrogen levels in shoot material. All root and shoot nutrient determinations are given in Table 3.

FIGURE 1. Mean plant heights over 15 months from germination.

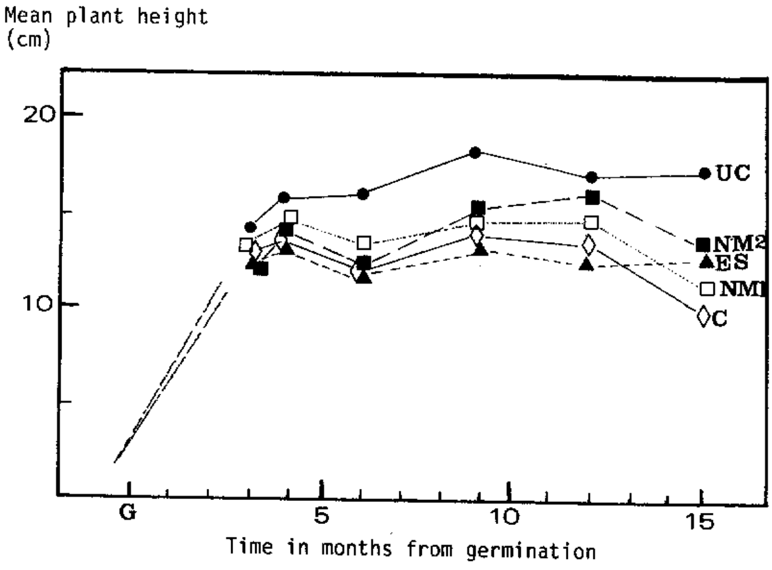


TABLE 3. Nutrient analysis levels for harvests at 7 and 10 months from germination, shoot and root material analysed separately. All values expressed as mg/g (nitrogen also at 6 months).

	Nutrient:	Nitrogen			Phosphorus		Potassium		Calcium		Magnesium		Sodium	
Treatment	Months from germination	6	7	10	7	10	7	10	7	10	7	10	7	10
Control	Shoots	7.8	10.3	8.0	1.40	1.30	1.16	1.06	3.46	2.44	1.60	1.87	7.37	4.42
	Roots	10.4	11.8	9.6	0.65	0.63	1.54	0.59	0.98	1.13	0.35	0.96	0.98	1.30
ES	Shoots	8.6	11.4	6.9	1.55	1.50	1.16	1.16	2.74	3.71	1.33	2.24	4.91	7.05
	Roots	10.1	17.5	9.5	0.63	0.80	1.25	1.44	0.78	1.43	0.27	1.09	0.81	1.80
NM1	Shoots	8.3	10.1	9.7	3.25	3.63	1.63	0.97	4.31	3.74	1.08	0.99	3.27	4.75
	Roots	9.4	9.7	9.8	0.93	1.25	1.18	0.83	2.14	2.56	0.23	1.33	1.14	1.36
NM2	Shoots	19.2	21.0	12.5	0.88	1.05	1.44	0.97	1.55	2.20	0.76	1.03	5.57	6.23
	Roots	16.1	16.7	12.4	2.25	0.63	1.63	1.06	0.88	0.93	0.31	0.26	0.81	0.98
UC	Shoots	10.1	13.6	10.9	3.13	2.82	0.97	0.69	5.76	3.30	4.34	2.83	5.24	4.91
	Roots	11.3	12.4	9.4	1.43	1.00	2.29	0.97	1.84	1.69	1.00	0.54	1.47	1.47

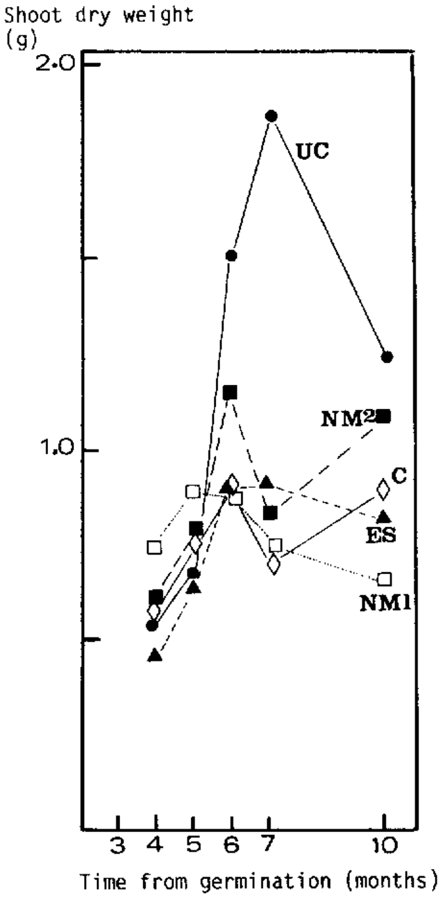
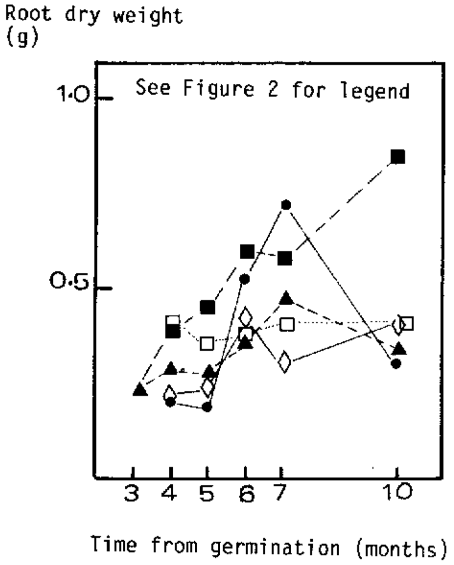


FIGURE 2. Shoot dry matter production at harvests 3-10 months from germination.

FIGURE 3. Root dry matter production at harvests 3-10 months from germination.



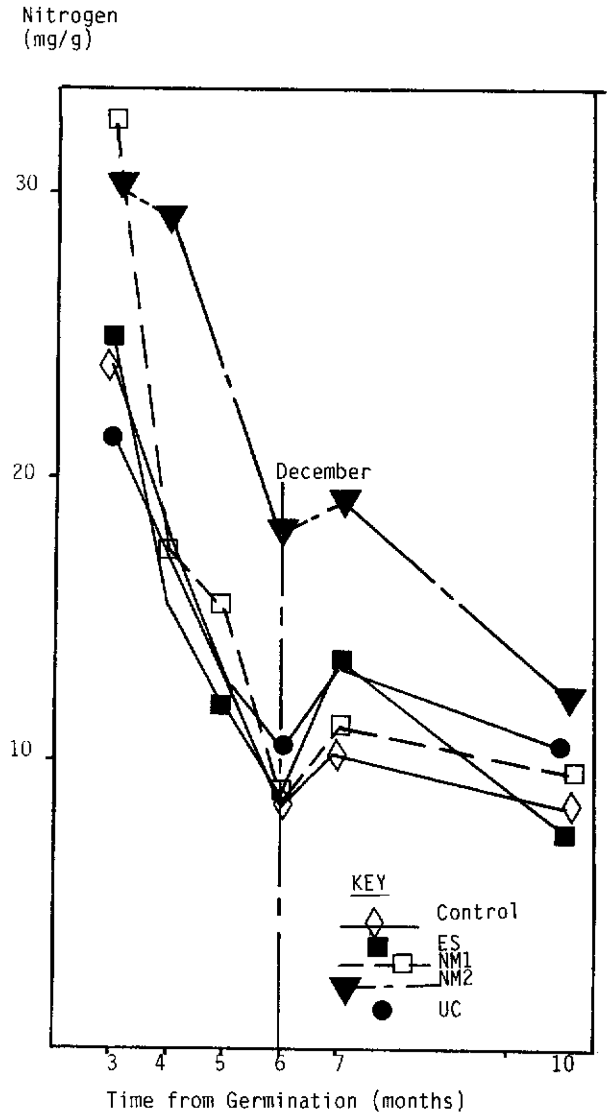


FIGURE 4. Nitrogen levels in sandalwood seedlings 3-10 months from germination.

Plant phosphorus levels were low (Figure 5) and except for NM2 shoot concentrations tended to be double the level of those in the roots. Control plants generally had lowest phosphorus levels.

Potassium concentrations are shown on a whole plant basis in Figure 6. A similar rapid decline to that shown for nitrogen was evident for all treatments. At 7 months all except NM1 had higher K levels in root material than in shoots. This position had changed at 10 months when only ES, NM2 and UC had higher root concentrations. At 10 months concentrations ranged from 0.59 mg/g in control roots to 1.44 in ES roots. The shoot range was from 0.69 in UC to 1.16 in ES (Table 3).

In the case of calcium interesting differences occurred as early as 3 months (Figure 7). Shoot levels were always higher than root concentrations at both 7 and 10 months. All treatments, except NM2, had higher root and shoot concentrations than the control plants. Root concentrations in NM1 remained consistently over 2 mg/g at 7 and 10 months, whereas all other mixtures had levels no higher than 1.8 (UC at 7 months).

Magnesium concentrations were only determined at 7 and 10 months from germination (Figure 8). Control plants had higher concentrations at 10 than 7 months, with greatest gains in root levels from 0.35 to 0.96 mg/g. All treatments except NM2 (slight decline) and UC (major decline) showed similar increases in root concentrations. Shoot magnesium was greater than roots in all except NM1 at 10 months where shoot concentration fell to just less than 1 mg g-1. Plants in UC mix had highest shoot concentrations with 4.3 and 2.8 mg/g at 7 and 10 months respectively (Table 3).

In contrast with potassium the levels of sodium recorded were higher in shoot tissue than in root tissue. Final mean sodium levels were of the order of 3-5 mg/g at 10 months (Figure 9). Several treatments showed increased sodium concentrations between 7 and 10 months. UC treatment remained similar throughout with about 5 in shoots and 1.5 mg/g in roots. Both shoot and root concentrations increased in ES, NM1 and NM2.

The mean number of haustoria recorded on harvested plants is given in Table 4, together with diameter range. Haustoria were recorded in all treatments including control, where numbers were particularly high at 5 months.

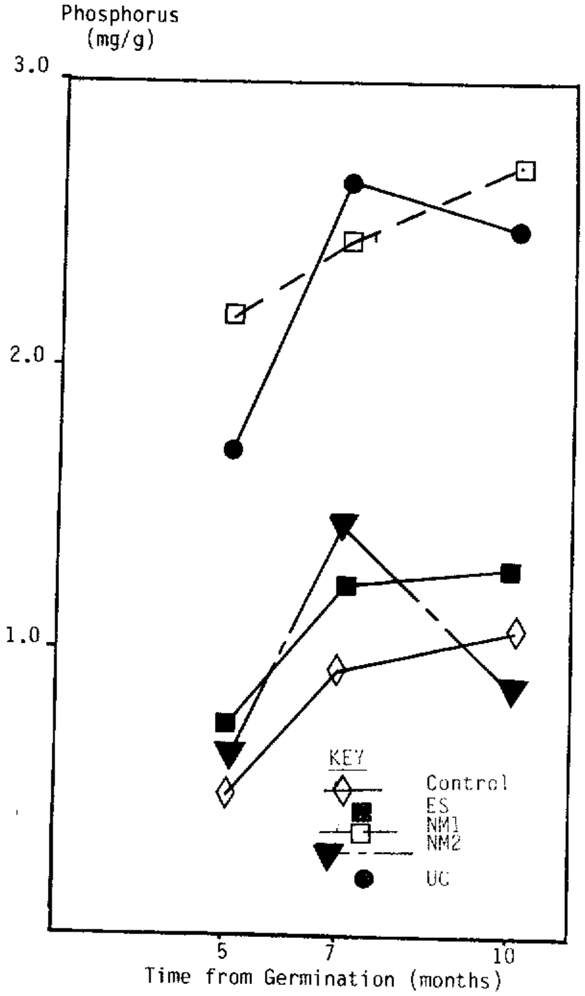


FIGURE 5. Phosphorus levels in sandalwood seedlings 3-10 months from germination.

Discussion

Growth

Improvements in plant growth over the control were apparent in the UC soil mix at about 3 months from germination (Figure 1). The 'native' soil mixes initially produced a stunting of roots presumably associated with the high bark and sawdust content in these mixes. Although dry matter production was high the roots were short and thick in appearance. By 4 months however, this effect appeared to have been overcome. From this point fertilised plants consistently maintained a height advantage over control plants. Mean plant height reached a peak in four treatments at 9 months from germination. Plant height and condition began to deteriorate at about 10 months from germination, with the exception of plants in NM2 mix which continued to gain height up to 12 months.

Dry matter production reached a peak at 6 or 7 months from germination in all treatments. Plants in the UC soil produced markedly higher values for shoot dry weight from 6 months, and root dry weight between 6 and 7 months. Plants in the NM2 treatment also produced a high shoot dry matter content from 6 months, and high root weights from 5 months. NM2 plants continued to produce high dry matter values, especially root dry matter, up to 10 months, while dry matter production in other treatments was declining.

Nutrition

Nitrogen levels were first determined for plants at 3 months from seedling germination. At this stage nitrogen concentrations were considerably higher in the 'native' soil mixes (Figure 4) and lowest in the 'UC' mix. NM2 plants maintained a higher N percentage throughout, possibly as a consequence of the higher level of N supply in this mix. Plant nitrogen levels declined over time in all treatments. The lowest N levels (Figure 4) coincided with the period of peak dry matter production at 6 months (Figure 2). Peak dry matter production in December was followed by a decline in January. This decline was accompanied by an increase in N concentration. Hence it appears the N content in plant tissues had been diluted due to growth. The initially low N levels in UC plants therefore, appears to be a reflection of their faster growth rates. That is, when a fast growing plant is compared with a slow growing plant, the total N content of the bigger plant may be lower. This nitrogen will be distributed over a larger weight, so that similar absolute amounts of nitrogen may have been absorbed.

Phosphorus concentrations in seedlings were generally higher in NM1 and UC mixes (Figure 5). Plants in NM2 mix showed a marked increase at 7 months. This was mainly due to an exceptionally high analysis for root material, which was not seen at 10 months. P deficiency symptoms were observed in some plants in the form of a reddish colouration of leaves in the early months.

Potassium concentrations in seedlings (mg/g) were higher in the two 'native' soil mixes at 3-4 months (Figure 6). These two soils contained higher amounts of K. Potassium levels had declined dramatically by January (7 months) and continued at similar levels into April. By this stage there were no differences in K levels of seedlings associated with treatments.

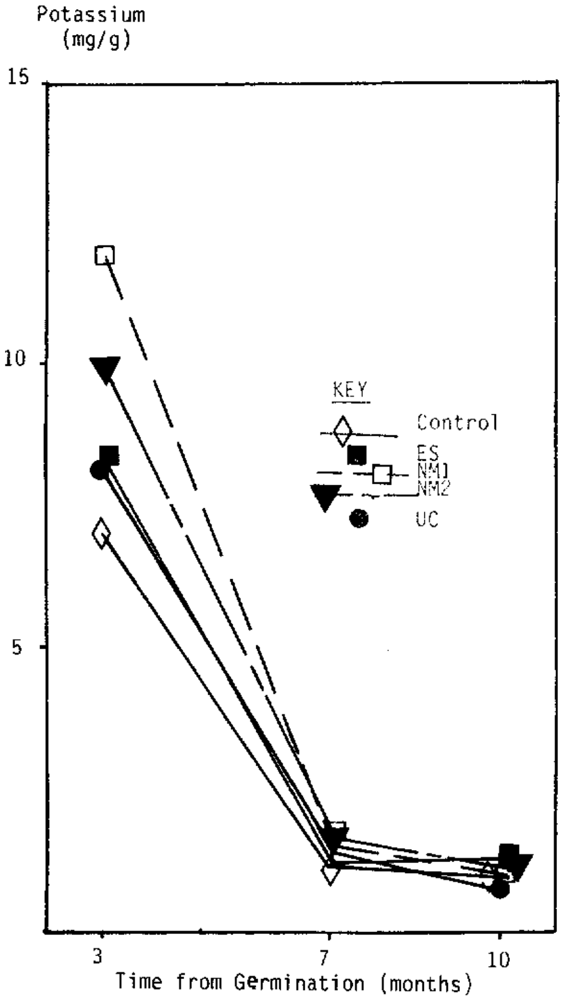


FIGURE 6. Potassium levels in sandalwood seedlings 3-10 months from germination.

Sodium levels were initially lower in the fertilised treatments and higher in the unfertilised plants (Figure 9). The levels appear to be inversely proportional to those of K, reflecting the interchangeability of these cations. In the control soil, where K was not supplied, sodium appears to have been taken up in its place. Considering that both potassium and sodium are involved in plant water relations, this is not an unexpected result. The high level of sodium intake of control plants growing in a relatively barren soil may be explained by the water regime. The bore water used to irrigate the experiment contained small amounts of some nutrients. From January (7 months) Na levels were also similar for seedlings of all treatments.

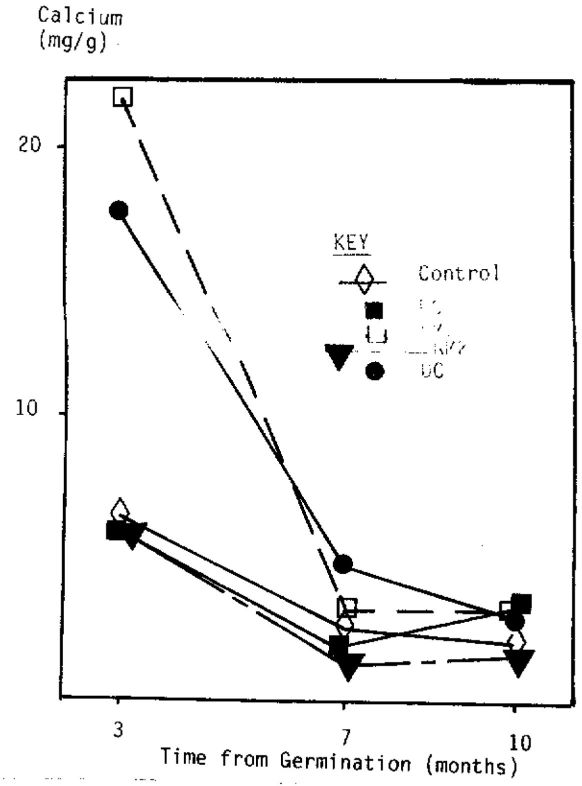


FIGURE 7. Calcium levels in sandalwood seedlings 3-10 months from germination.

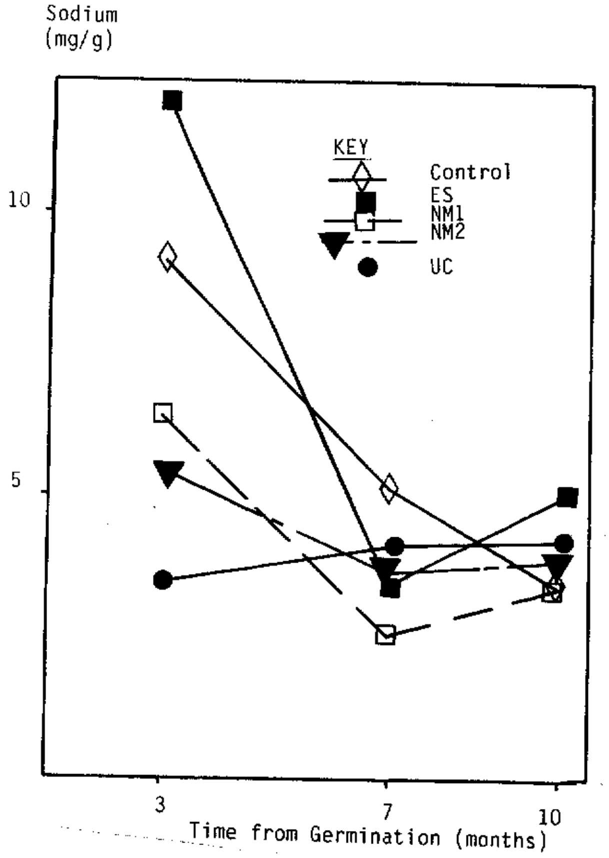


FIGURE 9. Sodium levels in sandalwood seedlings 3-10 months from germination.

Calcium concentrations at 3-4 months were higher in seedlings of NM1 and UC soils (Figure 7). The concentration of this nutrient declined but a similar trend was maintained, associated with treatments, at 7 months suggesting both uptake where this nutrient was supplied and rapid utilisation in the growing plants.

Magnesium level (Figure 8) was highest in the UC soil in January, reflecting the high level supplied in this soil mix (Table 1). The Mg contents of plants in the 'native' mixes were lower than those for unfertilised plants. This effect is difficult to explain as dolomite was included in the preparation of these soil mixes. Dolomite is a slow release fertiliser, however plants in these treatments should contain levels at least similar to the control plants, assuming that some magnesium may have been supplied in bore water, or from the sand. It is possible that the composition of the native soil mixes may have in some way affected the rate of Mg uptake.

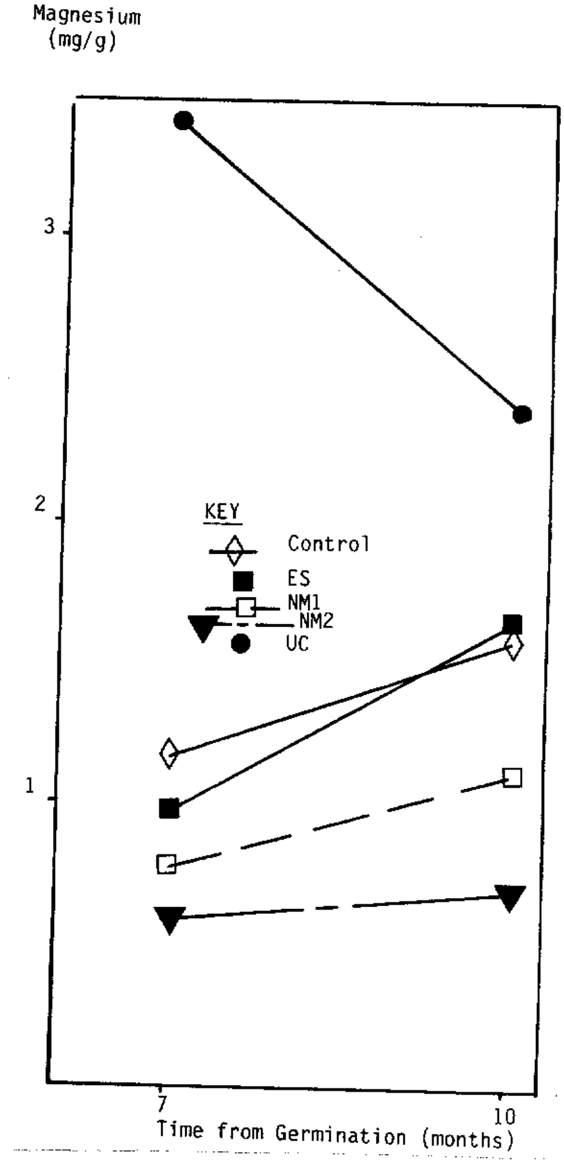


FIGURE 8. Magnesium levels in sandalwood seedlings 7-10 months from germination.

Overall results suggest that nutrient levels in the UC mix and in NM2 appear to provide useful estimates of rates required by seedlings of sandalwood. Performance of plants in pots prior to field planting should be concerned with survival and maintenance of plants in a healthy condition to the time at which host roots are available. If the investment in potting does not result in good subsequent survival then clearly the use of seed or fresh germinants may be preferred.

Transplanting and Haustorial Formation

At 10 months from germination, the condition of plants in most treatments began to deteriorate. Although height was maintained in some treatments, survival rate declined rapidly especially in the control and ES treatments. Three plants from each treatment were transplanted into a 2/3 year old A. aneura bed in June 1985. At September 1985 only 1/3 of NM1, UC, ES plants and 3/3 NM2 plants of those transplanted remained alive. From those which had been maintained in pots with no hosts at April, 1/5 survived in Control and UC treatments, 1/4 in the ES, 3/4 in NM1 and 6/7 in NM2. The healthier condition of NM2 plants at the time of planting appears to have ensured the survival of seedlings in transplanting.

Haustorial formation increased in all fertilised treatments up to 4 months. Plants within the UC treatment ceased to produce haustoria after the intitial 5 months, but plants in the native soil mixes continued to produce high numbers (Table 4). There are indications that haustorial formation is a mechanical response to physical stimuli in that roots often display haustorial development against pot walls. These however do not persist. Haustorial production may be dependent on nutrient availability, as well as physical stimuli.

Conclusions

Fertilising soil mixes increased plant growth in terms of height and dry matter production. Plant height reached a peak value at 12 months in NM2 soil and at 9 months in other soils. Thereafter plants began to deteriorate from about 10 months. The deterioration of plants coincided with the age at which sandalwood seedlings tend to die should their roots have failed to attach to suitable hosts. The deaths therefore may be due to either: a) the host requirement i.e. inability to obtain some type of element for which the host is essential, or b) inability to take up sufficient nutrients to maintain growth. The plants did not display any obvious signs of specific nutritional deficiency during latter stages of growth. However nutrient concentrations in plants declined dramatically from 3 to 7 months. The initial levels of nutrients (at 3 months) are comparable to those observed in 2 year old vigorously growing plants with host connections (Barrett et al. 1985). At 3 months seedlings are relying heavily on seed resources. Following depletion of seed reserves, the rate of uptake may be inefficient or the levels supplied may not have been adequate to maintain nutrient concentrations required for growth.

The NM2 soil mix was able to support plants beyond the 12 month stage. This capacity suggests that fertilisers can not only improve the growth rates of seedlings but may also support them for some time in the field prior to host attachment while a host is being located. The lower levels of similar nutrients supplied in NM1 appears to have been insufficient to produce similar levels of uptake and hence growth.

Therefore, questions arise as to

1. the amounts of nutrients required to produce optimum growth, and
2. whether some nutrients can be adequately provided by hosts and hence will not be required from soil, following host contact.

TABLE 4. Mean number (No.) of haustoria per plant and diameter (d) range (mm).

Months from Germination	Control		ES		NM1		NM2		UC	
	No.	d	No.	d	No.	d	No.	d	No.	d
3	2	1-2	4	1-2	2	1-2.5	12	1-4	4	1-2.5
4	5	1-1.8	4	0.3-3	16	1-1.8	18	0.6-2.4	12	0.8-2.2
5	25	0.5-2	6	0-1	3	1	12	1-2	3	<1
6	1	0.5-2	6	0.5-2	10	0.2-1	21	0.5-2.5	0	-
7	4	<0.5	4	0.5-1	20	0.5-2	9	<1	<1	0.5
10	5	0.5-2	2	0.5	6	0.5	16	0.5-1	<1	0.5-1

The nutrient levels in the UC mix and NM2 mix appear to provide useful estimates of rates required by seedlings of sandalwood. However, the nature and the proportions of nutrients supplied by hosts and the proportions the parasites are able to take up from the soil as it grows older, require to be known before fertiliser requirements of hosts and sandalwoods at more than 1 year can be determined.

Acknowledgements

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THE POTENTIAL GROWTH OF KIKUYU GRASS AND THE USEFULNESS OF AMMONIUM SULPHATE AS A SOURCE OF FERTILISER NITROGEN - A REVIEW

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Summary

Kikuyu grass (**Pennisetum clandestinum**) is a stoloniferous, rhizomatous, turf-forming, perennial grass species from East and Central Africa. It is widely naturalised in Australia wherever winters are mild and summer moisture available. It tends to be relatively dormant in winter and frost susceptible, it is deep-rooted and drought-tolerant. It will grow well on well-drained soils and responds to fertiliser nitrogen. Applied nitrogen increases the competitive ability of kikuyu relative to other grasses. It can persist well through the summer months with irrigation. At very high levels of added nitrogen it is probable that excessive top growth will occur which will provide a drain on other plant nutrients. This top growth can be mown off for hay or mulch material. Continued healthy growth may require additional fertilising with other nutrient elements.

In the eastern states on acidic soils ammonium sulphate applied to kikuyu pastures tends to increase soil acidity. This should not be a problem on W.A.'s coastal calcareous sands where leaching losses may lead to lower total responses. However heavier soils of the traditional irrigation areas may become sour.

Introduction

Ammonium sulphate has been used as a lawn fertiliser, in pasture production and as a nitrogen source for grain crops. In this paper attention is drawn to published records of the quantities used and the effects in terms of yield and N uptake. Particular reference is made to the growth of Kikuyu grass (**Pennisetum clandestinum**) in relation to nitrogen fertilisers. Other grasses are referred to in relation to effects of N fertilisation, mowing and general yield predictions.

Kikuyu has become naturalised in Eastern Australia mainly in areas with a humid sub-tropical climate and on soils of medium to high fertility. In such areas kikuyu grass has become important as a pasture species. The potential for high levels of milk and beef production when fertilised with nitrogen has been demonstrated (Colman & Kaiser 1974, Mears & Humphreys 1974). Kikuyu has also spread through pastures in W.A.'s south-west irrigation areas. Due to its low digestibility milk production from cows grazing kikuyu is limited (Olney & McGhie 1981). Some farmers consider kikuyu to be useful, others treat it as a weed in these irrigation areas (W. Russell, pers. comm.). Irrigated kikuyu is a satisfactory source of feed for growth in cattle (Suiter et **al.** 1981).

Properties of Ammonium Sulphate

Most nitrogen fertilisers are water soluble and derived from ammonia. The more important for general farm use are ammonium sulphate, nitrate and phosphate, ammonia itself either anhydrous or in solution, and urea. Should the fertiliser persist in normal soil for any length of time, then the ammonium will be oxidised to nitrate. Thus fertiliser nitrogen taken up from non-acid soils in a few weeks after application is likely to be in the form of nitrates. These fertilisers differ in effectiveness, with nitrates tending to be usually more efficient than urea or ammonium sulphate when used as a quick acting fertiliser (Russell 1973). Ammonium sulphate contains 21 percent N and 24 percent S.

Ammonium sulphate added to a soil causes it to lose exchangeable calcium or some calcium from any calcium carbonate present. In general for every 100 kg of ammonium sulphate added to a soil about 45 kg of calcium are removed in drainage water. This is due to that part of the sulphate in the fertiliser not taken up by the crop washing out as calcium sulphate; also a part of the nitrate formed from the ammonium washes out as calcium nitrate. The loss of sulphate accounts for about 30 kg of calcium and of nitrate about 15 kg. The loss of about 45 kg of calcium per 100 kg of ammonium sulphate applied has been found over a wide range of conditions, in both temperate and tropical countries, provided the soils are not too acid. On low pH krasnozem soils in New South Wales losses may be higher. Awad & Edwards (1977) calculate that 2680 kg N ha-1 of ammonium sulphate applied over a six year period to kikuyu pasture resulted in the removal of 1749 kg Ca, 52 kg Mg and 753 kg K. That is per 100 kg ammonium sulphate losses of 65.3 kg Ca; 1.9 kg Mg and 28 kg K.

Although all ammonium fertilisers cause a loss of soil calcium as nitrate, ammonium sulphate is the only one in common use whose anion washes out almost completely as the calcium salt, thus causing greatest drain on soil calcium of any of the fertilisers in general use. Because ammonium sulphate causes this large loss of calcium from the soil, it is often recommended that it should only be used with caution in field experiments. Many results obtained in the past using this fertiliser have been due as much to the acidity the fertiliser has caused as to the nitrogen or sulphur it has supplied (Russell 1973).

Ginzo **et al.** (1982) provide an example of a fairly rapid lowering of pH from 6.5 to 5.4 over a three year period of heavy ammonium sulphate dressing to pasture grasses. This fertiliser can also influence the botanical composition of mixed pastures quite rapidly. Normal nitrogen fertiliser management in the Wollongbar area of New South Wales is to apply the fertiliser in three equal dressings e.g. September, late November and February. Ammonium sulphate usage on the heavy soils of this area leads to high soil acidity (Awad & Edwards 1977) which may be countered with liming treatments, giving direct

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benefits to animal health (Awad, Edwards & Huett 1979). On the far north coast of New South Wales manganese toxicity on bean crops increased in severity following constant use of ammonium sulphate. Lime is necessary to cure the problem (Siman et al. 1971). Levels of 12.9 to 76.3 kg ha-1 of ammonium sulphate were tested at three localities in W.A. for wheat crops over 1961-1972. There was some decline in yield at the higher levels of ammonium sulphate (Mason & Toms 1975).

Residual Effects of Ammonium Sulphate

Water-soluble nitrogen fertilisers applied to a crop used to be considered to have no residual effect on the following crop, except in so far as soil acidity was affected. Nitrogen fertilisers applied to arable crops have little effect on the level of soil organic matter or organic nitrogen in the soil, so that it is not possible to build up the nitrogen reserves in a soil by a generous use of nitrogen fertilisers, as happens with phosphate and potash. However, with suitable conditions a heavy dressing of nitrogen fertiliser to one crop can have a residual effect on the succeeding crop, as some soils can store nitrates in their subsoil over a winter (i.e. North Temperate Winter). In England the mean residual effects of 190 kg ha-1 N as sulphate of ammonia given to potatoes, for the following wheat crop has been shown equivalent to 63 kg ha-1 N as top dressing in the spring. The residual effect of 125 kg ha-1 N top dressing on winter wheat was equivalent to 25 kg ha-1 N applied to the following potato crop. This residual effect depends on rainfall, being larger in years of dry than of wet winters (Russell 1973). The effect of varying the pattern of fertiliser N input is complicated by residual responses, interaction between successive applications, as well as the length of the regrowth interval (Hunt et al. 1981).

Feigin et al. (1982 a, b) used barley following celery to estimate the total uptake of N from applied ammonium sulphate. At Kojonup on sandy loam and sand soils ammonium sulphate was applied at 0, 280 and 840 kg ha-1 in equal aliquots in autumn and early spring. Over a five year period the ammonium sulphate treatments had reduced pH from just over 6 to 5 or less (Watson et al. 1973). There was little in the way of long term enhancement of soil nitrogen status.

Ammonium Sulphate and Soils Rich in Calcium

Ammonium sulphate can be a very inefficient nitrogen fertiliser if broadcast on the surface of calcareous soils, particularly on those containing more than 10 percent calcium carbonate. Then ammonium sulphate will react with the carbonate to give calcium sulphate and free ammonia. Ammonium sulphate appears to suffer a greater loss of ammonia in this way than does ammonium nitrate or phosphate (Russell 1973).

The role of N forms in affecting soil acidity are discussed by Helyar (1976). In general nitrification of the ammonium ion will lead to plants taking up nitrates and hence acidification. When ammonium fertilisers are used acidification can be balanced by the use of liming materials.

Sulphur

Ammonium sulphate contains 25 percent S. The ratio of protein nitrogen to organic sulphur in leaves of a variety of crops is about 15. Thus leaf protein production can be limited on sulphur deficient soils. Grasses take up more sulphate from low sulphate soils than with associated legumes. New Zealand examples quoted by Russell (1973) of production on sulphur-deficient soils include grass taking up 6.0 kg ha-1 S, clover 0.7 kg, and with 12 kg S added as gypsum grass took 12 kg and clover 4.5 kg ha-1. Kikuyu responded to sulphur on a krasnozen soil in Queensland after repeated cutting and heavy watering in pot experiments (Cassidy 1972).

Levels of Fertiliser N Used in Agricultural Systems

Some workers stress the complexity of experimental procedures required to test the levels of fertiliser N that may be applied. For example Hunt et al. 1981 suggest there have been few yield response studies to N in herbage regrowth. The residual effects of fertiliser N applied for primary growth can be substantial particularly when the primary growth has been harvested at an active stage of growth. These authors suggest that the subject requires experiments with large numbers of treatment combinations and complex fertilising and harvesting schedules. Three experimental factors must be included:

a) varying rates of N,
b) varying dates of application, and
c) a succession of dates of harvesting after applying N to establish growth rates.

Efficiency of Response

The efficiency of response to fertiliser is defined as the additional dry wt (dm) of plant production over no fertiliser divided by the weight of nitrogen applied. That is one must deduct the dry wt produced from a control, untreated set, from all experimental treatments to obtain the additional value. The efficiency of response then estimates dry matter production per unit of applied nitrogen. This is of concern to agriculture as the weight of herbage for grazing animals may not increase in proportion to fertiliser added beyond certain limits. Response to nitrogen has been defined (RN) by Colman & O'Neill (1978) as the slope of the linear regression of dry matter yield on nitrogen fertiliser applied.

A level of 10 kg dm/kg N applied is suggested as a minimum response level for productive agricultural systems by Hunt **et al.** (1981). In joint grass/legume systems high levels of applied nitrogen may adversely affect the legume component (Haggar 1975; Ginzo **et al.** 1982). In the case of **Andropogon gayanus** Haggar (1975) reports that the highest return of dry matter per unit of applied fertiliser was 14.4 kg dm/kg N at 28 kg N ha-1 over a range of 0 to 896 kg ha-1 N. Highest yield however was at about 500 kg N ha-1 with 7 kg dm/kg N. Haggar found that continued use of ammonium sulphate resulted in a relative lowering of its efficiency compared with calcium nitrate or nitrochalk.

Uptake Levels of Nitrogen From Fertiliser Added

The nitrogen present in a soluble fertiliser applied to an established ley or permanent pasture during periods of active growth may be taken up almost completely by the grass, if allowance is made for the nitrogen in the root growth as well as in the tops. If allowance is not made for roots, between two-thirds and three-quarters of the applied nitrogen is usually found in the tops. Arable crops rarely take up more than between one-third and one-half of that applied (Russell 1973). The uptake level is obtained by chemical analysis of samples of harvested material to give a percentage nitrogen content. This percentage is then multiplied through the dry matter production values to estimate the total amount of nitrogen present in the harvested material. The quantity of nitrogen present in the untreated control harvest is deducted from the total amounts present in the various treatments. These values are then considered to be the uptake of additional nitrogen due to fertiliser treatment and net of any soil effect on nitrogen uptake. These net values are expressed as a percentage of the total nitrogen applied to the various treatments in the fertiliser added. Apparent percentage nitrogen recovery (ANR %) has been defined by Colman & O'Neill (1978) as the slope of the linear regression of nitrogen yield on nitrogen fertiliser applied. The uptake of nitrogen declines as soils dry out (Alston 1979).

Feigen **et al.** (1982 b) used 314 kg ha-1 as ammonium sulphate to grow celery followed by barley. The ammonium sulphate was applied in a band dressing. Two irrigation levels were used, 400 and 500 mm of water. Control plots at 400 mm took up 18 kg ha-1 N whereas the treated areas gave 193 kg ha-1 N at 400 mm and 158 kg ha-1 N at 500 mm. These latter represent 61.6 and 50.2 percent respectively of the nitrogen applied in the ammonium sulphate with barley contributing 49.3 and 39.8 kg ha-1 N respectively.

At Katherine, in the Northern Territory, Myers (1979) grew grain sorghum with ammonium sulphate at 50 kg ha-1 N. The uptake of N was as in Table 1.

TABLE 1. Effect of nitrogen by method of application on percentage nitrogen recovered with grain sorghum in a field experiment.

Treatment	N recovered (%)	
	1971	1972
Ammonium sulphate		
Banded	23.4	29.2
Mixed	21.8	23.0
Split	17.4	22.0
Mean	20.8	24.8

A rate of 326 kg ha-1 yr-1 allowed nine cuts of grass (of various species) per annum under U.K. conditions (Wilman & Wright 1978a).

N utilisation efficiency is affected by the timing of N application, amount of leaching, depth of crop rooting and length of growing season (Feigen **et al.** 1982b).

Kikuyu Grass

Kikuyu grass (**Pennisetum clandestinum**) is a stoloniferous, rhizomatous perennial, first introduced into Australia from Africa as seed in 1919. This prostrate perennial grass may form a loose sward to 50 cm tall but when mown or grazed it assumes a dense turf. It spreads vigorously from rhizomes and stolons which root readily at the nodes (Mears 1970).

Short leafy branches come from stolons. Leaf blades are strongly folded in bud, later expanding to 45-115 mm long and 6 mm broad. Leaf surface is sparsely and softly hairy. The ligule can be recognised by a ring of hairs and the collar by its pale yellow colour. Stems of kikuyu may be ascendant, stoloniferous, rhizomatous or a combination of one or more. New growth from an established sward occurs in the form of new stems which arise from leaf axils on the stolon-like older stems. These then grow vertically to about 45 cm (including extended leaves) before lodging. As the stems elongate new leaves are formed continuously under suitable conditions (Whitney 1974b). The initiation of root buds is a sign of a high potential for growth and formation of many secondary shoots is an important factor in the realisation of strong growth (Cassidy 1972).

The flower is small borne on a spike of 2-4 sub-sessile spikelets which are partly enclosed within the uppermost leaf sheath. Spikelets are bisexual or functionally unisexual. Florets are protogynous and stamens are exserted rapidly on long filaments, usually in the early morning. The stigma is branched and feathery, seed is 2 mm long, dark brown and flat with a prominent style (Mears 1970).

Kikuyu occurs naturally in east and central Africa between 1950 and 2700 m.a.s.l. in regions with 1000-1600 mm rainfall. Seed was brought to Australia from the Congo in 1919. Material from vegetative material arising from one seed which germinated at Sydney Botanic Gardens was widely distributed as cuttings in late 1920, including to Western Australia (Mears 1970). Separate introductions from Kenya were brought to South Australia (Parker 1941). The species is now well distributed along the eastern dairy country of Australia between latitudes 17-37°S (Mears 1970). Most of the published Australian literature is from this general region. The potential productivity of kikuyu when fertilised with nitrogen was demonstrated by Colman (1966a) for New South Wales and by Gartner (1966) in Queensland.

A survey of Kenya resulted in the recognition by Edwards (1937) of 3 ecotypes. These were based mainly on leaf morphology and flowering behaviour. The ecotypes were named Molo, Kabete and Rongai. Considerable variation exists in the material presently used in Australia, with sources from both seed and cuttings (Parker 1941), but Mears (1970) considered it would be difficult to recognise the ecotypes of Edwards in existing kikuyu pastures. Later introduction of both seed and vegetative material represented at least some of the genetic variation described by Edwards. The use of kikuyu in Australia was restricted to vegetative propagation until the early 1970s when two seedling cultivars 'Whittet' and 'Breakwell' were registered and released. Breakwell is more prostrate and densely tillered than Whittet with narrower leaves, shorter internodes and thinner stems (Cook & Stillman 1981). Kikuyu seed runs at 400-500 per g.

Pests and Diseases of Kikuyu

Larvae of the pasture scarab beetle (**Rhopea magnicornis**), **Tarsonemus** mites and the soldier fly **Atlermetapomia rubiceps**, have all caused temporary damage to kikuyu grass. Kikuyu often supports large numbers of the black beetle **Heteronychus arator**, both adults and larvae of which feed on roots (Braithwaite 1959).

A disease known as 'Kikuyu Yellows' gives patches of yellow chlorotic leaves which develop and expand. The agent is believed to be a soil-borne fungus (Mears 1970). In Queensland two caterpillars **Oncopera mitocera** and **O. brachyphylla** damage kikuyu and paspalum (Elder 1965), see also Gartner and Everett (1970). Eight days after cutting kikuyu pastures treated with solid nitrogen fertiliser showed 'burning' of top growth. Ammonium sulphate caused a severe white burn (Gartner & Everett 1970).

Tolerance of Kikuyu to Nutrient Levels

Kikuyu grass fertilised with nitrogen is one of the most productive pastures along the east coast in humid climate regions. It is particularly important in intensive dairy production on the north coast of New South Wales. The productive system is not without its problems as grazing cattle can suffer nutritional disorders from feeding on material containing unbalanced mineral elements (Awad, Edwards & Huett 1979). It is often noted that kikuyu pasture may have poor nutritive value (Colman & Kaiser 1974). In particular low phosphorus concentrations in herbage may be associated with heavily N-fertilised pasture (672 kg N ha-1 yr-1). Herbage cut from this high N level contained as little as 0.18 percent magnesium and as high as 3.7 percent potassium and 5.2 percent N. Ammonium sulphate at 672 kg N yr-1 accelerates the removal of Ca, Mg and K.

Kikuyu can maintain high nitrogen content in the grass, from 1.3-4.6 percent dm (Mears 1970). Leaf nitrogen can be higher than this e.g. Wilson and Haydock (1971) reported 5.4 percent nitrogen in kikuyu after 20 days growth from a glasshouse experiment. Yellowing of tops indicates nitrogen deficiency (Rayment & Verrall 1980).

The phosphorus content of kikuyu grass is high, from 0.20 to 0.42 percent (Mears 1970). On krasnozem soils it has not responded strongly to added phosphorus (Gartner 1966). Gartner and Everett (1970) found that kikuyu fertilised with ammonium sulphate contained 0.33 percent phosphorus. The critical percentage for optimum growth has been suggested as 0.23 percent or 0.22 percent (Awad & Edwards 1977) as limiting in tops.

Potassium deficiency symptoms in kikuyu are burnt leaf tips, and senescence of lower leaves at levels of 0.64-1.00 percent or less. Potassium deficiency has been induced with high N and clipping in New South Wales (Mears 1970) and on the Atherton Tableland. This induced potassium deficiency limits yields from high-nitrogen treatments (Gartner & Everett 1970). Nitrogen increased the potassium concentration in kikuyu herbage (Awad, Edwards & Huett 1979). Potassium deficiency gives stunted growth and yellowing of top leaves (Cassidy 1972). Gartner and Everett (1970) found that kikuyu fertilised with ammonium sulphate contained 1.23 percent potassium in the dry matter. A level of 1 percent may be a suitable criterion for adequacy of this element for optimum growth.

Cassidy (1972) conducted hydroponic studies to detect possible deficiency symptoms due to absence of nutrient elements (Table 2). Kikuyu is tolerant of sodium chloride at a rate equivalent to more than 1t ha-1 (Russell 1976). The effects of minor elements have not been reported in detail. However Mears (1970) quotes the following levels (ppm) for growth in Kenya:

Mn 48.5; Fe 117.0; Cu 8.0; Zn 33.8 and B 4.5

TABLE 2. Deficiency symptoms in kikuyu grass. (Source Cassidy 1972).

Element Deficient	Overall Appearance	Leaves	Roots	Adventitious +/-
P	Runt	Small, pointed, dark	Fair	-
K	Runt	Yellowing of top leaves; older ones green but necrotic tips; small red spots	Very poor	-
S	Runt (Pink stem, ligules)	Yellowing of shoot tip from base of individual leaves upwards	Very fair	-
Mg	Runt	Yellow longitudinal striping	Fair	-
Mg+S	Runt	Top leaves yellowish striping	Fair	-
Cu	Very Poor	Light green	Poor	-
Mn	Fair growth (red stem)	Tips of leaves tender, dead after one month	Poor	-
Fe	Very poor growth	Interveinal yellow/white striping	Fair-Poor	?
Zn	Good growth	Young leaves yellow-white tips	Large-fibrous	+
Mo	Good growth	Some yellowing of tips	Large, fibrous	+
Ca	Fair growth	Characteristic yellowing then collapse, from mid lamina of youngest leaf	Good	+
B	Very good growth	Normal	Good	+

Nitrogen decreased magnesium and manganese concentrations in kikuyu herbage (Awad, Edwards & Huett 1979). Kikuyu has a high tolerance to manganese (Rayment & Verral 1980). Awad and Edwards (1977) report that 4 ppm soluble Al in soil and 140 ppm Al in tops is associated with a 20 percent reduction in yield. Higher levels of Al can be tolerated with adequate Ca and P available. These authours give the following concentrations of elements in tops:

N 2.2-4.4 percent — Mo ppm 0.16-1.51
Ca 0.15-0.48 percent — Mn ppm 89-299
Mg 0.22-0.27 percent
K 2.6-3.8 percent

Response of Kikuyu to N-Fertilisers

Morrison (1966) reported that the response to N fertiliser at high altitudes in Kenya was 19-20 kg dm/kg N applied, from infrequent harvests. Growth curves produced by Colman (1966 a, b) for kikuyu in northern New South Wales suggested that a ceiling to yield was 30,000 kg dm ha-1 yr-1 with 1120 kg ha-1 N. Whitney (1974a) in Hawaii, at a lower latitude, exceeded this level with 35,300 kg dm ha-1 at a nitrogen rate of 874 kg ha-1 applied in 10 weekly aliquots of ammonium sulphate. These results were obtained with irrigation, and 351 kg of K ha-1 as potassium sulphate also applied in aliquots through the year. Whitney (1974a) suggested that responses by kikuyu generally have varied from 13 to 43 kg dm/kg N. Experiments reported by Kemp (1976) on soil of high nitrogen status with irrigation gave dry matter responses per kg N applied of a lower order (Table 3).

The highest yield here was 25,200 kg ha-1 at 9 weeks frequency at the higher nitrogen level. Gartner and Everett (1970) obtained the yield shown in Table 4 in North Queensland over one year from April 1965 with ammonium sulphate applied in two equal dressings on April 9th and June 18th to a pure sward of kikuyu. The red-brown clay loam soil had pH 5.8 and good P, K status, but in addition superphosphate and muriate of potash were also applied in a basal dressing of N:P:K at 2:1:2. Thus the results were not influenced by limitations of phosphorus or potassium.

TABLE 3. Response to nitrogen (after Kemp 1976).

Cutting Frequency	950 kg ha-1 N	2860 kg ha-1 N
3 weeks	8.89	2.96
6 weeks	13.24	4.81
9 weeks	10.55	3.62

The area is one of heavy rainfall. I estimate 2180 mm over the period of the experiment. In the period to first harvest 249 mm was received, high uptake levels of N from ammonium sulphate during this period combined with leaching probably account for the large fall by second harvest (Figure 1); for the period from fertilising to second harvest a total of 599 mm of rain fell. The resupply by means of the second half of the fertiliser, after 2nd harvest enabled uptake levels to rise again by the 3rd harvest (H2-H3 368 mm). Removal of N from all but the highest level N declined by 4th harvest (H3-H4 51 mm) and the generally drier months of July-November (total rain for 5 months 293 mm or 58.5 month) is reflected in generally lower total yields. Rainfall was again high from the 5th-7th harvests, reflected in increased yields at all lower levels of fertiliser.

The fall off in yield at high levels for the 7th harvest was associated with lower soil pH and exchangeable potassium and lower concentrations of potassium and nitrogen in the herbage (Gartner & Everett 1970). Grass production is likely to be higher if the nitrogen is supplied in more frequent dosages and yields in excess of 22400 kg ha-1 dry matter are possible if higher nitrogen rates are used, providing phosphorus and potassium levels are maintained.

The efficiency of response in northern New South Wales lay between 18 and 24 kg dm/kg (Colman 1966 a, b). Similarly 17-24 kg dm/kg N is reported for the Atherton Tablelands (Gartner 1969) where a kikuyu dominated pasture yielded 12170 kg dm ha-1 yr-1. Mears (1970) quotes Wright (1968) and other studies as showing 13-27 kg dm/kg N response from other New South Wales localities with N at 112-134 kg ha-1 applied to autumn growth of kikuyu. The efficiency of response by kikuyu to ammonium sulphate in the experiments reported by Gartner and Everett (1970) have been calculated to be:

56 kg ha-1 N	44.6 kg dm/kg N
112 kg ha-1 N	27.3 kg dm/kg N
224 kg ha-1 N	26.4 kg dm/kg N
448 kg ha-1 N	25.3 kg dm/kg N

Awad and Edwards (1977) note that ammonium sulphate has been applied commercially to dairy pastures in New South Wales north coast at annual rates equivalent to 300 kg ha-1 N and experimentally to 1000 kg ha-1 N.

In the experiment reported by Colman and O'Neill (1978) the efficiency of response (not ammonium sulphate) was between 12.5 and 48.6 kg dm/kg with lower values during late autumn-winter (low temperature) or in periods of moisture stress.

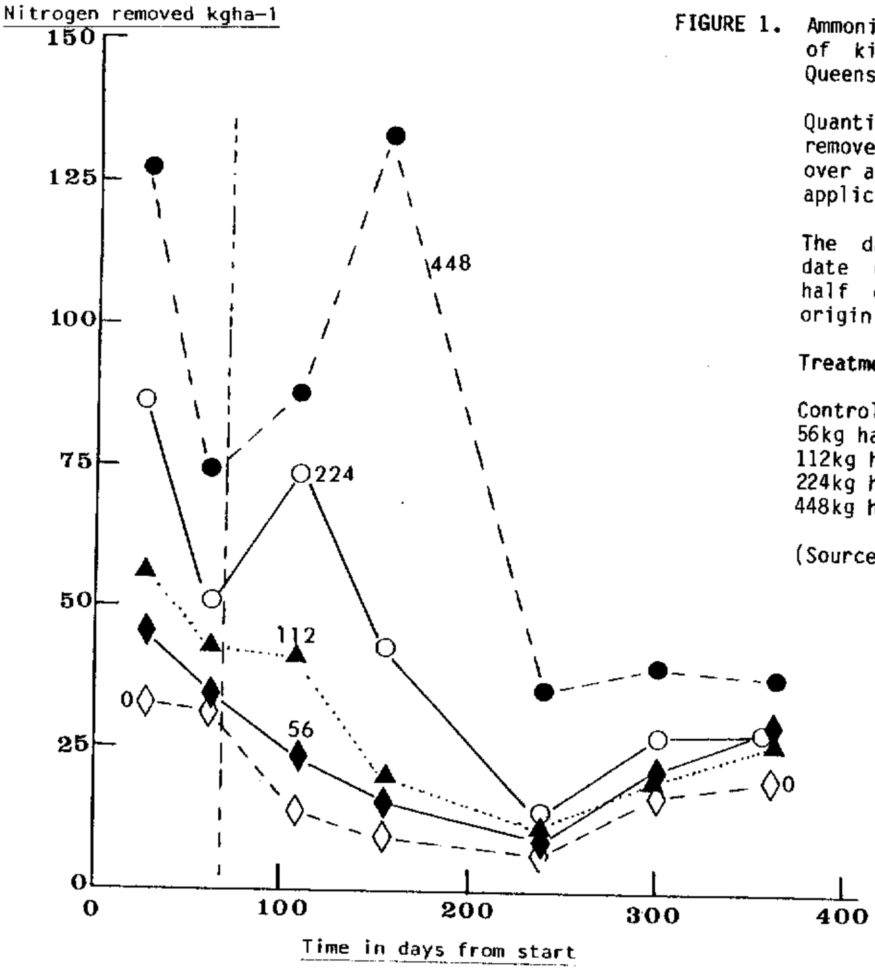

FIGURE 1. Ammonium sulphate applied to pasture of kikuyu at Millaa Millaa, North Queensland.

Quantities of nitrogen in foliage removed at seven successive harvests over a one year period, by nitrogen application level.

The dashed vertical line represents date of application of the second half of fertiliser N, first half at origin (April 9th).

Treatment Levels: Ammonium sulphate

Control - no	N added open diamonds
56kg ha-1 N	closed diamonds
112kg ha-1 N	closed triangles
224kg ha-1 N	open circles
448kg ha-1 N	closed circles

(Source: Gartner & Everett 1970)

Uptake of Nitrogen by Kikuyu

Response to nitrogen reported by Colman and O'Neill (1978) ranged from 0.028 to 0.914 kg dm ha-1 day-1 per kg N during the experiment. The highest nitrogen content was measured in winter when growth was restricted by temperature. Apparent nitrogen recovery was related to both temperature and available soil moisture for 4 weeks growth and varied from 1 to 56 percent. With 8 and 16 weeks growth seasonal variability in apparent nitrogen recovery was reduced and in most periods was in the range of 40-60 percent. This was greater than values reported by Kemp (1975) of 25-37 percent and by Murtagh (1975) of 5-30 percent. Colman and O'Neill (1979) at Wollongbar, used 3 levels of fertiliser N (calcium ammonium nitrate): 0, 112 and 224 kg ha-1 N with four periods of growth, 2, 4, 6 and 8 weeks after nitrogen application. The experiment was repeated at weekly intervals from August 27th of one year until July 8th of the next year on plots of 1.5 m square. Growth curves for successive time replications followed seasonal trends largely determined by temperature. Most curves showed a lag phase during the first 2 weeks of growth and a linear increase from 2-6 weeks. The highest yields occurred during summer with production of 8 weeks being 1500, 5000 and 7500 kg dm ha-1 for 0, 112 and 224 kg ha-1 N respectively. Estimated potential annual yield at the highest rate of nitrogen (6 applications of 224 kg ha-1) exceeded 30,000 kg dm ha-1.

Growth rates ranged from 2 to 78 kg ha-1 day-1 at zero nitrogen, 11 to 152 kg at 112 kg N and 13 to 237 kg ha-1 day-1 at 224 kg ha-1 N (Figure 4 shows responses for the highest rate of N applied). Growth rate of kikuyu fell markedly as a result of declining temperatures and reduced available soil moisture. At 224 kg ha-1 N predicted growth rate at mean temperature of 23°C was 196 kg dm ha-1 day-1, compared with 38 kg at 13°C. Predicted growth rates for 93 and 23 percent available soil moisture were 200 and 66 kg dm ha-1 day-1 respectively.

Climatic Responses of Kikuyu Grass

Kikuyu is able to utilise moisture at depth (Hosegood 1963) which can mitigate the effects of dry periods, especially if nutrients are not limiting. Mantell (1966) estimated the mean water use of a lawn in Israel at 3.2 mm day-1 over June-October. Without nitrogen increasing irrigation had little effect of dry matter production. With N applied at 42 kg ha-1 dry matter yield increased from 750 to 2458 kg ha-1. Some 60 percent of the total water extracted came from 0.60 cm depth which contained 90 percent of total root weight. Thus relative root weight is an efficient indicator of water use with depth. The results of Murtagh (1975) also demonstrate the sensitivity of kikuyu to soil moisture stress.

The combination of temperature and moisture response imply seasonal effects on growth in non-irrigated areas. In general kikuyu is able to make good autumn growth and some winter growth in eastern Australia. Nitrogen will increase the growing season length (Mears 1970) and it is of interest that nitrogen concentrations were lowest at the fifth harvest of Gartner and Everett (1970) taken at the end of the dry season (Table 4). Strong seasonal variations are universally recorded (e.g. Whitney 1974a).

Kikuyu will not survive winter frosting. In 1970 Mears noted a lack of information on the effect of temperature on growth. He suggested that poor performance in low latitudes suggested that it was not adapted to high temperatures. Colman and O'Neill (1978) provided kikuyu the opportunity to grow at different rates of N fertiliser, but with no other mineral nutrient limitation. Growth rate and response to added nitrogen were closely related to mean temperature and moisture supply. Significant growth, in excess of 20 kg dm ha-1 day-1 is recorded at mean temperatures around 13°C. However kikuyu grass probably ceases growth at mean screen temperatures of 10-11°C. These authors derived formulae relating growth to environmental parameters in an effort to model predicted growth of kikuyu (see Table 8).

With nitrogen applications of 224 kg ha-1 N the predicted growth rates at 13 and 23°C mean temperatures were 38 and 196 kg dry matter ha-1 day-1. At 112 kg ha-1 N at the higher temperature production was predicted at 106 kg dm ha-1 day-1. The same study showed that peak growth rate was reached in summer at 237 kg ha-1 day-1 at mean temperatures of 22.1°C and available soil moisture of 60-100 percent. This rate is high and has only been exceeded by a short measurement under irrigation in New Zealand.

Very large seasonal fluctuations in the nitrogen content of kikuyu grass can occur. Two weekly harvests in the Wollongbar area showed ranges of from less than 2 percent N to 5.2 percent at 672 kg ha-1 N; 2.2 to 4.2 percent at 134 kg ha-1 N and 2.2 to 4 percent at zero current ammonium sulphate fertilisation. Changes were sometimes quite rapid, with increases in concentration following rainfall. It is suggested that such a high level as 5.2 percent N would not have been detected at mowing intervals greater than 2 weeks (Awad, Edwards & Huett 1979). At Wokalup, Harvey, W.A. Olney et al. (1981) report monthly pasture production for summer months from an irrigated kikuyu pasture treated with 11 levels of nitrogen (ammonium nitrate) from 0 to 1000 kg ha-1. This was applied in five equal aliquots as a top dressing immediately before an irrigation. Water was supplied at the rate of 1000 m3 ha-1 every 14 days. The highest rate of production was in January 1981 with a mean temperature of 23.4°C. It is clear that production is related to solar radiation (Whitney 1974a).

Established Grass Crop vs Crop Establishment

Three cases require consideration. The application of fertiliser to an established kikuyu sward, treatment of a mixed arable stand of species and the establishment of kikuyu into new ground.

TABLE 4. Dry matter yields of kikuyu in North Queensland at seven successive harvests, using five levels of ammonium sulphate.

N Rate kg ha-1	Time Period	HARVEST NUMBER 1	2	3	4	5	6	7	Annual Yield (weighted annual % N)
	Days from 1st fertiliser	27	62	108	155	239	300	364	
	Days from 2nd fertiliser	-	-	38	85	169	230	294	
		Dry matter yields at harvest (and nitrogen concentrations) kg ha-1 (%)							
0	DM	1424	1469	796	493	628	1222	1300	7331
	% N	(2.31)	(2.15)	(1.76)	(1.91)	(1.07)	(1.42)	(1.53)	(1.79)
	N in kg ha-1	32.9	31.6	14.0	9.4	6.7	17.4	19.9	131.9
56	DM	1872	1625	1177	818	919	1513	1917	9831
	% N	(2.42)	(2.14)	(2.01)	(1.94)	(1.05)	(1.41)	(1.50)	(1.80)
	N in kg ha-1	45.3	34.8	23.7	15.9	9.7	21.3	28.8	177.0
112	DM	2074	1749	1682	908	986	1368	1625	10392
	% N	(2.73)	(2.44)	(2.43)	(2.13)	(1.16)	(1.43)	(1.58)	(2.08)
	N in kg ha-1	56.6	42.7	40.9	19.3	11.4	19.6	25.7	216.2
224	DM	2836	1782	2164	1715	1076	1838	1838	13250
	% N	(3.06)	(2.81)	(3.41)	(2.46)	(1.25)	(1.47)	(1.52)	(2.42)
	N in kg ha-1	86.8	50.1	73.8	42.2	13.5	27.0	27.9	320.7
448	DM	3453	2018	2007	3912	2511	2803	1950	18653
	% N	(3.67)	(3.62)	(4.34)	(3.39)	(1.39)	(1.40)	(1.40)	(2.80)
	N in kg ha-1	126.7	73.1	87.1	132.6	34.9	39.2	27.3	522.3

(Source of data: Gartner & Everett 1970)

Contrasts in Nitrogen Utilisation

A difference between arable and established grass is that the superficial roots of the grass permeate the soil intimately, whereas those of arable plants are much further apart. Then nitrates can wash through soil without coming into contact with roots. The root system of a grass pasture will usually take up fertiliser from the soil fairly rapidly, whereas, with arable crops, it may last an appreciable time in the surface soil and in consequence has a greater probability of being denitrified. It is difficult to get good field evidence on fate of nitrogen not taken up, but indications are that losses of nitrogen are higher than can be accounted for by leaching (Russell 1973).

Much of the literature dealing with fertilisers and kikuyu incorporates a consideration of accompanying legume species. A range of clovers and other legumes have been grown in pasture with kikuyu to improve soil nitrogen status without resort to costly N fertiliser. Close grazing or mowing is necessary to avoid the build up of a dense mat of stolons which may smother the legume companion species. Kikuyu does not readily combine with legumes unless continuing attention can be given to maintaining the legume. The total yield of the combined crop may also be lower than that of kikuyu alone (Mears 1970).

Cumulative weights of nitrogen removed in harvests reported by Gartner and Everett (1970) are shown in Figure 2. These levels exceed the amount of nitrogen added in the ammonium sulphate fertiliser. In Figure 3 I have deducted the effect of N in the soil prior to treatment and it is clear that all treatments were able to remove at least 70 percent of applied nitrogen in foliage. The highest level (448 kg ha-1 N) showed removal by kikuyu of 389 kg ha-1 N or 86.8 percent of that applied.

Note also that a consideration of the removal of N by kikuyu grass during the first period following fertilisation gave uptake levels, net of that for nil treatment, as in Table 5.

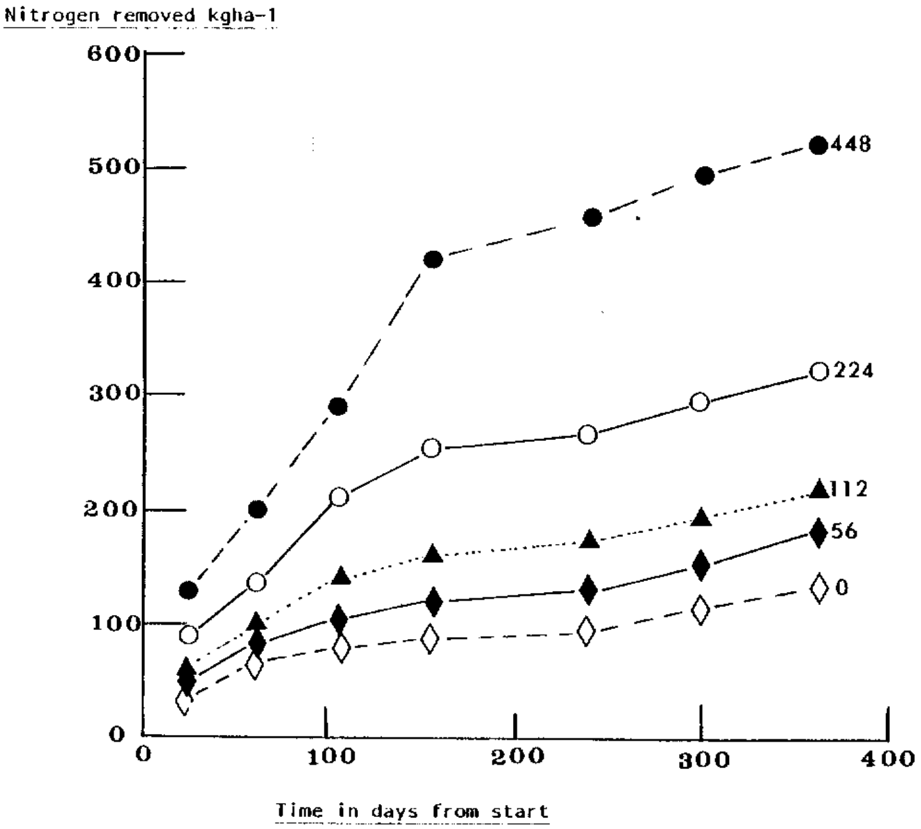

FIGURE 2. Ammonium sulphate applied to pasture of kikuyu at Millaa Millaa, North Queensland.

Cumulative weights of nitrogen over the period of observation by nitrogen application level. Legend as for Figure 1.

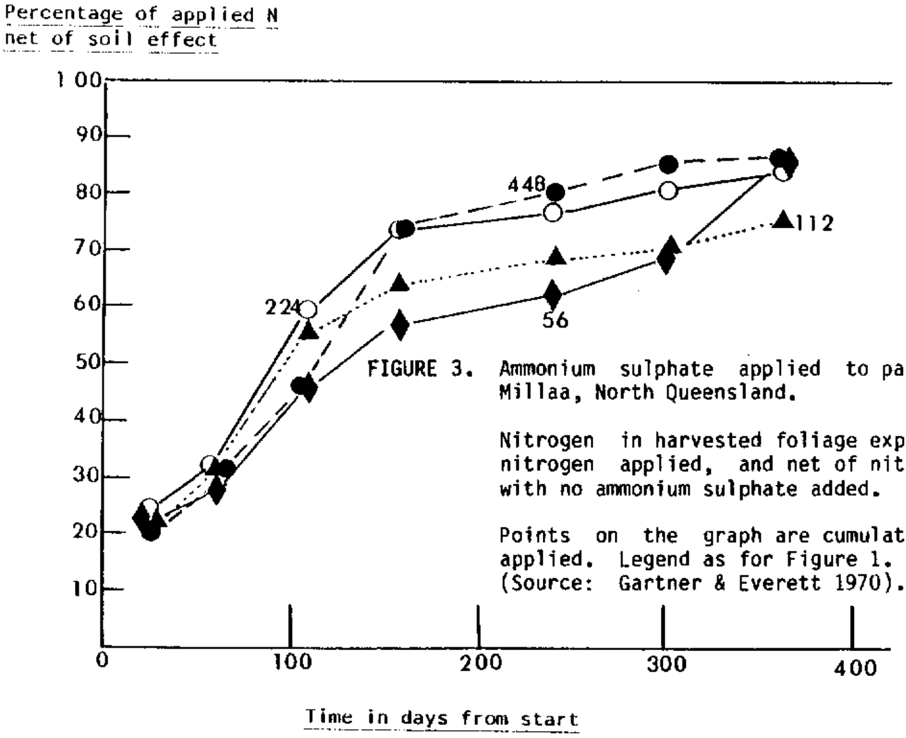

FIGURE 3. Ammonium sulphate applied to pasture of kikuyu at Millaa Millaa, North Queensland.

Nitrogen in harvested foliage expressed as a percentage of nitrogen applied, and net of nitrogen taken up by treatment with no ammonium sulphate added.

Points on the graph are cumulative (to date) of total N applied. Legend as for Figure 1.
(Source: Gartner & Everett 1970).

TABLE 5. Uptake levels of nitrogen (after Gartner & Everett 1970).

Fertiliser Level (kg ha-1 N)	Harvest Percentage 1	2
56	44	55.7
112	42	62.1
224	48	64.6
448	42	60.4

The higher treatment level was able to absorb 60.4 percent of applied nitrogen during the 62 days following application of 224 kg ha-1.

The rate of N application affects the concentration of N in all plant organs. Mears and Humphreys (1974) report, for an annual rate of 672 kg ha-1, kikuyu as having the following N percentages:

Leaf tissues	3.0 or more
Stems	1.5-2.6
Rhizomes	1.5-1.8
Roots	1.4

Underground organs of kikuyu in the upper 10 cm of soil varied from 5-10,000 kg ha-1.

Conversion to Kikuyu

Kikuyu is often associated with **Paspalum dilatatum** and **Axonopus affinis** in sub-tropical Australian dairy pastures (Gartner 1966). Kikuyu rapidly becomes dominant where fertiliser N has been applied at the minimum rate of 224 kg ha-1 (Gartner 1969). Nitrogen rates of over 200 kg ha-1 eliminated clover in a kikuyu nitrogen trial at Wokalup (Olney et al. 1981). Kikuyu is considered a weed in lawn and pasture cultivation in the Metropolitan area of Perth because of its tendency to dominate stands. Once established it is also difficult to eradicate.

Seeding and Planting of Kikuyu

Prior to seed being available conventional establishment used rooted stems planted at 0.5 to 1 m by broadcasting and rotary hoeing. Of the seed cultivars Whittet is favoured. Whittet outyielded Breakwell in first year growth under Queensland conditions (Cook & Stillman 1981). It is generally larger in form than the common kikuyu. It is slower to form a close sward but is more productive of higher feed quality and possibly more tolerant of low fertility (Reid 1981). The Whittet cultivar has 400,000 seeds kg-1. It is estimated that 1-3 kg ha-1 of seed is adequate for establishment of pasture. However, if weeds are a problem or if an early pure sward is desired then seeding rates of 3-4 kg ha-1 may be justified. Up to 11 kg ha-1 is suggested for erosion control (Reid 1981). Cuttings on a 1 m grid also give good results (Cook & Stillman 1981). If seeding is used then it is usual practice to apply nitrogen fertilisers after seeding e.g. within 2-3 weeks (Mason & Toms 1975). It is not recommended that nitrogen be added with seeding as chlorosis and depression of kikuyu may result from applying nitrogen with seed. This may be ascribed to a cation deficiency induced by an excessive uptake of nitrogen in the ammonia form (Cook & Stillman 1981).

Mowing Effects

The weight of water per unit weight of N in herbage was approximately constant from 6-18 days of regrowth but somewhat lower with N added in fertiliser (Wilman & Wright 1978b). Where N was applied herbage contained more water (lower dry matter content), than when no N was applied (Wilman & Wright 1978a).

The dry matter content for several species of mown grass regrowth following a cut tends to be moderately high after 1 week of regrowth. It then tends to decline by several percentage points in the second week and then to increase again. The increase may be delayed by application of nitrogen. The moderately high dry-matter content in early regrowth may be associated with moisture shortage within the plant (Wilman & Wright 1978a). Where silage or dried grass is required with a high proportion of green leaf as well as high digestibility an interval between cuts as short as 3 weeks may be considered worthwhile. There may be a sigmoid pattern of regrowth following cutting with comparatively slow regrowth during the first 2 weeks (Hunt et al. 1981).

Following cutting there appears to be a relationship between chemical composition and dry-matter content. Wilman and Wright (1978b) report that chlorophyll content in leaf blades increased during regrowth and was increased by N application.

Mowing Effects on Kikuyu

Effective maintenance of kikuyu grass with applied nitrogen demands a knowledge of the interaction of frequency and severity of cutting with nitrogen application rates. Mowing is a sudden event. Regrowth from cut stubble involves slow development of new shoots which would have been shaded previously. Kikuyu may be better suited to gradual defoliation under grazing than to mowing as grazing would favour the continuous formation of new shoots and maintenance of more residual leaf area. If kikuyu is mowed then the regrowth period must be long enough to allow a recovery period followed by a period of rapid growth. Whitney (1974b) suggests that, for Hawaii at least, this should be at least 6 weeks in all. Colman (1966b) examined the interaction of cutting interval and N application. Cutting frequencies were 2, 4, 6 and 12 weeks against 0, 112, and 224 kg ha-1 N.

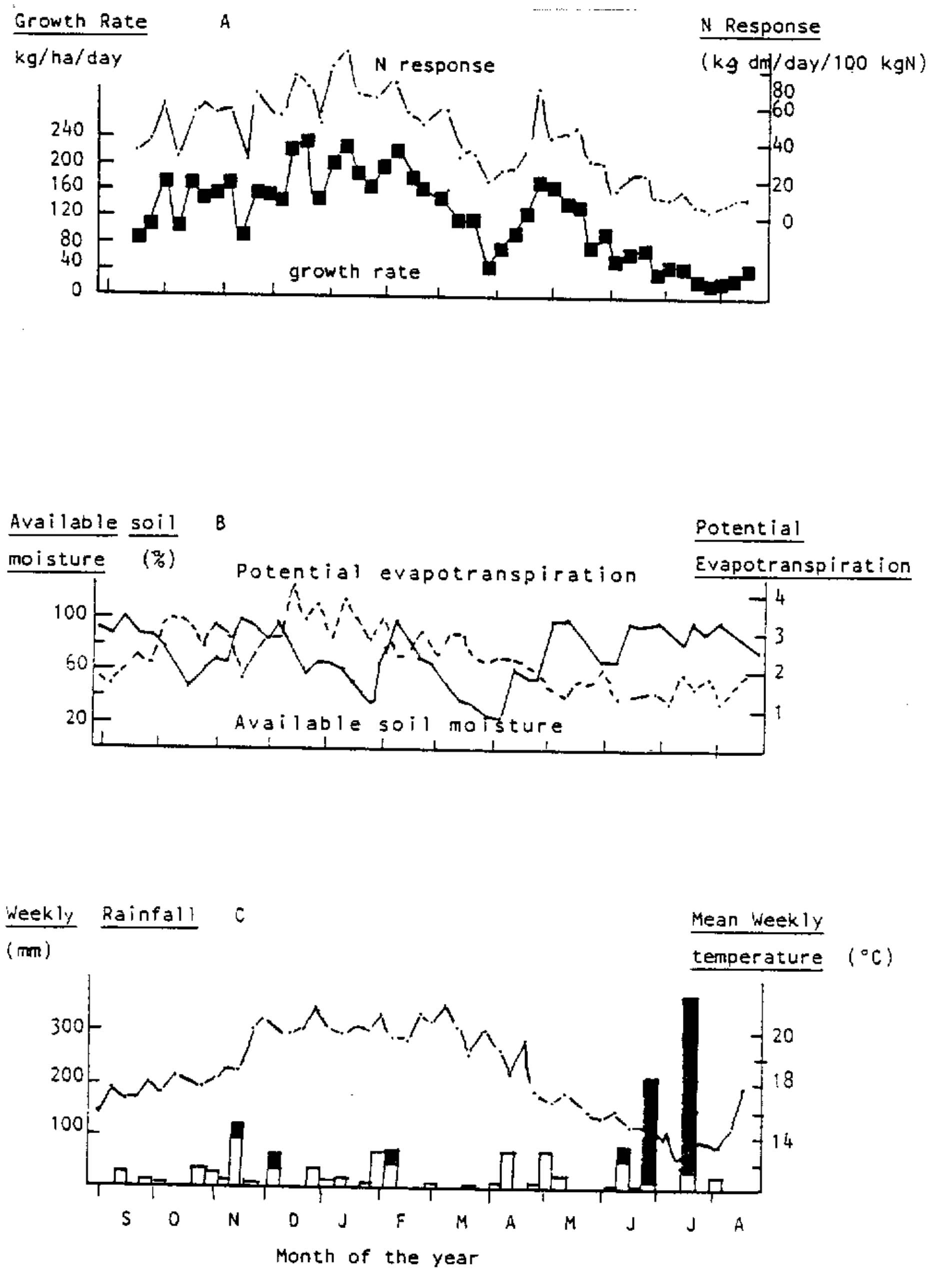

FIGURE 4. Mean 2-week growth rates of kikuyu grass at 224kg N and N response (A); available soil moisture and potential evapotranspiration (B); rainfall and temperature (C) over one year (After Colman & O'Neill 1978).

Frequent cutting (every 2 weeks) reduced dry matter yield by 54 to 25 percent compared to the maximum yield at the 12 weekly cutting interval. The depression of dry matter yield was greater in the presence of nitrogen than in its absence.

Maximum yields are perhaps more likely with heavy grazing compared with cutting. Sudden, complete defoliation of well-grown kikuyu in high-nitrogen treatments delays regrowth (Gartner & Everett 1970). Murtagh (1975) avoided the problem of repeatedly cutting the same plots by using replication in time.

Level of Cutting of the Sward

Plots established by Awad, Edwards and Huett (1979) were mown to a height of 5 cm whereas Colman and O'Neill (1978) used 3 cm for cutting with a shearing handpiece. A cutting height of 10 cm was used in experiments reported by Cook and Stillman (1981).

Colman and O'Neill (1978) suggest that close mowing prior to fertilisation may have improved leaf density and increased the number of tillers (Mears & Humphreys 1974). Higher nitrogen recovery rates by Colman and O'Neill (1978) may be attributed to their low cutting level. The suggestion is that more nitrogen is retained in stubble at higher cutting levels. The large yield of rhizome material (Mears & Humphreys 1974) under kikuyu could also retain nitrogen. The high level of retention reported by Gartner and Everett (1970) may have been influenced by grazing between harvests.

Irrigation

It is possible to increase efficiency of nitrogen fertilisers particularly when the crop foliage is well developed, by spraying the crop. This will give uptakes of the order of 70 percent, but it is only possible to apply a relatively low dressing (about 10 kg ha-1 N per application) if efficiencies as high as this are to be obtained. In practice, the correct timing of the application, after the crop roots have developed and during conditions of active growth will increase the proportion of fertiliser taken up.

After some 3-5 years of irrigated growth kikuyu will build up a mat of fibrous tissue beneath the actively growing grass (McGhie et al. 1981). It is then necessary to scarify the material. Similar problems also occur on sandy soils with heavily irrigated turf species. The latter is referred to as 'soil clogging' in the description by Carbon (1980). It is caused by build up of a thatch of material between the green grass and the soil surface. The dead parts of the grass not removed in mowing may not break down quickly under irrigation. The thatch then restricts water infiltration into the sand below. It is important that mown grass tops be removed, that no surface dressings of clay materials be applied and that water collection into low lying places be avoided as far as possible. When the thatch has accumulated scarification may allow some control. The thatch can be physically removed, or the entire grass system removed, the surface regraded and resown. For a turfgrass stand of burmudagrass, Cynodon dactylon, Meinhold et al. (1973) record that ammonium sulphate increases the rate of thatch accumulation. After 3 years growth in Hawaii thatch accumulation affected regrowth of kikuyu (Whitney 1974a).

No references have been unearthed dealing with the incorporation of fertiliser in the water supply. For lawns sprinkler systems are in use but other tighter swards are usually preferred to kikuyu. In the south-west irrigation is by flood application at intervals. Kemp (1976) provided details of the nitrogen uptake in irrigated kikuyu at Taree. Table 6 is taken from his work.

These uptake levels are lower than many rainfed systems and suggest that the mobile nitrogen sources are more readily lost with irrigation. Although the quantity of N recovered increased with higher application, it was proportionately low. The nine week cutting frequency produced significantly greater yields (see above, mowing effects) than 3 weeks at all N levels and was also more productive than at 6 weeks, though not significantly so.

TABLE 6. Percentage nitrogen recovery (Kemp 1976).

Nitrogen Level	0	N Applied	
Cutting Interval	(N recovered kg ha-1)	950 (kg N)	2860 (kg N)
3 weeks	275	40.6	16.8
6 weeks	239	52.3	23.3
9 weeks	315	49.8	21.6

Economic Value

The annual responses of accumulated harvests to accumulated inputs of fertiliser N show 'profitable responses' to annual totals of 448-504 kg ha-1 N with perennial ryegrass (Hunt et al. 1981). Conventional economic value is related to dry matter production provided this is sufficiently well balanced in nutrients to be edible (without detriment) to stock. Frequency of defoliation affects chemical composition of kikuyu. With increasing age of regrowth, crude protein and mineral content decline while fibre content increases. Kikuyu as silage suffers considerable loss of dry matter and digestibility is 19.5 units lower than the freshly cut grass.

Several studies have examined seasonal fluctuation in nutrient content of kikuyu. Generally the mineral requirement of grazing stock can be satisfied from fertilised kikuyu, with the possible exception of calcium for beef cattle in Hawaii (Mears 1970). The leaves tend to have a high crude protein content and levels in cuts taken at 31-150 days of regrowth never fell below 12 percent. The digestibility of kikuyu dry matter compares favourably with other tropical grasses but values are lower than those for temperate species at equivalent stages of growth (Table 7).

TABLE 7. Maximum and minimum dry matter digestibility of kikuyu pasture.

Location	Maximum (%)	Minimum (%)
New South Wales	73.9 (36)	53.3 (180)
Hawaii	60.4 (42)	40.2 (168)
Queensland	63.0 (20)	53.0 (150)

( ) days of regrowth (after Mears 1970).

Highest nitrogen contents occur in very young herbage and older growth when growth rate is reduced by low temperature (Colman & O'Neill 1978).

Growth Prediction

A series of regression equations produced by Colman and O'Neill (1978) to describe growth are:

1 $GR = 1.52\ W + 0.16$

2 $GR = 1.93\ W + 21.22$

$RN = 5.98\ TM - 66.93$

$RN = 0.61\ W + 7.93$

$ANR\% = 4.11\ TM - 49.61$

$ANR\% = 0.56\ W - 7.39$

Where GR = growth rate in kilogram dry matter per hectare per day at either of
1 112 kg N ha-1 as calcium ammonium nitrate or
2 224 kg N ha-1 as calcium ammonium nitrate, applied before the growth period commenced.

RN = response to nitrogen as kg dm ha-1 day-1 per 100 kg N applied,
ANR% = apparent percentage nitrogen recovery of that applied,
TM = mean temperature and
W = available soil moisture.

Table 8 illustrates predicted and measured yields. It is suggested that differences between the two at the same location may be due to:-

1. growth limitation due to moisture stress
2. inclusion in yield of slow growth periods
3. variable N application and cutting strategies
4. differences in temperatures.

Alternative Species and Systems

A range of grass species have been irrigated to obtain high growth rates. Of six irrigated forage grasses grown in Colorado although all showed increases in percentage nitrogen content with fertiliser N (urea) over the range 0-717 kg ha-1 only 3 did not show a continuous decline in percentage nitrogen recovery. These three peaked at 179 kg ha-1 N with levels of 46-64 percent. Two species, **Agropyron intermedium** and **Bromus inermis** had highest percentage nitrogen recovery at 717 kg ha-1 with 35 percent. These species had 2.8 and 3.4 percent tissue nitrogen at this recovery rate (Dotzenko 1961).

In the coastal plain region near Perth Roberts and Carbon (1969) examined the growth of a range of grass and legume species using sprinkler irrigation. The grass species which yielded most dry matter was **Pennisetum purpureum** (elephant grass) at 42,900 kg ha-1. Other high yielding species were:

Eragrostis curvula	32,800	(weeping lovegrass)
Chloris gayana	23,600-26,200	(Rhodes grass)
Digitaria decumbens	21,000-21,500	(Pangola grass)
Hyparrhenia hirta	30,318	(African bluestream)

TABLE 8. Predicted annual dry matter production with adequate moisture and nitrogen compared with actual dry matter production of kikuyu grass from successive harvests in cutting experiments.

References	Location	Latitude	Yields Predicted (t ha-1 yr-1)	 Measured (t ha-1 yr-1)	Nitrogen Rate (kg ha-1 N yr-1)
1	Wollongbar	29°S	43.2	31.4 d	1345
2	Taree	32°S	34.2	24.9 i	950
3	Hawaii	20°N	36.9	23.7 i	874
3	Hawaii	20°N	46.1	30.0 i	874
4	Kenya	0°	6.7	8.4 d	246
*	New Zealand	40°S	14.4	14.9 d	500
	(October-April)		13.7	16.8 i	-
*	New Zealand	35°C	26.7	8.7 d	142
	(November-April)		17.6	12.3 i	242

d = dryland; i = irrigated

References: 1 Colman and O'Neill 1978; 2 Kemp 1976; 3 Whitney 1974a; 4 Morrison 1966; * see reference 1 (extracted from Colman & O'Neill 1978)

These production figures relate to plots on Spearwood sand. Production from Bassendean sand was lower in each case. By contrast production from kikuyu grass was 12,000 kg ha-1. These high yielding species are all predominantly summer growers and were provided with '45-60 mm' of water per week through the summer in 2 or 3 instalments. The rates of fertilisers used were (N:P:K) 252:99:202.5; 348:150:480; or 252:99:270; kg ha-1 in equal dressings, spaced out with two-thirds given in summer and one-third in winter months. No information is provided on nitrogen uptake. Subsequently further work was undertaken on **Eragrostis curvula** (Carbon **et** al. 1973). The production of this species was some 30,000 kg ha-1 dry matter on plots receiving 300 kg ha-1 N in summer, and some winter growth was reported.

The potential uptake of nitrogen was not given in the above work. Turfgrass of **Cynodon dactylon** has been recorded as receiving 862 kg ha-1 N in the U.S. as ammonium sulphate divided into fortnightly applications over a summer growing period. Complementary potassium of 431 kg ha-1 was also supplied (Meinhold **et al.** 1973). Cooper (1970) reviewed the apparent productivity of a range of grass species worldwide (Table 9).

The possibility exists for growth of a winter/early spring crop of perennial ryegrass combined with a summer crop of kikuyu. Alternatively summer forage species could be grown for hay (Stuart 1983) with an over winter crop of oats or ryegrass. These kinds of combinations may entail twice annual seeding and careful management. Both Rhodes grass and Elephant grass may recover up to 80 percent of nitrogen applied (B. Carbon, pers. comm.). The advantages of these species, and also of perennial rye winter growth is that hay can be made from the cutting regimes. Kikuyu being a lower grass is not readily made into hay, and there is little market for it. Most growers store it as silage for their own use (W. Russell, pers. comm.).

Conclusions

Mobile nutrients such as N are concentrated in young tissue and are exported to other growing tissues as this tissue ages. Hence a continuous removal of new young growth could theoretically tie up maximum amounts of nitrogen in plant material. Mowing at a particular time or stage of regrowth is inevitably a compromise in removal of tissue and N with the resupply of N and recommencement of growth.

Nitrogen from ammonium sulphate in solid form may become available 2 weeks or more after it is applied (Whitney 1974a). Regrowth is generally rapid from about 4 weeks and the total annual harvest yield appears to be at a maximum when cutting is taken at intervals greater than 6 weeks and up to 10 weeks from previous cutting.

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TABLE 9. Maximum production and nitrogen used for fast growing grass species.

Species		Maximum production	N applied kg ha-1 yr-1	Country Reported
Lolium perenne	Perennial ryegrass	25.2	706 (892)	UK
Cynodon dactylon	Couch	30.1	1344(1792)	USA
Chloris gayana	Rhodes grass	23.5	448	Australia
Pennisetum clandestinum	Kikuyu grass	30.0	1120	Australia
Pennisetum purpureum	Elephant grass	84.7	896(1344)	Puerto Rico
Digitaria decumbens	Pangola grass	50.6	1344	Colombia

Figures in brackets represent the following yields (t ha-1 yr-1) 892 = 19.5 (UK); 1792 = 27.2 (USA); 1344 = 66.5 (Puerto Rico). (Source: Cooper 1970).

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ECOLOGICAL NOTES ON ACACIA SPECIES
2. ACACIA CYCLOPS

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Introduction

Acacia cyclops A. Cunn. ex G. Don is a common plant of the coastal dunes. It occurs naturally in Western Australia and South Australia. It is a dense, low branched, rounded shrub. Phyllodes are 3-9 cm long and conspicuously veined. Flower-heads are stalked, axillary and produced in summer. Legumes are leathery, twisted and remain on the plant for a year or so after the seed has ripened. Seeds are distinguished by a thick orange to red funicle which encircles the seed. It is referred to as Western Coastal Wattle by Whibley (1980) and in South Africa it is known as Rooikrans (Hall & Boucher 1977).

Geographical Distribution

Distribution is wholly coastal. In Western Australia it is reported from the Hill River map sheet north of Perth to Burnabbie in the south-east (Hnatiuk & Maslin 1980). In South Australia it occurs patchily from the Nullabor through Eyre Peninsula and eastwards with a few occurrences on Yorke Peninsula, and the Northern Lofty and Kangaroo Island regions where it is doubtfully native (Whibley 1980).

Acacia cyclops occurs on a number of islands off the Western Australian coast. It is present on Carnac, Garden and Rottnest Islands west of Perth (Marchant & Abbott 1981) and is also present on North Boullanger (30°19'S), Hamelin (34°13'), Middle Doubtful (34°22'S), West Doubtful (34°22') (Abbott 1980a) and, near Albany, on Mistaken and Michaelmas Islands (35°03'S) (Abbott 1981).

It has not been recorded on the Western Australian coast between mapsheets Augusta and Albany (i.e. absent on sheets Pemberton, Irwin Inlet, Mount Barker). It is absent from Chatham Island (p.c. I. Abbott). There are large gaps in its recorded distribution between Eucla and Yorke Peninsula (Whibley 1980).

Habitat

a) Climate and Topography

Acacia cyclops occurs in the region with a typically Mediterranean climate. There is a cool, wet period and a warm, dry period with short periods of transition. During May to August the south-west is subject to rain bearing winds. During the winter there is a surplus of rainfall over evaporation while during the summer there is a marked deficiency of rainfall. Rainfall effectiveness increases rapidly around April and decreases just as rapidly in late August. For the intervening six months conditions are drier. Some soil water is still available until early December. During the summer plants probably obtain much of their moisture requirement from dew forming at night. To the north rainfall is 540 mm per annum (Jurien Bay, north of Hill River) where evaporation is 2000-2400 mm, with a 4-5 months growing season from May to September. In the extreme south-west (Yallingup, near Augusta) rainfall is 930 mm, with evaporation less than 1000 mm and 7-8 months growing season from April to September. Albany, at the southern limit of **A. cyclops'** distribution has an annual rainfall of 944 mm per annum. Evaporation here is less than 1000 mm per annum, and the growing season is 8-9 months long, from April to December. Higher rainfall (1000 mm) coupled with low temperatures may explain its absence between the Augusta and Albany map sheets.

In southern Western Australia it generally occurs no more than about 20 m above sea level, in and near coastal dunes, or to 50 m or so on cliffs.

In South Africa it is found on the lower slopes of mountains, with an upper limit of about 300 m altitude.

b) Soils

Acacia cyclops is common on beach sand dunes, on sandy soils over limestone outcrops and on limestone soils of the coastal plains. The soils are calcareous sands, shallow calcareous loams to sandy loams, or brown calcareous earths. It may extend up river courses if limestone soils are present. On the south coast it may occur up to 25 km inland. In both Australia and South Africa it can be found on disturbed soils of an alkaline nature. The S. African distribution is shown in Hall and Boucher (1977).

A. cyclops is apparently sensitive to soil pH, preferring neutral to slightly alkaline soils, and is one of the few Acacias adapted to alkaline soils.

Roux and Middlemiss (1963) suggest that the altitudinal limit is set by soil pH, as the soil reaction of higher mountain slopes is known to be acid. The lower slopes of mountains facing prevailing winds are usually covered to some depth by wind blown sand in South Africa, and so might be expected to exhibit pH and other conditions resembling those of dunes.

In Western Australia **A. cyclops** is not limited in its geographical distribution by edaphic characteristics as calcareous sand dunes extend both north and east of its limits. Although acid swamp soils occur near the coast between Augusta and Albany, they do not reach the coast which is composed of calcareous dunes. The absence of **A. cyclops** there may be presumed due to extremely moist soils or low temperature.

The distribution of **A. cyclops** inland is determined by edaphic conditions. It will not grow on the older sand dunes of the coastal plains, from which carbonates have been leached out, and only occurs to any extent inland along water courses.

Mulga Research Centre Journal No. 8
Published November 1st 1985, 59-68.

Communities

A. cyclops occurs in association or alliance with other shrubs on both sand dunes and granite lithic complexes of the south west. These are generally low stature communities best described as coastal heath or scrub.

The seaward fringe of dunes is usually colonised by such species as **Cakile maritima** and **Arctotheca populifolia.** Behind these plants the long creeping rhizomatous grasses **Spinifex hirsutus** and **S. longifolius** bind the sand for plants such as **Scirpus nodosus, Calocephalus brownii, Lepidosperma gladiatum, Carpobrotus** sp., **Pelargonium** sp. and **Tetragonia decumbens** to become established.

Swales follow the primary dunes. These are followed by secondary dunes where salt and sand-blasted bushes of such species as **Olearia axillaris, Scaevola crassifolia, Myoporum adscendens, Santalum acuminatum** and **A. cyclops** occur. These grow to various shapes and heights, depending on the degree of protection provided from wind by the dunes.

In the Darling botanical district, the Perth basin with its narrow strip of Recent or Pleistocene sand dunes carries an association including **Acacia rostellifera, A. cyclops, A. cochlearis** over most of its length. Species observed closely associated with **A. cyclops** include **Ammophila arenaria, Scaevola crassifolia, Tetragonia decumbens** and **Olearia axillaris.** Similar vegetation extends north into the Irwin botanical district (Aplin 1975). Further south **Agonis flexuosa** becomes common with the mixed coastal Acacia species. Further along the coast into the Eyre botanical district, **Eucalyptus platypoda** occurs with **Acacia cyclops** in coastal heath.

Woodman Point, south of Fremantle, is perhaps a typical location for **Acacia cyclops** (see Powell & Emberson 1981, Rye 1981). From more or less natural areas Rye (1981) recorded a total of 74 species of plants. Of these species some 24 are non-native and 50 are native. Only 2 species, **Eucalyptus gomphocephala** (tuart) and **Callitris preissii** could be classed as trees, though both **Acacia rostellifera** and the much less common **A. saligna** of the wattles and also the quandong, **Santalum acuminatum** sometimes grow into tree form. A further 4 species may be classed as tall shrubs:- **Acacia cyclops, Leptospermum laevigatum, Leucopogon australis** and **Melaleuca huegelii.**

Of the remainder 20 are shrubs, 5 climbers, 1 mistletoe, and 39 herbs. Of the herbs 24 are annuals, the remainder perennials. Thirty three plant families are represented amongst the species. Of particular interest is the absence of any Proteaceae, and presence of comparatively few Myrtaceae (4 species) and Fabaceae (4 species, 2 of which are exotic weeds). **Acacia rostellifera** tends to be the most frequent woody perennial but both **Acacia cyclops** and **A. cochlearis** are fairly common in and near **Callitris** stands. However **A. rostellifera** forms dense thickets in its own right, and is often intermingled with **Callitris** and extends into the adjacent tuart woodland.

Information on associated species present on island communities is given in McArthur (1957) particularly for Garden Island, and in Abbott (1980b) particularly in respect of Carnac Island. **Acacia cyclops** is scarce on Rottnest and Carnac but commoner on Garden Island (p.c. I. Abbott).

Response to Biotic Factors

Evidence from South Africa suggests that **A. cyclops** may have allelopathic properties. There is an absence of undergrowth associated with the species. This appears to be mainly a shade or root competition effect in Western Australia. Jones **et al.** (1963) obtained root, pod and leaf extracts and tested their effects on the germinaton of endemic South African flora. The species tested were **Senecio burchellii, Cnidium suffruticosum** and **Chironia baccifera.** Germination of **S. burchellii** was slightly inhibited and delayed by extracts of roots and pods. No effects of extracts of leaf material could be demonstrated. Similar effects were shown with the other two species treated with root extracts. Boiling extracts briefly significantly decreased the inhibiting properties, indicating that the inhibiting substance(s) is(are) thermolabile. Jones et al. (1963) demonstrated that germination inhibitors were not toxic to all plants and that antibacterial substances are produced by young living seedlings.

Fire will kill mature plants but is not believed to be an important stimulus to seed germination in Western Australia as the coastal dune habitat rarely burns. However Hall (1961) suggests fire may have assisted its spread in South Africa. Some evidence is available from an exclosure plot at Yalgorup National Park that rabbits may cull small seedlings.

Performance

a) Gregariousness

Plants occur singly in exposed locations on dunes. In swales several plants may occur together. The dense thickets reported from South Africa (e.g. Jones **et al.** 1963) are not generally seen in Western Australia where Acacia **rostellifera** tends to dominate with a superior suckering ability and strong regrowth after disturbance.

b) Performance in Various Habitats

The principal habitat is the coastal sand dune belt. There the height and shape of individuals is affected by the degree of protection. In exposed places the pruning effects of wind, sand and salt produce a low, spreading shrub which tends to lean away from the prevailing wind direction. Where plants grow on the rear side of dunes, shoots grow to a height determined by the top of the dune in front.

In sheltered localities **A. cyclops** is more tree-like, with several spreading main branches bearing a canopy of foliage often reaching down to the ground.

A. cyclops is useful for fixing mobile dunes. King (1939) considered that **A. cyclops** was preferable to **A. saligna** for this purpose as it is more resistant to salt-laden winds. **A. cyclops** was introduced successfully to the Cape Flats in South Africa in the 1870s, in an attempt to stabilise drifting dunes (Roux & Middlemiss 1963). This attempt was successful, but **A. cyclops** has since become a weed in South Africa, displacing the native flora. In South Africa it is confined to the coastal dunes, the Cape Flats and lower slopes of mountains. It is found among native species in new sand dunes (New 1984).

In both Australia and South Africa **A. cyclops** is found in disturbed areas, such as road edges.

c) Effect of Extreme Conditions

Salinity

Leaf scorch can occur due to foliar salt scorch on exposed phyllodes.

Calcareous Substrate

Acacia cyclops is a calcicole.

Drought

Acacia cyclops is xeromorphic. It has heavily cutinized phyllodes and phyllode rigidity may also serve to restrict moisture loss. The species has been grown in semi-arid country overseas. Data on growth of **A. cyclops** in the Negev desert region is given in Heth and Dan (1978).

Frost

It is possible that low temperatures may be a limiting factor to **A. cyclops**' spread eastwards. Although frost is not considered an important factor for coastal locations occasional occurrence could be important. The most susceptible parts of the plant to frost damage are the actively elongating internodes and the young apical tissues (Perry 1972). Damage is caused by ice crystal formation within plant tissue, believed due to dehydration and mechanical disruption of cell membranes, following growth of extracellular ice and withdrawal of water from cells. It may be speculated that tolerance of phyllodes, and to a lesser extent stems, to ice formation, is associated with large proportions of intercellular space. More compact tissues found in the apex and rapidly elongating section of the internodes appear incapable of tolerating internal crystal formation.

Adaptive Features

a) Morphology

A. cyclops has been described by Whibley (1980) as a dense bushy, rounded, glabrous spreading shrub. It grows 2-4 m tall and to 6 m or more across. Branches occur close to the ground, with foliage often drooping to ground level. Phyllodes are narrowly oblong to narrowly obovate 3-9 cm x 6-12 mm, straight or curved, leathery with 3-5 longitudinal nerves. The phyllode apex is obtuse with a small, hard lateral mucro, glands are basal. Flowers are borne in short racemes with 2-3 heads, globular, and are yellow in colour. The legumes are 4-10 cm x 8-12 mm, curved and twisting on drying, leathery and greyish brown when mature. Seeds are black and shiny with a thick conspicuous arillate funicle, red to yellowish orange in colour, which encircles the seed in a double fold.

The young plant has pinnate foliage which is replaced by rigid phyllodes when a height of about 15-20 cm is attained. The phyllodes are iso-bilateral, flattened in the vertical plane and strongly xeromorphic. The stomata appear sunken beneath the cutinized epidermis. Lignified sclerenchyma surrounds the vascular bundles. These features all assist the plant in minimising moisture loss.

b) Mycorrhiza

No observations have been made on mycorrhiza. Root nodules occur, and appear as early as 2.5 weeks on glasshouse grown seedlings.

Roux and Warren (1963) examined symbiotic nitrogen fixation in **A. cyclops**. Germinating seeds were sown in sand and watered daily with a nutrient solution lacking nitrogen. Plants were reared in twelve separate containers; six were innoculated with an infusion of root nodules of **A. cyclops**; six served as controls. After five months the six individual plants in the innoculated section and one plant in the control section were still growing. All other plants had lost their leaves or were dying. All seven healthy plants showed well developed root nodules. It appeared that one of the plants in the control section had been innoculated by accident.

The seven plants were dried and assayed for nitrogen. Ten ungerminated seeds of **A. cyclops** were assayed in the same way. Total nitrogen per plant was found to be 19.4 mg. Total nitrogen per seed was 12.1 mg. Thus, 7.3 mg of nitrogen was fixed by each plant, proving that nitrogen fixation had occurred.

Phenology

Acacia cyclops flowers from about December to March. During this period, flower heads mature independently of one another. Thus, at any stage during the flowering season any one plant will exhibit all stages of flower development, from bud to mature flower.

Flowering ceases between March and May. During this period the first mature pods begin to appear on the plant. On maturity the pods twist and split down both edges. The seed is either dispersed then or may remain hanging by the funicle until agitation by wind causes the seeds to fall. Old mature pods remain attached to the wood for some time.

Most seeds remaining attached to the pods are attacked by insects. Birds frequent the larger shrubs, possibly aiding in dispersal of the seeds. Ants can be seen in late summer on branches and on the ground under the shrubs. These may be observed carrying seeds into middens spaced out around the shrubs.

Leaf fall appears heaviest in mid-winter.

Life History

a) Floral Biology

The flowers form an inflorescence known as a head. Two or three heads, borne on short branches, are found in the leaf axils. The heads are globular and 5 mm diameter. Flowers are small, about 40 to a head, and yellow. They are regular and bisexual. Stamens are numerous, possess two pollen sacs and are basifixed. The elongated style projects beyond the anthers suggesting that **A. cyclops** is pollinated by insects. Bees may be important as pollinators since they are strongly attracted by yellow, scented flowers (Wilson & Loomis 1962). Other possible insect pollinators are members of the Coleoptera, Diptera and Hymenoptera.

The small flowers, reduced perianth and long stamens are also suggestive of wind pollination. **A. cyclops** is thus assured of cross pollination, for if the pollen is not removed by insects it may be carried away by wind.

b) Hybrids

Hybrids are not known.

c) Seed Production and Dispersal

Although many flowers in a head may be fertilised only 1-4 pods generally mature into a curled cluster, with the remainder aborting early. Some 6-12 seeds develop per pod; Milton (1980) gives a mean value of 8.8 per pod. She reports seed production of 1000-3000 seeds per square metre of projected canopy foliage per annum from mature shrubs.

The seeds commence to fall to the ground after pods have dried and opened. On the ground they may be collected by ants for their funicles, and aggregated at middens, in common with many Australian Acacias (Berg 1975). The seed may persist attached to the funicles for as long as five months (Glyphis **et al.** 1981). The bright colour may be attractive to birds, and birds are believed to disperse A. cyclops in South Africa (New 1984). Some 21 species of birds have been listed as potential dispersers of the species in South Africa (Middlemiss 1963). Dispersal by birds may be 100 m or more from the parent shrub (Glyphis et al. 1981). Birds have been observed to feed on seeds in Western Australia (p.c. I. Abbott).

Mean seed weight is 28.3 ± 0.7 mg with funicles intact and 19.8 ± 0.4 with funicles removed, for a batch collected at Yalgorup National Park, south of Perth.

d) Viability of Seeds, Germination

Soft Seed

In common with many other species the seed is hard. Waxy or pectic materials are associated with the outer palisade cells of the thick seed coat. Tannin from the pods probably also adheres to the seed coat (Bailey 1963). These factors account for the impermeable nature of the seed coat, and this requires some abrasive action to permit moisture absorption. The concept of 'hard-seededness' in legumes generally is usually taken to relate to the proportions of 'soft' seed in a batch. Here 'soft' seed means those seeds which germinate without any pre-treatment, that is the seed will germinate with the provision of moisture.

It has been suggested that **A. cyclops** seed germinate readily with no pre-treatment, and that it does not tolerate experimental heat treatment (Christensen & Kimber 1975). In this context hard-seededness is said to be rare or absent in **A. cyclops** (Christensen 1978). Martin **et al.** (1975) observe that moist heat increases germination in some legumes and dry heat does so for other species. In some Western Australian forest species both dry and moist heat may promote germination, there are considerable differences between species and time is important (Christensen & Kimber 1975). It is generally the case that extended periods of high temperature will result in seed death, and this mortality factor is probably related to the degree of protection afforded by the seed coat.

In an experiment undertaken at WAIT in 1978 a batch of 400 seed collected from Yalgorup National Park was boiled for 5 minutes prior to being distributed to 4 different temperature regimes in growth cabinets. After 20 days this experiment was terminated as no germination had occurred and it was presumed that all seed had been killed by the treatment. Christensen et al. (1981) indicate that a similarly high viability of **A. cyclops** seed can be obtained with no heat treatment to that given two minutes exposure to dry heat at 90, 120 and 150°C, or to 10 minutes exposure at 90°C. The viability declined rapidly for exposures greater than 90°C for more than 2 minutes, but remained high for 3 hours exposure to 90°C.

These experiments suggest that with **A. cyclops** there is a degree of soft seededness, that severe heating is lethal, but that total germination attained differs little between non-lethal treatments. Christensen **et al.** (1981) did not report the percentage germination or the time taken to reach the equivalency of viability. The freshness of this seed was also not reported. All three factors are of interest, but seed freshness is likely to produce greatest effect on soft seededness.

A further experiment conducted at WAIT in 1978 examined whether removal of the funicle affects germination rate. In this experiment batches of seed were given no heat treatment prior to placement in growth cabinets at a range of conditions. There was no difference in viability to 50 days with or without funicle, with mean viability of 7.7 percent. Total germination was highest in a 25°C 12 hr light/15°C 12 hr darkness regime (12 percent) where no more germinants were recorded after 30 days. At lower temperatures germination time was prolonged and the final 50 day viability rate was lower (mean of 13 and 18°C regimes 5.5 percent). The overall mean time course of germination is illustrated in Figure 1.

Milton (1980) reports a 2 percent viability for freshly collected seed germinated with no treatment, and refers to unpublished work giving 17 percent. The solution to the enigma of soft seededness in this species appears to lie in the ageing process. Milton (1980) notes that only 20-40 percent of seed will remain dormant after 1-2 years storage, so that depending on the time from collection the soft-seeded component will increase fairly rapidly. The hard-seeded soil store does not build up as quickly as in other Acacia species, and Milton (1980) reported only 26 percent germination of **A. cyclops** seed after fire. In the case of seed taken from the soil she found 9 percent soft seed.

Conditioning and Viability

Moist heat is thought to simulate conditions in a forest fire more closely than dry heat, as moisture is available from thermal degradation and combustion of woody fuels as well as the subsoil (Martin **et al.** 1975). Results obtained by Jones (1963) indicate that the best moist heat treatment for **A. cyclops** seeds is to pour boiling water over and through the seeds. This resulted in a germination percentage of 90 percent in 67 days.

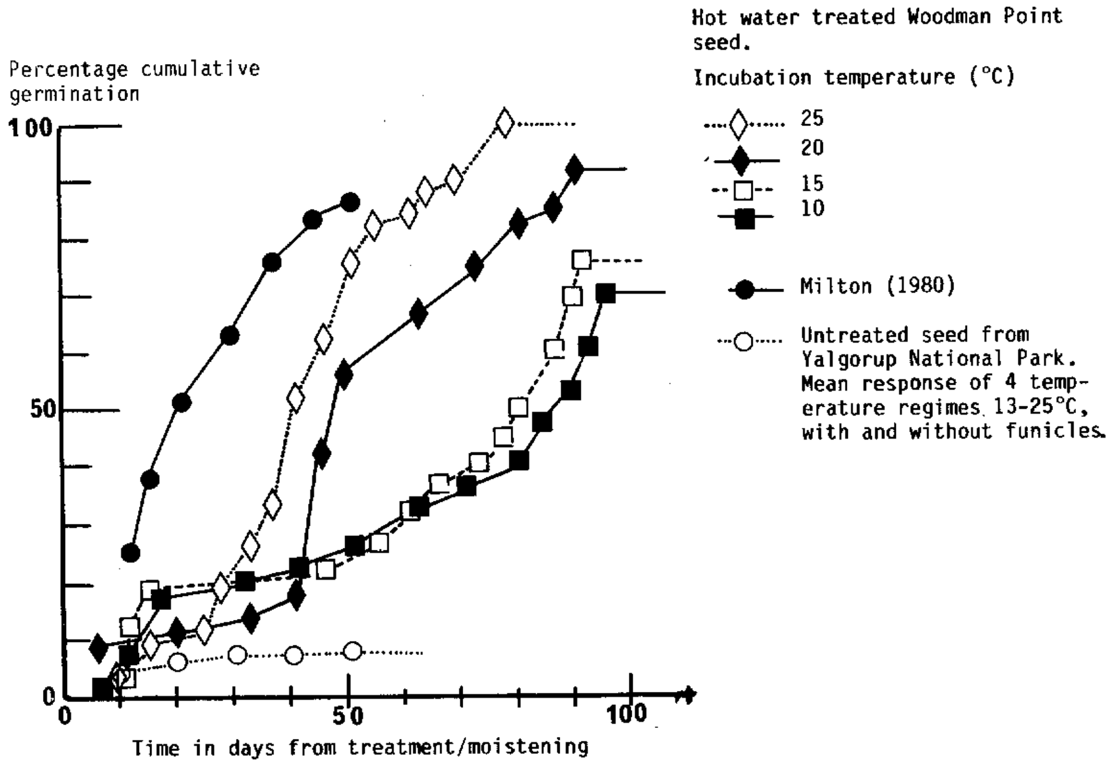

FIGURE 1. Time course of germination in Acacia cyclops. Four sets given hot water treatment and placed in growth cabinets at 10, 15, 20 and 25°C (seed ex Woodman Point); untreated seed (ex Yalgorup National Park); and soil stored seed given two hot water treatments (Milton 1980, Milton & Hall 1981).

Nicking the seeds (without exposing the embryo) and certain sulphuric acid treatments have been found to be more effective than boiling water in increasing the germination of viable seeds. Jones (1963) obtained 92 percent germination after 33 days by nicking seeds and 88 percent after the same time following 240 min. in sulphuric acid. These high viability levels suggest that seed maturity must have an effect on the effectiveness of pre-germination conditioning treatments.

A batch of freshly picked seed was subjected to hot water treatment at WAIT in early 1980. This seed came from Woodman Point. Funicles were removed prior to treatment. Sets of 50 apparently sound seed were transferred to growth cabinets (in petri dishes) set at 10, 15, 20, 25°C in darkness. The time course of germination for this experiment is shown in Figure 1. The seed absorbed moisture irregularly, some seed containing 60 percent moisture a day after treatment, but others did not swell up for some time. The first germinations were recorded after 6 days at 10 and 20°C. The overall viability (up to 96 days from treatment when observations ceased) was 84.5 percent. Table 1 summarises the germination measurements. The rate of germination was more rapid at increasing temperatures, and viability (to termination at 100 days) was also temperature related.

TABLE 1. Germination measurements for **Acacia cyclops** ex Woodman Point, tested in 1980.

	Temperature			
Measurement	10	15	20	25
Final percentage	70	76	92	100
Days to final	96	91	91	78
Germination rate (mean days)	60.7	61.0	52.7	41.3
Peak Value	1.07	1.13	1.33	1.49
MDG	0.73	0.84	1.01	1.28
GV	0.78	0.95	1.35	1.91
Energy 21/42 (%)	81.8	100	100	50
G. Capacity 42(%)	22	18	18	52
Vigour	3.7	5.6	5.6	1.0

Terminology used as in Fox (1981).

The 25°C treatment produced the best overall results with all seed germinated by 78 days, though for the first 27 days greater numbers had germinated at both 10 and 15°C.

The germination curves for 10 and 15°C differ from those of the higher temperatures which are S-shaped. Seed at the lower temperatures may have shown this had the experiment continued longer. The curve for 25°C started rising steeply at 25 days, and that for 20° did so at 40 days.

It must be assumed from these results that **Acacia cyclops** can germinate and grow well at any time of the year provided adequate soil moisture is available, and that seed dormancy (hard coat) has been broken. Small plants of this species are not common in the area of seed collection and this may be related to the absence of fire.

For the South African seed taken from soil Milton (1980) (see also Milton & Hall 1981) found 21 percent germinated after hot water treatment, but that 87 percent germinated after 2 hot water treatments. The time course of germination for the latter test is also illustrated in Figure 1.

The hot water treatment is not a very precise experimental tool **per se** in that the effect of moist heat will depend very much on the quantities of water used in relation to seed mass, on the type of container, the rapidity of cooling, and also, to some extent, on the time that seed is left in the cooling water. However we may equate the results for Woodman Point seed with those obtained by Milton. It is unlikely that there is a major difference between seed from Western Australia and South Africa.

Milton subjected freshly collected seed to the twice hot water treatment and obtained 78 percent germination in 6 weeks. In all her tests (Milton 1980) very little seed germinated within the first two weeks. Her other results with **A. cyclops** seed were:

34 percent with seed taken from bird droppings (see also Glyphis **et al.** 1981)
64 percent for 2 yr old seed derived from soil

The most rapid germination observed came from seed which had been treated with hot water and acid and then stored for 2 years. This gave 88 percent germination in two weeks and 92 percent in 6 weeks.

The possible effect of the funicle on germination ability is unclear. Most of the tests reported used seeds without the funicle present. In the 1978 test, essentially on soft seededness, there was little difference with or without the funicle. Nevertheless it is possible that part of the conditioning process which leads to an alteration in the degree of dormancy, may be associated with loss of the funicle. Moist heat is thought to provide the best stimulus but comparative tests with moist and dry heat on seed aged to different times is required to resolve the story completely. In particular our 1980 experiments did not examine the degree of soft-seededness.

e) Seedling Morphology

Following emergence of the cotyledons the first leaf is pinnate with 3-5 pairs of opposite leaflets. This is followed by a bipinnate leaf with 6 pairs of leaflets. The number of subsequent true leaves is variable but they remain bipinnately compound with up to 10 pairs of leaflets, until the first phyllodinous leaf appears. On this the petiole is swollen with a prominent nerve on the outer edge. In subsequent leaves the petiole expands, gradually giving more photosynthetic area to the phyllode component and less to the leaf, which becomes smaller in proportion.

The Woodman Point germinants were transplanted. These seedlings grew to 4 cm height after 5 days, to 8 cm by 25 days, to 11 cm by 40 days and to 14 cm after 75 days. The first pinnate leaf emerged 3 days after germination and by 150 days individual plants exceeded 30 cm in height. The fourth leaf was phyllodinous in this example.

Other Biotic Factors

a) Animal Feeders

A survey was carried out in Australia to establish the presence and importance of the natural enemies of those **Acacia** species naturalised in South Africa with a view to the possible use of biological control in that country (Van den Berg 1977, 1980a, b, c). Some 88 species of insects were recorded as feeding on **Acacia cyclops**. Of these 26 were Lepidoptera, 35 Coleoptera and 27 Hemiptera. Van den Berg (1977) estimates that more than 90 percent of **Acacia** seeds are destroyed by insects in their native habitat.

Important species described include:-

a) seed feeding Curculionidae (Coleoptera). Seven species of **Melanterius** and three **Diethusa** were either reared from or collected on developing seed pods. These reduce production of seeds by 15-25 percent.

b) an unnamed miner of the Cosmopterygidae (Lepidoptera) whose larvae mine phyllodes and young seed pods by feeding through a row of funicles. This species can damage up to a quarter of available seed.

c) **Macrobathra bigerella** (Decophoridae: Lepidoptera) feeds on funicles in green pods.

d) gall formers of **Atoposomoidea** species (Eulophidae: Hymenoptera) form galls in seed pods, in phyllodes and occasionally young branch tips.

e) seed feeding Hemiptera - eight species, six recorded from debris and two on the shrubs. **Coleotichus costatus** was reared from egg to adult in 8 weeks (Van den Berg 1980c).

f) **Pyrgoides** species (Chrysomelidae: Coleoptera). Larvae feed on developing flowers.

g) Stem borers (Cerambycidae: Coleoptera)

h) **Cryptophasa melanostigma.** (Xyloryctidae: Lepidoptera) feeds on bark and may ring bark branches or young trees.

A measure of the nutritive value of the seed is provided by Milton & Hall (1981) as 55.6 KJ g-1 for seed and funicle energy.

Other reports of animal interactions with **A. cyclops** include the observation that the striped rat can dislodge seeds in South Africa (Middlemiss 1963) and an example of bird ingestion given by Siegfried and Grindley (1967) who report **A. cyclops** seeds in faecal pellets of **Corvus alba.** Middlemiss (1963) observed 21 species of bird eating at least the funicle.

b) Plant Parasites

The coastal root hemi-parasite **Santalum acuminatum** (Quandong) is often found in association with **Acacia cyclops** which is probably a host species for it. **S. acuminatum** does not occur on coastal islands.

c) Diseases

Gathe (1971) did not observe the gall rust fungus **Uromycladium tepperianum** on **A. cyclops**, but noted that other workers had reported it. This can be confirmed with reference to my garden where **A. cyclops** is infested with brown cankerous swellings on branchlets and phyllodes.

Milton (1980) notes that 74 percent of **A. cyclops** which germinated under a parent shrub canopy died within a month of germination, apparently due to fungal infection.

History

The name is due to G.Don, **Gen. System** 2: 404, 1832 (Whibley 1980). 'Cyclops' is from the Greek 'round-eyed' and refers to the orange funicle surrounding the seed.

The specific name is misspelled in Blackall and Grieve (1954 and all subsequent editions to at least 1981) as **cyclopis** and this usage has inadvertently crept into much Australian literature. This error followed Bentham (1867).

Acknowledgements

Mr Peter Briffa as an undergraduate student at WAIT prepared a report on **Acacia cyclops** which formed the initial stimulus to preparing this account. He also undertook the germination study on Yalgorup seed. Mr Steve Zappia undertook the germination tests on Woodman Point seed. The illustration is based on a specimen from Yalgorup National Park (Figure 2).

FIGURE 2. Gross morphological detail Acacia cyclops.

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A PRELIMINARY TRIAL OF VARIOUS TREE AND SHRUB SPECIES FOR GROWTH IN COAL INTERBURDEN MATERIALS

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Summary

In a short-term trial of 10 species on amended and unamended mixed coal interburden materials the growth of all species was depressed on unamended material of low pH (3.7-3.9). Of the species tested **Cytisus proliferus** and **Albizia lophantha** showed best growth, however these two had largest seed weight of the species used. The more acid material when amended to pH 5.3-5.7 gave best growth for most species tested. **Acacia pulchella** and **Eucalyptus** species grew less well in the less acid material (pH 5.1-4.0) and the same material amended with lime (pH 6.8-7.6).

Small seedlings of Myrtaceae are unlikely to grow well in any of these types of material. Both **Acacia baileyana** and **A. extensa** show promise for revegetating unimproved mixed interburden materials.

Introduction

Natural colonisation of dumped overburden material from coal mine workings tends to be slow (Sisam & Whyte 1944, Gemmell 1973, Richardson 1976). Where the level of surface acidity is below pH 3.5 no colonisation has been observed in the Collie area, and revegetation is sparse below pH 5 (Bartle & Riches 1978). At low pH values, soil nutrients tend to be unavailable. This may therefore result in poor growth of plants in acidic spoils (unamended) compared with those of amended spoils. Poor plant growth on acidic spoils can also be caused by metal toxicity mainly due to high levels of aluminium, manganese and iron (Davison & Jefferies 1966). Liming has been used in many areas to amend low pH (e.g. Tacey **et al.** 1977) and a wide range of species can be grown on otherwise toxic soils amended with lime and nutrients to a pH of 5.0 (James 1966).

Various land use options are available for surfaces on which such materials have been deposited. It is aesthetically desirable that dumps should eventually blend into the landscape of the region. Where agriculture is the main land use then grass and forage crops may be sought. In forest areas some perennial vegetative cover is desirable. Pot trials are seen as a first, preliminary, step in determining appropriate treatments to restore vegetative cover.

An earlier report (Fox & Mathie 1982) examined pot grown seedlings of **Acacia extensa**, **A. pulchella**, **A. rhodoxylon**, **Cytisus proliferus** (= **Chamaecytisus prolifer**, tree lucerne), **Hardenbergia comptoniana**, **Kennedia coccinea** and **K. prostrata** grown in Nakina sand from Collie. This material had a pH of 4.6. Plants were grown in unamended sand, and in sand treated with lime (calcium carbonate) at 1 and 5 g per 1000 g. The present report deals with a similar experiment designed to contrast the performance of ten species on mixed overburden material of two classes, 'toxic' and 'non-toxic'. Both were also amended with lime.

Materials and Methods

Quantities of material from test drilled holes on an overburden coal dump were provided. The pH had been determined for each bag of soil, and ranged from 3.5 to 5.6. The bags were separated into two groups with those of less than 4.5 placed into one group (toxic), and those with pH greater than or equal to 4.5 placed into another group (non-toxic). Both groups were thoroughly mixed and the mean resultant pH for both was determined. The pH of the toxic soil was found to be 3.9, while the pH of the non-toxic soil was 5.1. Both materials were then divided into two lots. Samples of the two mixed soils were tested to determine a suitable addition of calcium carbonate to increase the pH by approximately 1.5. The toxic soil was amended from 3.9 to 5.3, while the non-toxic soil was amended from 5.1 to 6.8. In both amendments, 0.06 g of $CaCO3$ was used per 10 g of soil. 800 jiffy pots (volume 100 ml) were placed in large metal trays and filled with the soil materials, such that the four soils were evenly represented.

Seed of the following species was sown into germination trays on 16th July:-

* Legumes (heat-treated): **Acacia aneura**, **A. baileyana**, **A. extensa**, **A. myrtifolia**, **A. pulchella**, **Albizia lophantha**, **Cytisus proliferus**.

* Myrtaceae (directly sown): **Eucalyptus camaldulensis**, **E. gomphocephala**, **Melaleuca radula**.

80 seedlings of each species were transplanted into spoil in jiffy pots on 6th August such that each soil type had 20 seedlings per species. After planting, all plants were watered from below, by filling the bottom of the metal trays with water.

For the first week of growth in jiffy pots, any plants which died were replaced. Recordings were taken of plant height at 2, 5, 7 and 9 weeks from potting. After 26 days 5 plants per treatment for each species were harvested. These were washed free of soil, dried in paper towels and then divided into tops and roots, weighed, dried in a 40°C oven for 48 hrs, and then reweighed, to obtain shoot and root fresh weight and shoot and root dry weight for each individual plant. The number of leaves for each harvested plant was counted, and the leaf area of each plant was determined with a planimeter.

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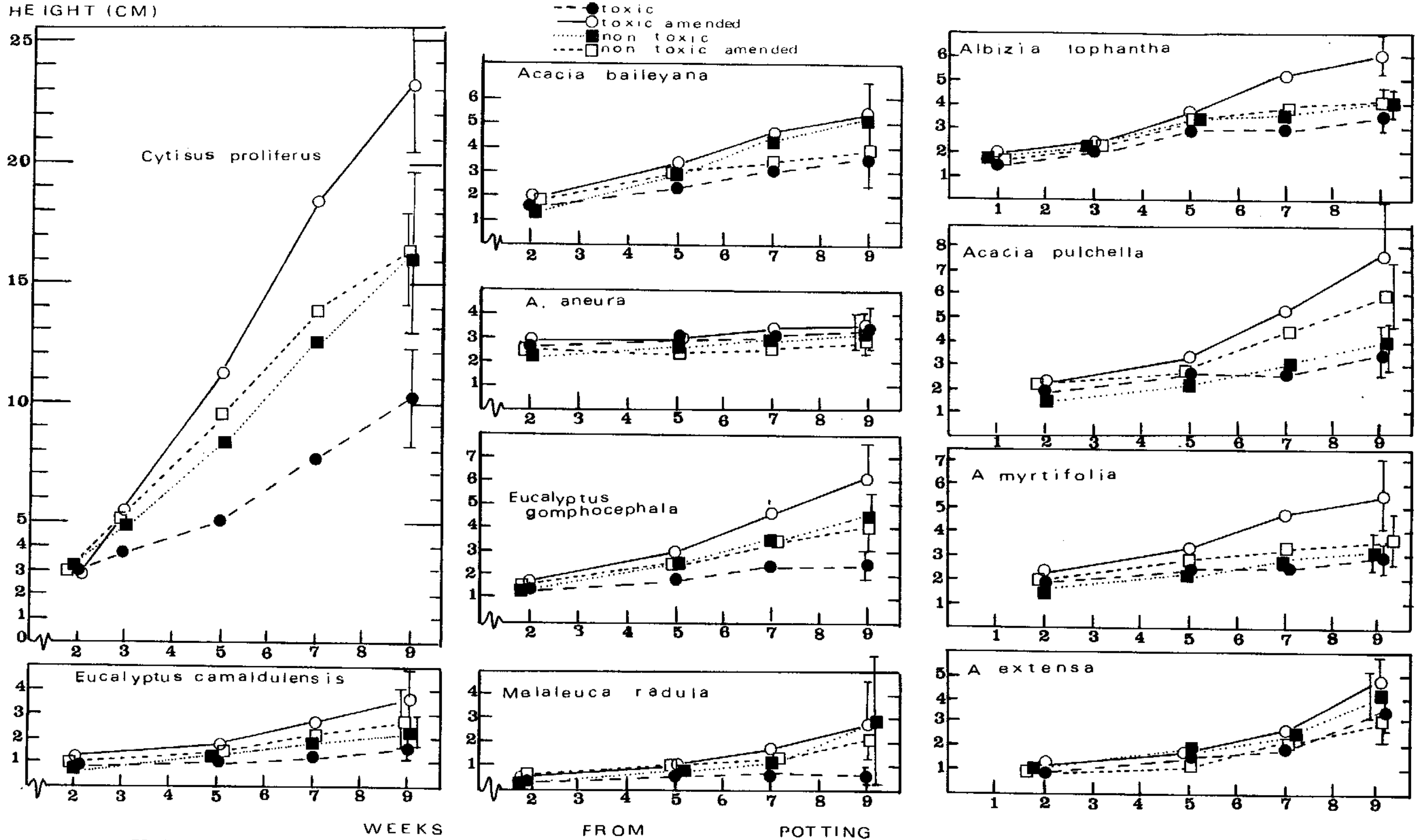

FIGURE 1. Mean plant heights by spoil type from potting to final harvest.

Potassium and calcium contents of the harvested plants were determined. **Eucalyptus camaldulensis** and **Melaleuca radula** were not taken at 26 days as these species were very small in stature. After 62 days a further 10 plants were harvested from each species and treatment media as before. Where plant material was sufficient, nitrogen and phosphorus were determined in addition to K and Ca. At this harvest all 10 species were taken. Nitrogen was determined by the Kjeldahl method, the phosphorus content from an aliquot taken from the acid digest for nitrogen, using the ammonium molybdate/stannous chloride method. Potassium and calcium contents were determined by the flame photometer method.

Results

The pH of the toxic (T) and toxic amended (TA) materials was relatively constant over the experimental period. However the non-toxic (NT) spoil showed a decline from pH 5.1 to pH 4 at 9 weeks, whereas the pH of the non-toxic amended (NTA) material drifted up from 6.8 to 7.6. In Nakina sand (Fox & Mathie 1982) lime (calcium carbonate) added at 0.1 and 0.5 percent by weight brought initial pH to 5.6 and 6.6 respectively. These levels were one and two pH units above unamended material initially. By 6 weeks the pH had drifted upwards to 5.2, 6.9 and 7.5 for unamended, at the lower and upper lime levels respectively. The drift experienced in NTA is not, therefore, unexpected. However the decline in pH of NT in the present work is less readily accounted for and implies that considerable acid generating potential existed in this mixture.

Figure 1 illustrates the mean height of plants by spoil type over the 9 week period between potting and second harvest. Two main patterns of height growth are seen. While all species showed best height development in the TA spoil, five species **Acacia myrtifolia**, **A. pulchella**, **Albizia lophantha**, **Cytisus proliferus** and **Eucalyptus camaldulensis** grew as tall or taller in NTA compared with NT material, suggesting less tolerance of acidic conditions. Height differences had not become as clear cut in **Acacia aneura**. Height growth was poorest for all species except **A. extensa** in the unamended toxic spoil, where pH was 3.9 at the start and 3.7 at the end.

In Table 1 the mean heights and foliage numbers are shown for the 9 week final measurement. Best overall height growth was seen in **Cytisus proliferus**. Of the **Acacia** species the order of tallest growth in TA was
A. pulchella > **A. myrtifolia** > **A. baileyana** > **A. extensa** > **A. aneura**.
Height growth in T was poorest in **A. myrtifolia** with the other species being similar. In general the foliage numbers were similar in rank order to heights by growth media.

Deaths in treatments were as follows:-

E. camaldulensis	T, 5 plants; TA, 5; NT, 2
E. gomphocephala	T, 1 plant
Melaleuca radula	T, 17 plants; TA, 3; NT, 7; NTA, 2
Acacia aneura	T, 5 plants; TA, 1

TABLE 1. Differences in mean heights (cm) and foliage (leaf numbers) after 9 weeks growth by species.

Species	Heights				Foliage			
Acacia aneura	TA > 3.5	T > 3.5	NT > 3.1	NTA 2.8	TA > 6.4	NT > 5.9	NTA > 5.7	T 4.6
A. baileyana	TA > 5.5	NT > 5.3	NTA > 3.8	T 3.5	TA > 13.7	NT > 11.8	T > 9.3	NTA 9.1
A. extensa	TA > 4.8	NT > 4.2	T > 3.4	NTA 3.2	NT > 5.9	TA > 5.7	T > 5.5	NTA 4.3
A. myrtifolia	TA > 5.6	NTA> 3.7	NT > 3.2	T 2.9	TA > 10.4	NT > 8.7	NTA > 8.4	T 7.3
A. pulchella	TA > 7.5	NTA> 5.9	NT > 3.7	T 3.5	TA > 10.3	NTA > 9.1	NT > 8.1	T 6.1
Albizia lophantha	TA > 6.0	NT > 4.1	NTA > 4.0	T 3.4	TA > 20.3	NT > 15.7	NTA > 15.1	T 12.6
Cytisus proliferus	TA > 24.3	NTA> 16.2	NT > 16.0	T 10.2	TA > 38.7	NT > 27.1	NTA > 23.5	T 19.3
Eucalyptus camaldulensis	TA > 3.7	NTA> 2.7	NT > 2.3	T 1.6	TA > 9.4	NTA > 8.4	NT > 7.4	T 6.2
E. gomphocephala	TA > 6.1	NT > 4.4	NTA > 4.2	T 2.5	TA > 12.1	NT NTA	10.9 >	T 8.4
Melaleuca radula	NT > 2.9	TA > 2.8	NTA > 2.1	T 0.6	TA > 13.9	NTA > 13.7	NT > 11.8	T 8.0

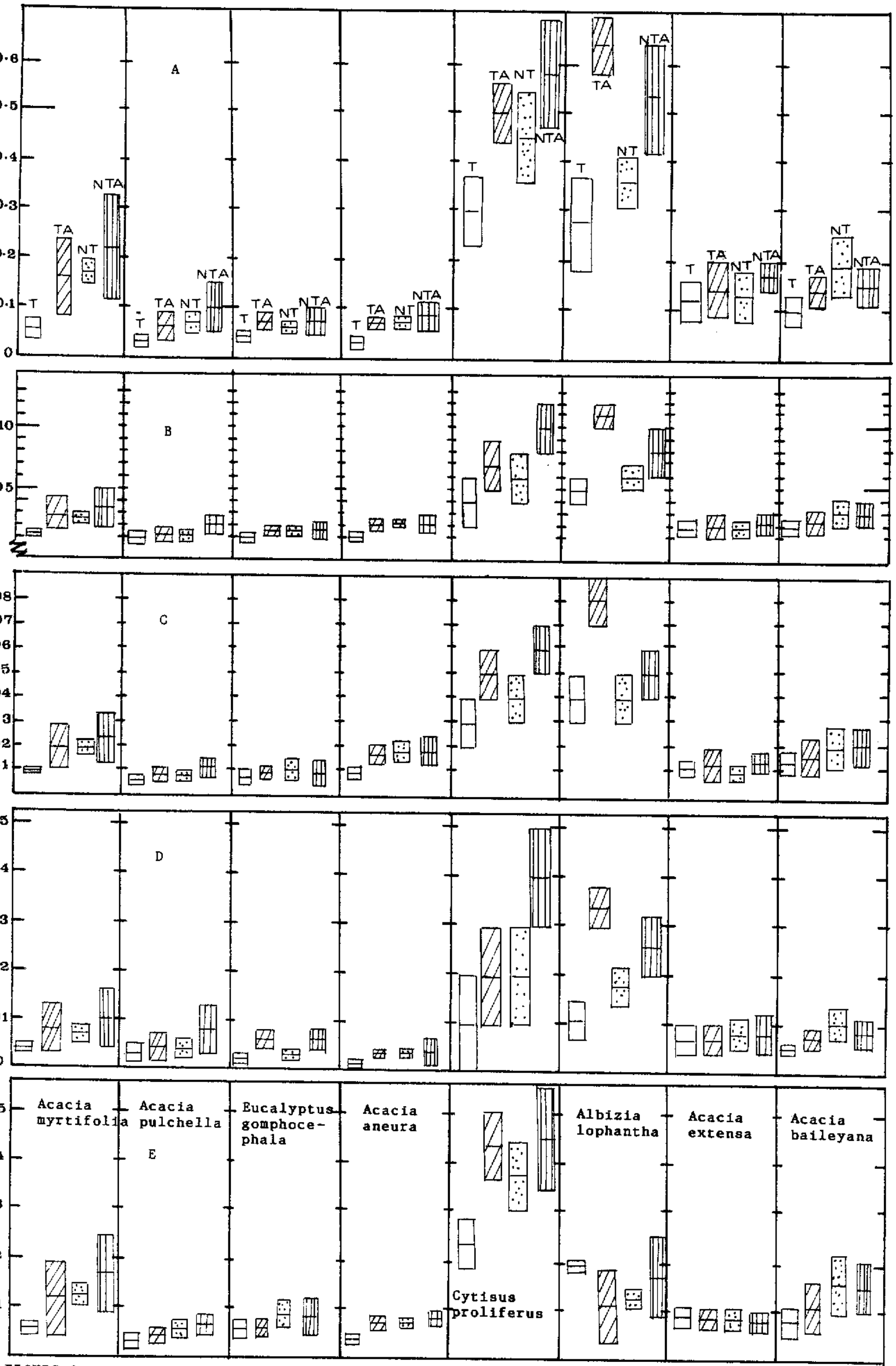

FIGURE 2. Mean values for fresh weight (A); dry weight (B); shoot dry weight (C); root dry weight (D); and leaf area (E); at 26 days from potting. A-D in g, E in cm^2.

TABLE 2. Mean dry weights (g) of plants grown in four types of spoil.

Species	Toxic spoil (T)		Toxic amended (TA)		Non-toxic spoil (NT)		Non-toxic amended (NTA)	
	Time of Harvest in Days							
	26	62	26	62	26	62	26	62
A. Legumes								
Acacia aneura	0.011	0.017	0.020	0.032	0.021	0.027	0.022	0.035
Acacia baileyana	0.019	0.097	0.023	0.125	0.031	0.168	0.029	0.127
Acacia extensa	0.019	0.048	0.020	0.097	0.016	0.090	0.024	0.093
Acacia myrtifolia	0.013	0.048	0.027	0.189	0.026	0.105	0.034	0.121
Acacia pulchella	0.010	0.044	0.012	0.133	0.012	0.062	0.020	0.096
Albizia lophantha	0.048	0.163	0.110	0.327	0.062	0.231	0.080	0.231
Cytisus proliferus	0.015	0.160	0.076	0.407	0.065	0.290	0.095	0.246
B. Myrtaceae								
Eucalyptus camaldulensis	*	0.005	*	0.071	*	0.024	*	0.023
Eucalyptus gomphocephala	0.009	0.022	0.015	0.105	0.014	0.044	0.015	0.088
Melaleuca radula	*	0.001	*	0.012	*	0.010	*	0.008

* insufficient plants for 2 harvests.

A number of the plants in T had yellowish, older, leaves by the conclusion of the experiment, suggesting that many more plants would have died in this medium if the growing period had been extended.

Figures 2 and 3 illustrate mean fresh weight, dry weight, dry shoot weight, dry root weight and leaf area for the 26 and 62 day harvests respectively. In these figures standard deviations are shown for each value, generally representing 5 plants for day 26 and 10 for day 62.

After 26 days growth the most frequent pattern of difference in mean dry weight was

NTA > TA > NT > T

This was exhibited by **Acacia myrtifolia, A. pulchella, Cytisus proliferus** and **Eucalyptus gomphocephala**. In **Acacia aneura** best early growth was in NTA and worst in T. **A. extensa** also had best early growth in NTA. Of the others harvested at 26 days **A. baileyana** had best growth in NT, then NTA, TA and T respectively; and **Albizia lophantha** showed the pattern

TA > NTA > NT > T

This pattern was the most frequent after 62 days and was shown by **Albizia lophantha** again, and also **A. extensa, A. myrtifolia, A. pulchella** and **Eucalyptus gomphocephala**. At the 61 day harvest growth in TA was also better than NTA in **Cytisus proliferus, Melaleuca radula** and **Eucalyptus camaldulensis**. These 3 had better growth in NT than in NTA.

Unamended toxic soil was generally responsible for poorest growth. The only exception was with **A. extensa** at 26 days where growth in T was better than NT (Table 2).

The results of analysis of variance of individual plant dry weights for the 4 spoil treatments by species are given in Table 3. In general significance increased with time, and was more pronounced on the species with heavier plants. **A. baileyana**, the only species with better growth in NT spoil, showed little difference between performance in the treatments. Differences reached p 0.05 or better in all cases where TA plants grew best except for **Acacia extensa**. This species showed a considerable change in ranks over the experimental period.

Dry weight is the most appropriate determinant of relative success. Table 4 presents relative dry weights compared to the performance of **Cytisus proliferus** in TA spoil, where the greatest mean weight was achieved.

At the 26 day harvest leaf area tended to be largest in NTA, especially in those species where the toxic soil gave very low leaf area. Exceptions were **Eucalyptus gomphocephala** and **Acacia baileyana** with largest area in NT and **Acacia extensa** and **Albizia lophantha** (Figure 2). The range within growth media was particularly high at the first harvest in **A. baileyana, A. myrtifolia** (for amended materials only), **Albizia lophantha** (as for **A. myrtifolia**) and **Cytisus proliferus**. At 9 weeks nearly all species had greatest leaf area in the TA spoil material.

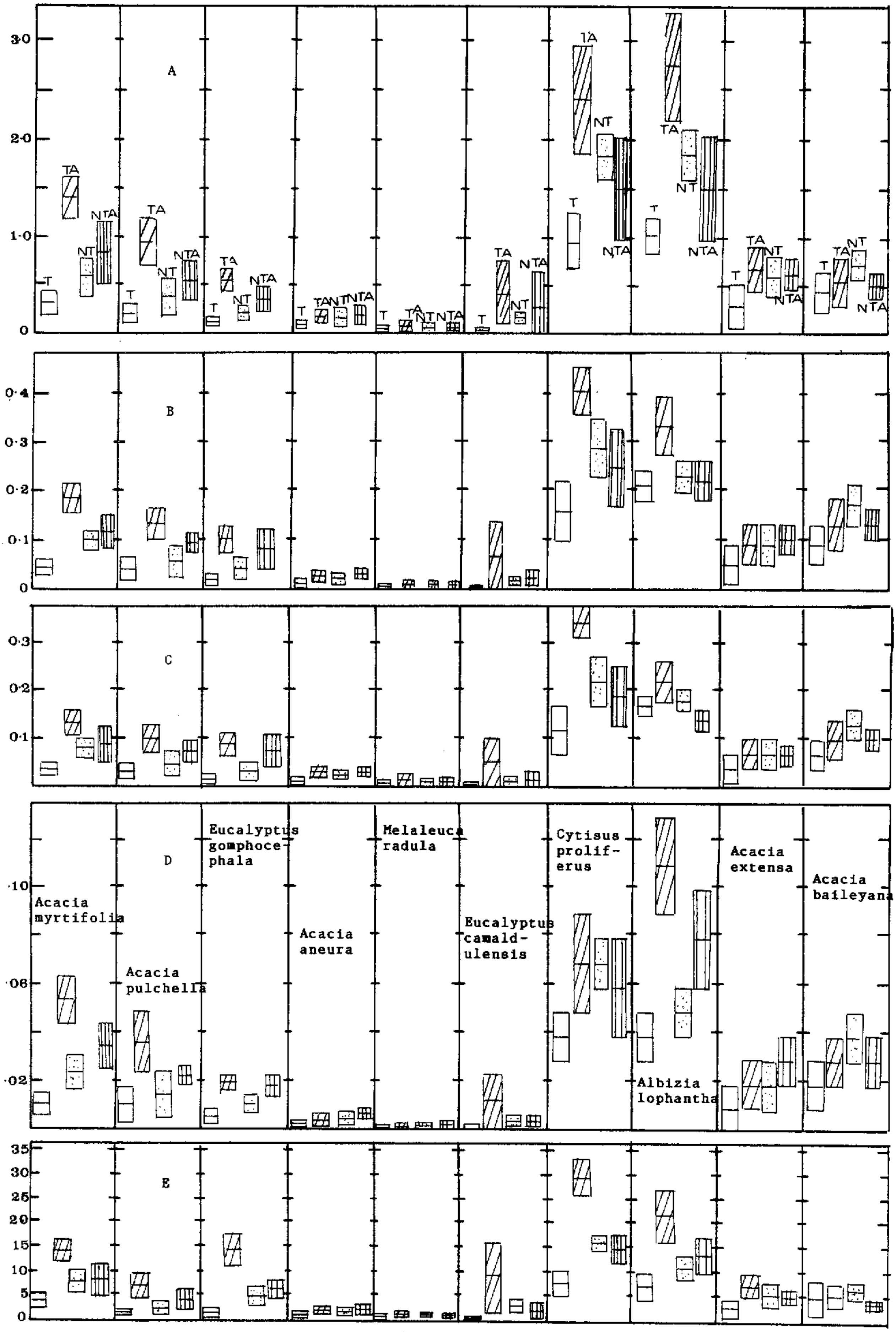

FIGURE 3. Mean values for fresh weight (A); dry weight (B); shoot dry weight (C); root dry weight (D); and leaf area (C); at 62 days from potting. A-D in g, E in cm^2.

The ranges in this material were high in **Eucalyptus camaldulensis** and **Albizia lophantha**. Acacia baileyana differed with slightly greater leaf area for plants in the NT medium, but in this species there was little difference between treatments (Figure 3). All species had greater leaf area in TA compared to T, most showed the same trend in the non-toxic material. Exceptions were E. **camaldulensis**, **Cytisus proliferus**, **Acacia baileyana** and **A. extensa** where NT was greater than NTA, however differences in these were small.

Table 5 presents the total fresh weight/dry weight ratios for both harvests. This ratio indicates the relative moisture contents of plant tissues. The highest ratio obtained was from **Melaleuca radula** at final harvest in toxic spoil. This species had a ratio of 10, but this was obtained from three plants only. Lowest ratios at 26 days for the toxic material were found in **Acacia aneura** and **A. pulchella** with a high ratio in **Cytisus proliferus**. The TA material had lowest ratios at 26 days in **A.** aneura, **A.** pulchella and **Eucalyptus gomphocephala** whereas **A. extensa** and **C.** proliferus were highest. By the second harvest for T, ratios declined in most species except for A. **myrtifolia**, **A. pulchella** and **A. aneura**, when E. **gomphocephala** was lowest. The ratios for T material in **A. extensa** were 6 for both harvests, and this material had the lowest ratio. It was also lowest for **Albizia lophantha**, **A. aneura** and **A. pulchella**.

In the NT material **Cytisus proliferus** had highest ratio at 26 days and **Albizia lophantha** highest at 62 days. Lowest ratios in NT were in **A. aneura** and **E. gomphocephala** at first harvest and **A. baileyana** and **E. gomphocephala** at second. In the NTA material **Eucalyptus camaldulensis** had the highest ratio at second harvest and **A. extensa** at the first, whereas E. **gomphocephala** and **A. aneura** were comparatively low.

It was of interest that **Acacia baileyana** had consistently lower fresh/dry ratios across the media at second harvest whereas **Acacia pulchella** ratios were consistently higher. The most succulent species generally were **Albizia lophantha**, **Acacia extensa**, **Cytisus proliferus** and **Eucalyptus camaldulensis**.

Table 6 summarises the shoot/root dry weight ratios. This ratio indicates the relative efficiency of aerial production per unit of root. The ratio tended to be highest in T, particularly for first harvest, and lowest in NTA, especially for the second harvest. In most cases the ratio increased between the 2 harvests, perhaps reflecting the restriction on root development incurred by smaller container size in comparison with use of large pots (cf Fox & Mathie 1982). The increase was particularly large for **Acacia extensa** in T, and to a lesser extent for **A. myrtifolia**, **A. pulchella** and **Eucalyptus gomphocephala**. In the TA material **A. aneura**, **Cytisus proliferus** and **E. gomphocephala** showed the largest increase

TABLE 3. Differences in species mean dry weights, and significance levels.

Species	Days	Ranking	F	Significance
Acacia aneura	26	NTA > NT > TA > T	4.70	*
	62	NTA > TA > NT > T	2.45	+
Acacia baileyana	26	NT > NTA > TA > T	1.84	°
	62	NT > NTA > TA > T	2.69	+
Acacia extensa	26	NTA > TA > T > NT	1.36	NS
	62	TA > NTA > NT > T	2.55	+
Acacia myrtifolia	26	NTA > TA > NT > T	3.41	*
	62	TA > NTA > NT > T	22.05	***
Acacia pulchella	26	NTA > TA > NT > T	2.90	+
	62	TA > NTA > NT > T	8.73	**
Albizia lophantha	26	TA > NTA > NT > T	22.23	***
	62	TA > NTA > NT > T	13.45	***
Cytisus proliferus	26	NTA > TA > NT > T	8.25	**
	62	TA > NT > NTA > T	14.02	***
Eucalyptus camaldulensis	62	TA > NT > NTA > T	4.36	*
E. gomphocephala	26	NTA > TA > NT > T	1.43	NS
	62	TA > NTA > NT > T	9.94	***
Melaleuca radula	62	TA > NT > NTA > T	1.59	NS

Significance: > 0.001 ***; > 0.01 **; > 0.05 *; > 0.10 +; > 0.20 ° < NS (not significant) between harvests. In these species, and also **E. camaldulensis**, the TA material had largest value for shoot/root ratio at 62 days.

The non-toxic materials tended to have lower ratios than toxic materials. The greatest increases in ratio for NT between harvests were in **Acacia extensa**, **A. myrtifolia** and **Albizia lophantha**. In the NTA **E. gomphocephala**, **A. pulchella** and **Cytisus proliferus** showed the greatest increases between harvests.

TABLE 4. Dry weights relative to **Cytisus proliferus** best performance in toxic amended spoil.

($\overline{x}$ = 0.4068 = 100)

Species	Toxic (T)	Toxic Amended (TA)	Non-Toxic (NT)	Non-Toxic Amended (NTA)
C. proliferus	39	100	71	61
A. lophantha	40	80	57	57
A. baileyana	24	31	41	31
A. myrtifolia	12	46	26	30
A. extensa	12	24	22	23
A. pulchella	11	33	15	24
E. gomphocephala	6	26	11	22
A. aneura	4	8	7	9
E. camaldulensis	1	18	6	6
M. radula	<1	3	3	2

Plant nutrients determined are shown in Table 7. Calcium concentration in plants grown in amended materials was much greater than in the unamended spoils. In T the highest concentration of calcium occurred in **E. gomphocephala** and **Acacia pulchella** at 26 days and in **Albizia lophantha** and **Acacia myrtifolia** at 62 days. In TA **A. myrtifolia** and **A. pulchella** had highest concentrations at both harvests. In NT **A. pulchella** and **A. baileyana** had highest concentrations at first harvest and at second harvest **A. pulchella** and **A. extensa** were greatest. In the NTA medium **A. myrtifolia** and **A. pulchella** had highest concentrations at both harvests.

In the case of potassium the concentration in TA was less than in T at both harvests for all species except for **A. myrtifolia** and **A pulchella** at first harvest. Highest concentrations were in **A. baileyana**, **A. aneura** and **A. pulchella** at first harvest for T and in **A. extensa** and **E. camaldulensis** at second harvest. In TA **A. pulchella** and **A. myrtifolia** had highest values at 26 days and **E. camaldulensis** and **A. aneura** highest at 62 days. In the non-toxic material most species had higher potassium levels, at least at the second harvest, in the amended material. The wattles tended to have highest potassium concentration. In NT at first harvest **A. pulchella** and **A. baileyana** were highest but the **Eucalyptus** species were highest at second harvest. In NTA **A. myrtifolia** and **A. pulchella** were highest at first harvest with **Melaleuca radula** and **A. pulchella** highest at the 62 day harvest. Between harvests the percentage concentrations of calcium and potassium were much lower at the second harvest reflecting increased plant growth over the period.

Nitrogen concentration at 62 days was around the 2 percent level in most cases. The TA or NT medium had highest levels except for **Cytisus proliferus** where T had the higher level.

TABLE 5. Fresh/dry weight ratios of plants grown in four types of spoil.

	Type of Material							
Species	Toxic spoil (T)		Toxic amended (TA)		Non-toxic spoil (NT)		Non-toxic amended (NTA)	
	Time of Harvest in Days							
	26	62	26	62	26	62	26	62
Acacia aneura	2.7	4.1	3.5	4.6	3.3	5.3	3.6	4.5
Acacia baileyana	5.3	5.0	6.1	4.2	6.3	4.3	5.2	3.9
Acacia extensa	6.0	6.0	7.0	7.6	6.5	6.6	8.5	6.2
Acacia myrtifolia	4.1	6.7	5.9	7.5	6.5	5.5	6.5	6.9
Acacia pulchella	3.1	4.6	5.0	7.1	5.8	6.2	5.0	5.5
Albizia lophantha	5.6	4.9	5.8	8.4	6.0	8.0	6.6	6.9
Cytisus proliferus	7.5	5.8	7.1	6.1	7.5	6.3	5.8	6.0
Eucalyptus camaldulensis	-	6.0	-	5.9	-	7.0	-	11.7
Eucalyptus gomphocephala	4.4	3.8	4.7	4.8	4.3	4.7	4.7	3.7
Melaleuca radula	-	10.0	-	7.3	-	5.4	-	4.5

Plant dry weights were greatest in amended materials, and differences were significant at both harvests (Table 3). Best final performance was in TA where this species ranked third to **Cytisus proliferus** and **Albizia lophantha** (Table 4). In the other materials it ranked behind **Acacia baileyana**. Amended materials produced a considerable range in both shoot and root weights (Tables 2 and 3). The fresh/dry weight ratio increased between harvests in all but NT. The greatest difference between harvests was in T, where the ratios increased from 4.1 to 6.7 (Table 5). In the case of shoot/root ratio T also showed the greatest difference between harvests, increasing from 2.2 to 3.4 (Table 6). Unamended materials had higher shoot/root ratios than amended materials at final harvest. Nutrient contents were somewhat erratic. TA had much higher phosphorus levels than the non-toxic media, whereas nitrogen was highest in NT where calcium was lowest. This pattern was also seen in **Albizia lophantha**. Potassium content was higher in amended materials at first harvest, but levels were similar amongst TA, NT and NTA at final harvest.

Acacia pulchella

As with **A. myrtifolia** there was a gradation in height growth between spoil materials through the range TA, NTA, NT, T with least difference between the latter two, poorest, media. Foliage counts mirrored this pattern, as did mean plant dry weights at final harvest. These final weights were significantly different (Table 3). **Acacia pulchella** had greater dry weights in amended material than **A. extensa**, and this position was reversed in unamended material (Table 4).

Fresh/dry weight ratios all increased between harvests. These ratios were intermediate for most materials, but low in T where the final ratio was 4.6. The order of final fresh/dry ratios was TA > NT > NTA > T. The shoot/root ratio was lowest in TA at 62 days, and this material showed the smallest increase in ratio between harvests.

Calcium contents were high in amended materials but similar to **Acacia extensa** in unamended spoils. Potassium was higher than **A. extensa** in amended material but less in unamended material. **A. pulchella** had highest nitrogen and phosphorus levels, of those determined, for the TA medium.

Albizia lophantha

Height growth was best in TA, there was little difference between NT and NTA both of which were considerably better than T. The foliage counts at 9 weeks were similar in pattern (Table 1). This species produced more material than all other species in the unamended toxic spoil. Its mean dry weight at 62 days in this was 0.163 g (Table 2), a production greater than most of the Acacia species across all spoils. Differences in dry weight were consistently TA > NTA > NT > T and differences were highly significant at both harvests. Despite the high production in unamended materials the considerable improvement due to liming suggests that **A. lophantha** is not as acid tolerant as **Acacia baileyana** and perhaps **A. extensa**. The differences are probably due to the larger seed weight in **Albizia**. For media other than T **Cytisus proliferus** (also large seed) produced more dry matter.

Fresh/dry weight ratio increased between harvests in all but T where it fell from 5.6 to 4.9. Final ratios in TA and NT were higher than for all other species (Table 5). Final shoot/root ratios were lower than all other species in both TA and NTA at final harvest. This ratio fell in TA, was more or less constant in NTA between harvests, but increased in the two unamended media (Table 6).

Calcium content was higher than other species in T for final harvest (= to **A. myrtifolia**) and lower than all other species in NT. Potassium content reflected total production with lowest level in TA where dry matter was greatest. Phosphorus was highest in TA where it was lower than in **A. pulchella** and **A. myrtifolia**, and high in T (only two species analysed). Nitrogen levels were more or less similar across all media.

Cytisus proliferus

The pattern of height growth by the conclusion was similar to that seen in **Albizia lophantha** with TA material showing a clear margin over other materials and little difference between NTA and NT. Foliage numbers were much higher in TA than other media and NT had more leaves than NTA (Table 1). **Cytisus proliferus** performed best in terms of dry weight production, with greatest weight attained in TA. It produced more material than all other species in this and also in NT and NTA. Differences between treatments were highly significant although the order of dry weights changed between harvests (Table 3).

Fresh/dry weight ratios were high at 26 days but fell off to intermediate levels by second harvest. NT had the highest ratio (Table 5). Shoot/root ratios were constant in T but increased considerably in other materials (Table 6).

The good comparative early growth of **Cytisus proliferus** may not persist much beyond the 9 weeks of this trial. In another study comparative performance against other legume species was poor at 11 weeks growth in limed Nakina sand (Fox & Mathie 1982).

In terms of acid tolerance it ranks close to **Albizia lophantha** but behind **Acacia baileyana**. Calcium and potassium contents declined with growth (Table 7) such that values were generally lower than other species by the end of the experiment. Nitrogen contents were lower in all media than the other legume species, despite consistent nodulation in amended spoils.

Eucalyptus camaldulensis

Eucalyptus gomphocephala had the lowest (of those analysed) in NTA media. Phosphorus determinations were only made for **Albizia lophantha** and **Acacia baileyana** from all media at second harvest. In the case of **A. lophantha** the toxic materials gave highest phosphorus levels whereas **A. baileyana** had greater concentrations in the non-toxic materials. **A. myrtifolia** and **A. pulchella** had highest levels recorded, both in TA.

Discussion

Each species is considered in turn and general comments are presented in the conclusion.

Notes on Individual Species

Acacia aneura

Growth of this species was probably influenced more by low winter temperatures than by type of growth medium. There was little difference in final height growth between spoil types, with both TA and T showing similar mean heights. However foliage counts were higher in both NT and NTA than in T (Table 1). Losses were high in T where 25 percent of the initial plants had died by the fifth week. Thereafter only one more plant died; this was in the TA medium.

Plant dry weight increased least of all the Acacia species over the experimental period, with poorest performance in T and little difference between the two amended spoil materials (Table 2). Differences between materials were not significant (Table 3). The fresh/dry weight ratios for this species were particularly low with the highest value at second harvest in NT, where the increase between harvests was also greatest (Table 5). Fresh weight in NTA had greatest range at 62 days (Figure 3). Root growth was particularly poor and shoot/root ratios were very high (Table 6). Nutrients in plant tissue were only determined for calcium and potassium. The amended materials had relatively high percentage tissue calcium compared with unamended materials, and levels were similar to **Acacia baileyana**. Final harvest potassium contents were higher than for most Acacia species, reflecting the low total mass attained.

This species cannot be recommended for further trials. Although the species is tolerant of low moisture regimes it is slow growing in the absence of summer watering. The 'Laverton' variety used here also grows more slowly than other varieties.

Acacia baileyana

Height growth in TA and NT was similar and both produced considerably taller plants than NTA and T materials. Foliage counts reflected the same trend, but T had marginally more foliage than found in NTA (Table 1).

Differences in dry weights between treatments were not significant (Table 3) but the pattern of weight attained

NT > NTA > TA > T

was the same for both harvests. The NT yield was consistently higher than for other Acacia species, and **A. baileyana** also performed best of the **Acacia** species in T and NTA media. In this species the fresh/dry weight ratio declined considerably, in all except T, between harvests, such that it was amongst the lowest for NT, NTA and TA media (Table 5). There was little difference between shoot/root ratios across the materials, particularly at 62 days when TA, NTA and NT were all 3.3 (Table 6). The levels of nitrogen recorded were high in both unamended spoils, and that for T was the highest of those determined. Phosphorus uptake was greatest in the non-toxic materials where it was also the highest of those species analysed. Calcium contents were high but not as large as in **Acacia pulchella**. Potassium levels were similar to the latter species.

Acacia extensa

Poorest height growth at the conclusion of the experiment was seen in NTA (Table 1). This was marginally less than in T. Foliage numbers differed little between NT, TA and T media, with all considerably above that of NTA.

In this species the dry weights recorded showed different patterns amongst the materials used between the two harvests. Although growth was generally greater in the amended soils differences were not significant. Final dry weight was greatest in the TA material. This had the highest fresh/dry weight ratio at 62 days for this species. **A. extensa** had comparatively high ratios for both toxic and non-toxic media. Shoot/root ratio for dried material differed little at first harvest, but by final harvest the value for T (4) was considerably higher than for NTA (2.3) (Table 6). The shoot/root ratios showed considerable increases between harvests for all except NTA where the increase was modest. Nutrient determination suggests that this species was less able to accumulate calcium from amended materials as the plants aged, in comparison with the other species (Table 7). Potassium content remained fairly high through to second harvest, percentage nitrogen was high in TA as also was phosphorus. However these values are partly a reflection of comparatively poorer growth.

It is not possible to definitely predict the performance of this species in acidic materials. However it grew better than **Acacia pulchella** in the T and NT materials where pH was lowest. Its shoot/root ratios in these media were lower than those for **A. pulchella**.

Acacia myrtifolia

There was a considerable difference in height between the best material (TA) and the next (NTA) with little difference between NT and T. However foliage counts were similar for NT and NTA (Table 1).

TABLE 6. Shoot/root dry weight ratios of plants grown in four types of spoil.

Species	Toxic spoil (T)		Toxic amended (TA)		Non-toxic spoil (NT)		Non-toxic amended (NTA)	
	Time of Harvest in Days							
	26	62	26	62	26	62	26	62
Acacia aneura	4.5	4.7	4.0	6.8	4.3	5.8	4.3	4.0
Acacia baileyana	2.8	3.5	2.3	3.3	2.0	3.3	2.6	3.3
Acacia extensa	1.7	4.0	1.9	3.5	1.3	3.5	1.8	2.3
Acacia myrtifolia	2.2	3.4	2.4	2.5	2.7	3.4	2.3	2.5
Acacia pulchella	2.0	3.0	2.0	2.6	2.0	3.0	1.4	3.2
Albizia lophantha	4.0	4.3	2.7	2.0	2.0	3.6	1.7	1.8
Cytisus proliferus	3.0	3.0	2.5	4.9	2.0	3.1	1.5	3.2
Eucalyptus camaldulensis	-	1.5	-	4.3	-	3.0	-	3.6
Eucalyptus gomphocephala	3.5	2.5	1.5	4.3	3.3	3.0	1.5	3.6
Melaleuca radula	-	-	-	4.9	-	4.0	-	2.5

Height growth was poor, reflecting comparatively small size of seedlings at the start. Despite this there was a clear gradation in heights between treatment media by the conclusion (Table 1). The same pattern was seen in leaf count. Losses were particularly high in the toxic material where 25 percent died in both T and TA over the experimental period.

Dry matter production at 62 days followed the pattern

TA > NT > NTA > T

and differences were significant, though only TA produced a reasonable level of material. Fresh/dry weight ratios were high in less toxic media (Table 5) and the shoot/root ratio was particularly low in T (Table 6).

Small seedlings of this species are unsuited to growth in the materials used, though it is possible that larger plants could survive transplanting.

Eucalyptus gomphocephala

In this species height growth in TA was best, with a clear advantage over NT and NTA which were similar. Both these were much taller than height attained in T. **E. gomphocephala** was considerably superior in height growth to **E. camaldulensis** despite the fact that it is confined to coastal sandy soils over limestone. The leaf numbers in **E. gomphocephala** followed the same pattern as final height (Table 1).

TABLE 7. Tissue nutrient levels of plants grown in four types of spoil. For Calcium (Ca), Potassium (K) and Nitrogen (N) the element is expressed as percentage of dry weight, and for Phosphorus (P) is mg g-1 of dry weight.

	Toxic spoil (T)						Toxic amended (TA)						Non-toxic spoil (NT)						Non-toxic amended (NTA)					
Time of harvest (days)	26		62				26		62				26		62				26		62			
Element	Ca	K	Ca	K	N	P	Ca	K	Ca	K	N	P	Ca	K	Ca	K	N	P	Ca	K	Ca	K	N	P
SPECIES																								
Acacia aneura	2.51	1.96	0.48	0.57	-	-	4.91	1.36	0.97	0.33	-	-	1.58	1.40	0.41	0.32	-	-	4.06	1.04	1.32	0.33	-	-
Acacia baileyana	2.44	2.16	0.34	0.27	2.23	3.1	5.06	1.80	0.74	0.19	1.59	4.5	2.28	1.73	0.34	0.14	2.44	8.9	4.62	1.35	1.44	0.34	1.81	9.0
Acacia extensa	1.50	1.57	0.43	0.89	-	-	4.87	1.76	0.57	0.16	2.51	7.8	1.93	1.65	0.46	0.25	2.14	-	6.34	1.32	0.93	0.27	1.79	-
Acacia myrtifolia	1.41	1.16	0.73	0.33	-	-	7.73	1.86	2.61	0.14	2.29	9.4	2.10	1.00	0.24	0.11	3.07	0.5	7.93	2.09	2.92	0.13	1.87	0.6
Acacia pulchella	2.81	1.87	0.40	0.36	-	-	7.70	2.38	2.01	0.21	2.94	16.6	3.00	1.80	0.51	0.22	-	-	7.60	1.52	2.76	0.37	1.59	1.5
Albizia lophantha	1.10	1.15	0.73	0.21	1.93	7.8	2.87	0.66	0.92	0.01	2.15	8.3	1.02	0.72	0.21	0.13	2.29	5.7	4.01	1.02	2.49	0.16	2.01	4.3
Cytisus proliferus	1.10	1.06	0.13	0.16	1.87	-	3.73	0.02	0.47	0.04	1.38	-	1.57	0.78	0.16	0.09	1.16	2.5	6.05	1.24	0.79	0.14	1.25	-
Eucalyptus camaldulensis	-	-	0.61	0.82	-	-	-	-	0.91	0.43	-	-	-	-	0.80	0.46	-	-	-	-	1.06	0.31	-	-
Eucalyptus gomphocephala	3.50	1.52	0.41	0.46	-	-	2.82	1.27	0.55	0.22	1.73	0.9	0.89	1.07	0.44	0.38	1.60	0.7	3.00	1.38	0.66	0.26	0.87	0.7
Melaleuca radula	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1.22	0.91	-	-

The order of final dry weights was

TA > NTA > NT > T

presumably reflecting its natural preference for calcareous soils. Differences in dry weight were highly significant (Table 3). Growth in the amended materials was on a par with **Acacia extensa** but less than **Acacia pulchella.** Final calcium and potassium levels were similar across the materials used, but phosphorus and nitrogen levels were low (Table 7).

Melaleuca radula

The poor performance of this species is reflected in the unusual pattern of height differences between media (Table 1) where the NT gave marginally taller plants than TA material by the conclusion of the experiment. Foliage numbers were marginally greater in TA than NTA, and both held more leaves than plants in the NT medium.

Deaths were particularly high in the unamended materials where losses were 85 percent in T and 35 percent in NT materials. The very small size of seedlings used for this species mitigates against any useful comments being made about suitability, other than to suggest that, as for Eucalyptus camaldulensis, small seedlings are unsuitable.

Conclusions

The mixed sample materials in which the plants were grown showed interesting changes in acidity level over the course of the trial. However we are not as concerned in this report with material properties as such, but with comparative performances of the plant species used. If the final spoil acidity levels are considered then **Acacia baileyana** and, to a lesser extent, **Acacia extensa** show some acid tolerance at about pH 4.0. **Albizia lophantha**, Cytisus **proliferus** and **Eucalyptus camaldulensis** appear to prefer a higher pH of around 5.5. Acacia pulchella and **Eucalyptus gomphocephala** showed best performance at the higher pH levels. Acacia myrtifolia shows promise for further testing as do **A. extensa** and **A. pulchella** in relation to nutrient availability.

Survivals of **Melaleuca radula** and Eucalyptus camaldulensis were poor, reflecting initial small size of these species. The two legumes with heavier seeds (Cytisus **proliferus** and Albizia lophantha) produced greatest mean dry weights in all spoils at both harvests. **Cytisus** proliferus was generally heavier than **Albizia** lophantha, apart from toxic unamended spoil at both harvests and toxic amended spoil at first harvest. The Cootamundra wattle **A. baileyana** was generally the third heaviest species but it grew less well than **A.** myrtifolia in TA.

If Cytisus **proliferus** is acceptable then some indication of its behaviour in relation to fertilisers is required. It could be a pioneer for later seral species.

Albizia lophantha may have been able to continue high production had the experiment lasted longer. This species normally has a high water requirement, early growth may have been exaggerated by the higher seed weight in this species.

Larger seedlings of **Eucalyptus** species may perform rather better than the small seedlings used in this work.

The ranks and means for heights and leaf numbers at the end of the experimental period suggest that height or foliage numbers alone are not likely to give an accurate guide to dry matter production.

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OBSERVATIONS ON FOLIAR NUTRIENT CONTENT OF SANDALWOOD (SANTALUM SPICATUM R.Br. D.C.)

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INTRODUCTION

Sandalwood, **Santalum spicatum**, has been of economic importance to Australia since it was first exported in 1845. As a result of both agricultural development and commercial harvesting, natural stands have become depleted. Interest has therefore developed in replenishing stocks of sandalwood for marketing, focussing on attempts at re-establishing the species in natural environments.

To date attempts to grow sandalwood to maturity under both controlled field conditions and in many rural localities have been of limited success.

In attempts to better define establishment requirements for sandalwood, the School of Biology at the Western Australian Institute of Technology has conducted various experiments over the past 6 years. The following topics have been considered:

- optimum germination conditions
- optimum age for planting out
- soil types best suited for young plants
- shade requirements
- development of individual plants
- origin of seed and phenotype
- host suitability
- parasite/host dependence
- water and nutrient requirements

Results of this work suggest that a number of factors can enhance the chances of early survival of sandalwood. These include incising the seed case before planting (Wijesuriya 1985), using suitable soil mixes, e.g. the University of California soil mix - see Wijesuriya and Fox (1985 this publication), or planting seed directly into the ground (or using germinants). In addition observations to date suggest that growing young plants under shade, watering well and consistently, and finding a suitable host at an early age (probably by at least one year although haustorial connections can form much earlier), will also assist early survival of sandalwood.

Although mineral nutrition of the stem hemiparasite, mistletoe has been well studied (e.g. Lamont 1983, Lamont & Southall 1982), that of woody root hemiparasites has received little attention. Hocking (1980) analysed nutrients in **Nuytsia floribunda**; Klaren and van de Dijk (1976) and Klaren and Jansen (1978) studied **Rhinanthus serotinus**. Hirano (1977) examined propagation of some **Santalum** species; Struthers (1983) and Struthers **et al.** (submitted 1985) have investigated **Santalum spicatum**. Other mineral studies on sandalwood are reported in Crossland (1982).

This report is a summary of nutrient analyses performed to date on leaves (or shoots) of **S. spicatum** with and without fertiliser treatment and in nutrient omission studies. These studies are being undertaken in an attempt to investigate:

* optimum mineral levels in healthy plants,
* the role of individual nutrients in sandalwood growth,
* the degree and nature of dependence of sandalwood on host nutrient supply,
* how different fertilisers benefit growth.

Once these parameters can be satisfactorily understood commercial establishment of sandalwood trees should become more feasible.

Results and Discussion

Details of samples used and references to the sources of plants sampled are given in the Appendix. The mineral contents of each sample are given in Table 1. These figures are averaged and presented concisely in Table 2. Figures 1-6 were plotted using data from Table 2 in order to show graphically the relationship between age and mineral concentration of the leaves and shoots. All concentrations are based on the dry weight of samples. This work has continued over a number of years with different research workers. There is sometimes considerable variation in concentrations determined for different analyses of leaves from the same tree and amongst trees of the same age.

Nutrient Concentration Changes With Age

Figure 1 is a composite presentation of results for all minerals analysed. Similar trends can be seen in the graphs for nitrogen (N), phosphorus (P), calcium (Ca) and potassium (K) (Figure 2). The mineral contents present in the endosperm decrease for the first four to ten months after germination but after two years their concentration in the plant leaves is equal to or greater than those in the original endosperm. Sometime between the age of four months and two years there is a minimum mineral concentration. More information is required to determine the age at which this occurs but the N and Ca graphs suggest it is later than 10 months.

Other elements may well show this depletion for the first year or so, (Figures 1-6). However there are no data available for this period. At two years concentrations of N, P, Ca and K peak, (Figures 1 & 2). Thereafter N and P show a slow, progressive decline in concentration whereas Ca and K show a slow overall increase.

The sodium (Na) concentration (Figures 1 & 6), which is extremely low in the endosperm, increases over the time period examined with a maximum value in the 52 year sample. There is no peak but the rate decreases after two years to closely parallel the K curve.

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In the 52 year sample the nitrogen concentration is about half, and the phosphorus about a third of that in the original endosperm whereas potassium is about nine times greater. Levels of magnesium (Mg), copper (Cu), zinc (Zn), N and P are lower and values for iron (Fe), Na, Ca and K are higher in leaves of 52 year-old trees than in endosperm. Unfortunately only endosperm and 52 year-old leaf analyses were available for trace elements and Mg.

It seems reasonable to deduce that for N, P, Ca and K and probably other minerals too, the growing seedling relies heavily on its seed reserves for perhaps a year. But seed reserves and sandalwood root intake are not sufficient to reverse a decline in mineral concentrations as the seedling develops its shoot and root system. Since concentrations peak by two years it is suggested that haustorial connections must be made not later than the time of minimum concentrations. As nutritional intake from the host occurs concentrations rise.

Observations on the growth and health of young sandalwood plants at WAIT Field Trial Area (FTA) have shown that if no haustorial connections are made by about one year the plant foliage usually begins to yellow and the plant will then die. These observations support the deductions made from the mineral analyses.

Old and New Leaves

Sandalwood plants of ages two and four years were sampled. Leaves were subdivided into various categories as shown in Table 2 and plotted in Figures 3, 4, 5 and 6. New and old leaves were carefully selected as described in the Appendix.

a) Two-Year Old Leaves

N, P, K, Ca, and Na concentrations for two year old leaves were greater for old leaves than for new leaves. Possibly the 'old' leaves at two years were still in peak condition and functioning well whereas the new leaves were still developing. In fact no leaves on a two year old plant could be really old leaves.

b) Four-Year Old Leaves

At age four years, old leaves had less N and less K than new leaves. Both elements are mobile in the plants and are probably relocated from older to newer leaves as the tree ages. Depending on how long individual leaves remain on the tree, leaves which were considered old at two years may be older or even senescing at four years. It is interesting that at both two and four years the new leaf nitrogen content is much the same (24-25 mg/g).

P concentrations are similar in both old and new leaves. Ca and Na remain in higher concentrations in old leaves. Since Ca is relatively immobile and becomes fixed in, for example the cell wall, this is an expected result. The accumulation of Na may be related to water intake but may be simply a passive build up.

We note that a set of vigorously growing trees at WAIT FTA (i.e. 4 year old no's 52, 53, 57, 68) contained higher levels of N and P and lower levels of Ca than a more slow-growing set (25, 26, 35).

For four-year old leaves the mean concentrations of all minerals, except K, were higher in FTA leaves than in Jam Paddock leaves. This probably reflects the more adequate growing conditions in the FTA where plants appear vigorous and healthy (see Appendix).

If K (and Na) are involved in water uptake, the lower FTA leaf concentration may reflect less dependence on a high ion balance to increase the water gradient in a well-irrigated plot. One might expect a similar pattern for Na but the reverse is true.

Broad and Narrow Four-Year Old Leaves

Both broad and narrow leaves showed distinct characteristics. The broad leaf form had lower mineral concentrations than the narrow leaf form for all elements investigated. Remembering that elemental concentrations are based on dry weights this difference may reflect the fact that broad leaves have more storage and pallisade tissues than narrow ones. The latter would have more vascular and epidermal tissues per unit volume. It is also possible that the concentration variation represents inherent physiological differences in each type of leaf.

Seasonal Variations in Leaf Concentration

There is no overall pattern in mature trees (Figure 7). P, Na, Mg and Fe appear to reach maximum concentrations in Spring; N, K, Cu and Zn in Summer and Ca in Winter.

Endosperm Calcium

Calcium in the endosperm is very low, 0.4 mg/g, (only the Na concentration is lower) yet Ca is essential to the growth of the new plant. There must nonetheless be sufficient Ca to last either until the plants own roots function in Ca uptake or until a host connection is made. The minimum level is well below that found in healthy young two and four year old leaves. It may be that lack of Ca is the first limiting factor if no host attachments are made.

Optimum Nutrition

Nutrient levels in the young leaves of healthy two and four year old trees from the FTA may be considered ideal for vigorous growth. These levels are of the following order: N, 24-25 mg/g; P, 2 mg/g; Ca, 8 mg/g; K, 14 mg/g; Na, 5-6 mg/g. Controlled experiments could be devised to determine appropriate nutrient feeding levels to achieve these ideal mineral concentrations found in healthy leaves.

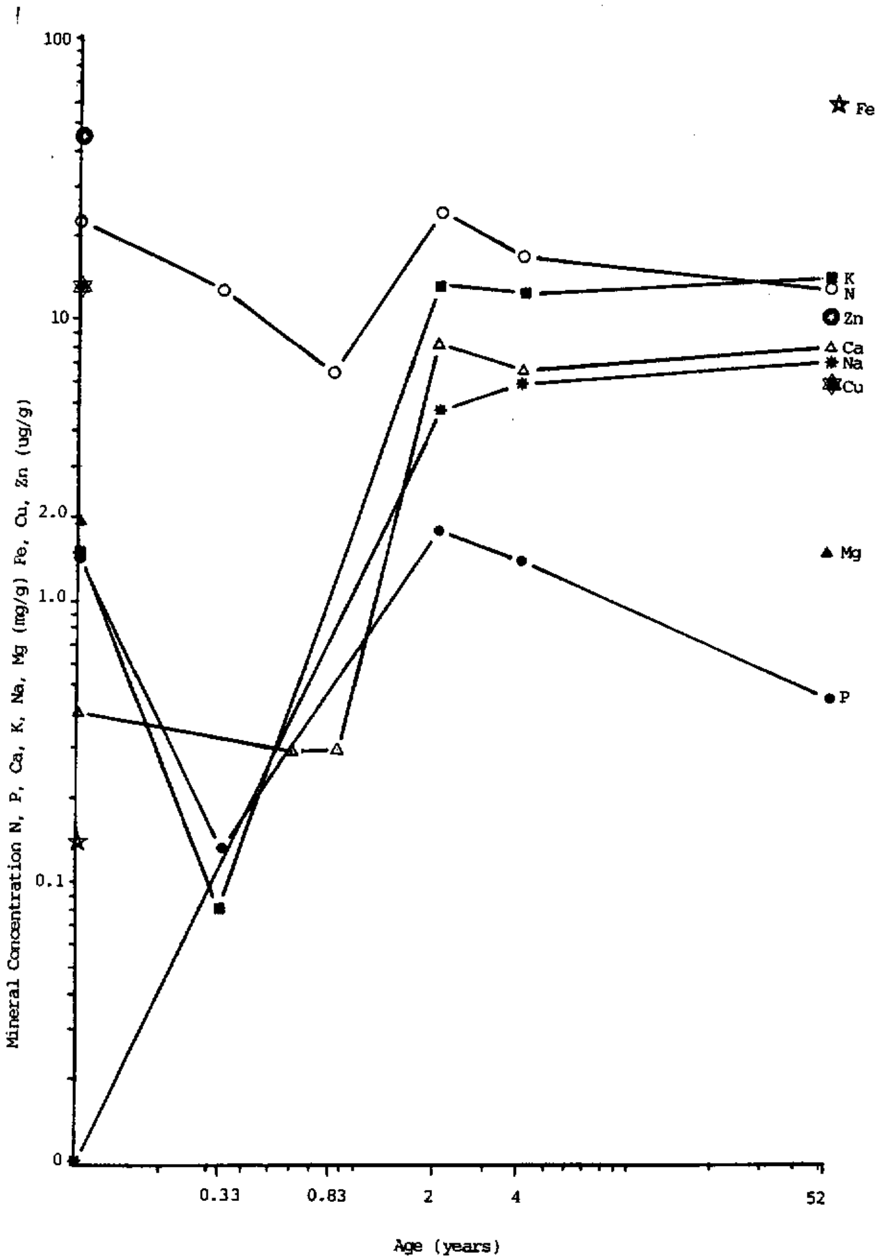

FIGURE 1. Average mineral concentration in leaves from Santalum spicatum of different ages.

Fertiliser Treatments

Establishment of sandalwood in the field may be improved if seedlings can be encouraged to survive for longer periods without a host and develop extensive root systems (to improve nutrient uptake and chances of locating a host). Once established, maximum growth rate can only be maintained if sufficient minerals are available to the plant.

In order to investigate the influence of fertilisers on growth parameters and nutrient content the following fertilisers were used by researchers at WAIT:

ammonium nitrate (agran) $NH_4\ NO_3$
ammonium sulphate $(NH_4)_2SO_4$
blood and bone
hoof and horn
osmocote slow release (14% N, 6.1% P, 11.6% K, 4.5% S)
superphosphate
sodium phosphate $Na\ H_2PO_4$
iron EDTA (chelate)
combinations of the above
various levels of K in an otherwise balanced treatment
various levels of Ca in an otherwise balanced treatment

A number of nutrient omission studies were also performed in which plants were grown without N, P, K, Ca, Mg, Fe, S and micronutrients.

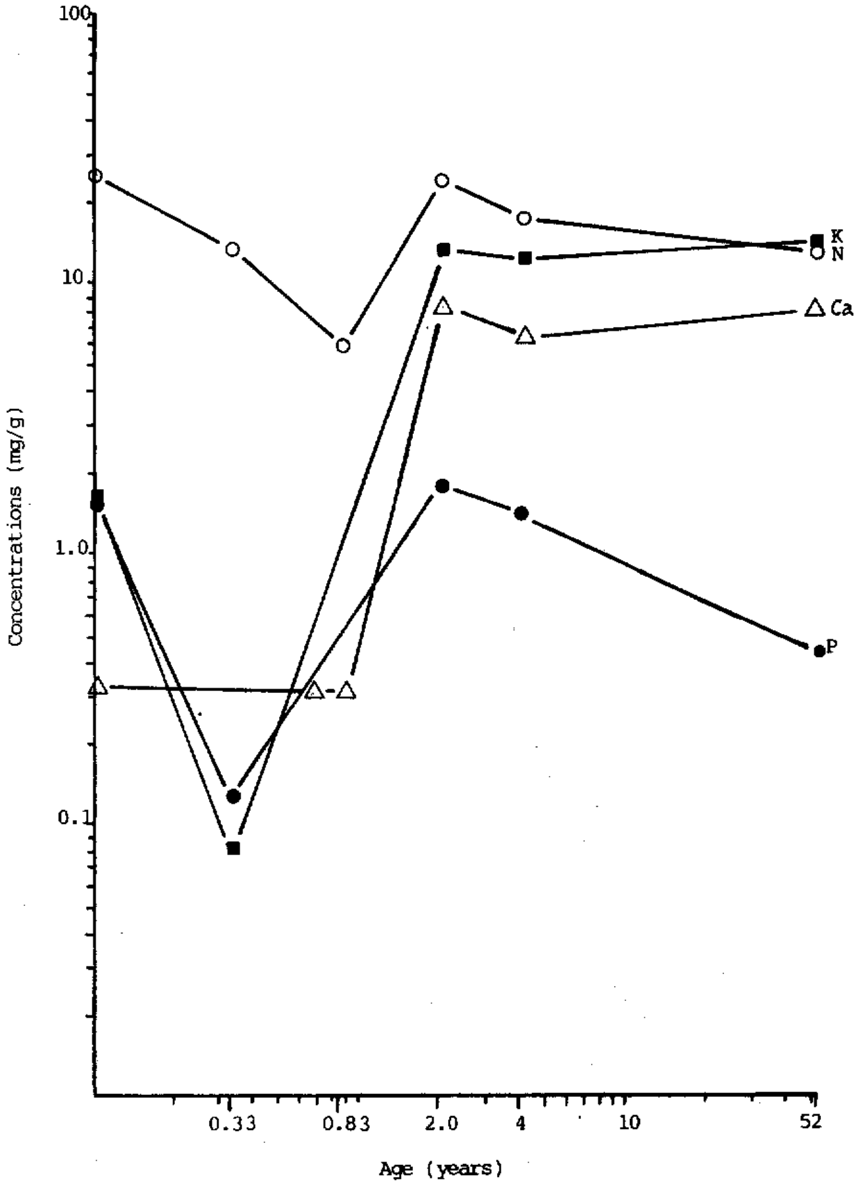

FIGURE 2. Nitrogen, phosphorus, calcium and potassium concentrations in leaves from Santalum spicatum of different ages.

Nitrogen and Phosphorus Treatments

Crossland (1982) and also Seman (unpublished report) applied Agran (ammonium nitrate) fertiliser to 4-5 month old seedlings without hosts in quantities ranging from 0-230 kg ha-1 over a period of 240 days.

The growth rate was uniformly slow and by the end of the experiments the N concentration had decreased considerably in all plants to levels below those at the start of the experiment, although higher than those of the control. This may reflect the trend observed for unfertilised plants where a depletion in N (and also P and K) occurs for about eight months. However, Agran and other fertilisers containing nitrogen: blood and bone, hoof and horn, and osmocote, all produced an increase in dry weight (and N, P and K concentrations) compared with the control. Crossland (1982) concluded that osmocote slow release fertiliser applied at 50 kg ha-1 was most beneficial to young seedlings. Certainly osmocote treated plants had greater root development and greater shoot N than other plants.

Sawyer (1981) applied many combinations of different fertilisers to seedlings with and without hosts. For plants harvested three months after treatment Sawyer concluded that there was no definite trend to indicate that N increases foliar mass whatever the levels of application. The same applied for P. The majority of plants given varying degrees of N and P fertiliser were yellow-green in colour and all tended to drop their leaves. Crossland (1982) found similar results after ammonium sulphate treatments ranging between 0 and 100 kg ha-1. Sawyer did find a few exceptions. Plants treated with

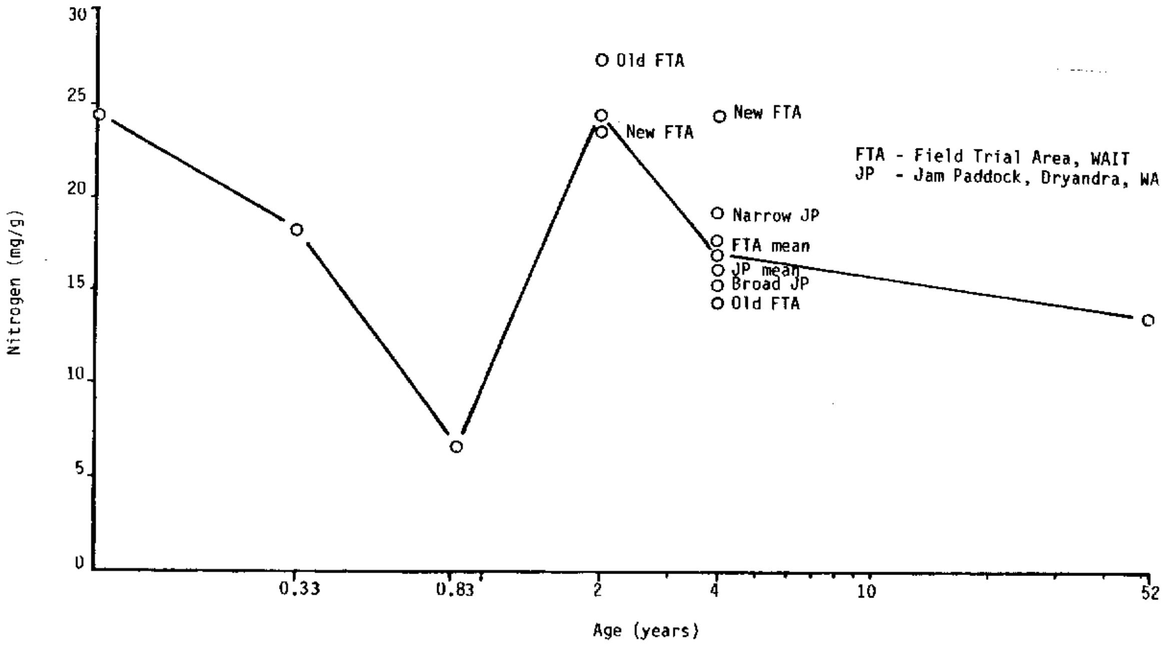

FIGURE 3. Nitrogen concentration in leaves from **Santalum spicatum** of different ages.

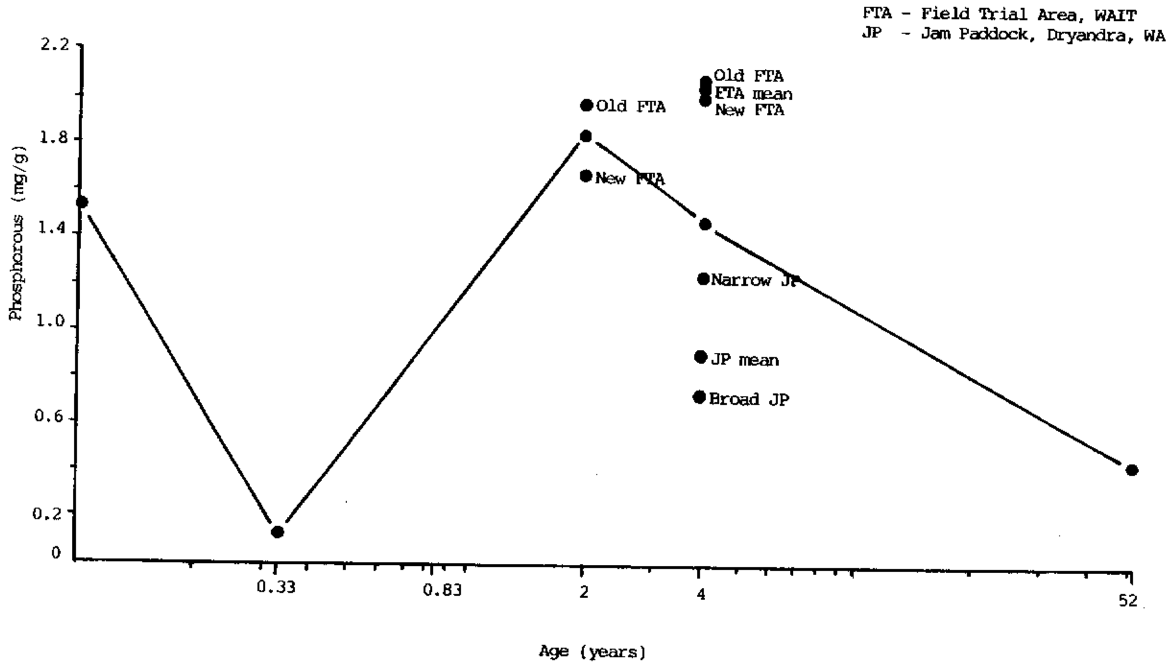

FIGURE 4. Phosphorus concentration in leaves from **Santalum spicatum** of different ages.

TABLE 1. Mineral content of sandalwood shoots and leaves of different ages.

Sample Description	Tree No.	Age (years)	Harvest/ Analysis Date	Host	Origin of Tree	Mineral Content													
						N%		P mg/g		K mg/g		Ca mg/g		Na mg/g		Mg mg/g	Fe µg/g	Cu µg/g	Zn µg/g
Seed Endosperm					Dryandra	2.26		1.2		1.99		0.33		<0.01		1.35	0.13	10.2	33.7
					Kalgoorlie	2.61		1.87		1.19		0.46		<0.01		2.59	0.15	15.9	47.5
Shoot		0.33	2.7.81	?	Leinster Downs	1.60		0.11		0.07									
Shoot		0.33	2.7.81	?	Narrogin	1.28		0.15		0.09									
Shoot		0.33	13.10.81	?	Bullock Hills	1.14													
Shoot		0.66	9.84	No	Kalgoorlie														
Shoot		0.83	13.10.81	?	Leinster Downs	0.65						0.31							
Shoot		0.83	13.10.81	?	Narrogin	0.66													
Shoot		0.90	1.85	No	Kalgoorlie							0.31							
New leaves	1	2	3.85	Yes	FTA 1983	2.69		1.84		11.96		6.67		2.99					
Old leaves	1	2	3.85	Yes	FTA 1983	2.60		2.13		11.91		12.62		6.91					
	13	2	3.85	Yes	FTA 1983	2.73		1.38		8.27		8.51		7.05					
New leaves	84A	2	3.85	Yes	FTA 1983	2.33		1.62		14.88		2.73		2.73					
Old leaves	84A	2	3.85	Yes	FTA 1983	2.63		2.26		18.66		11.43		6.76					
New leaves	84A	2	3.85		FTA 1983	2.05		1.57		12.23		6.75		2.23					
Old leaves	84A	2	3.85		FTA 1983	2.20		2.20		16.98		9.38		6.25					
Trees well watered New leaves used	(52 (	4	3.85	Yes	FTA 1981	2.32	(2.49 (2.15	2.04	(0.59 (3.50	18.31	(17.37 (19.25	4.25	(4.12 (4.38	3.49	(3.37 (3.62				
	(53 (	4	3.85	Yes	FTA 1981	2.47	(2.61 (2.32	1.72	(1.50 (1.94	16.31	(14.00 (18.62	4.74	(4.37 (5.12	3.24	(2.62 (3.87				
	(57 (	4	3.85	Yes	FTA 1981	2.86	(3.04 (	2.10	(1.76 (2.44	13.44	(12.25 (14.63	5.87	(5.75 (6.00	3.27	(2.40 (4.15				
	(68	4	3.85		FTA 1981	2.19	(2.06 (2.31	2.26	(2.00 (2.53	7.12	(6.50 (7.75	5.81	(5.62 (6.00	6.12	(5.75 (6.50				
Trees well watered Old leaves used	(52	4	3.85	Yes	FTA 1981	2.48		4.54		20.12		14.00		11.37					
	(53	4	3.85	Yes	FTA 1981	1.88		1.51		8.12		11.25		15.62					
	(57	4	3.85	Yes	FTA 1981	1.91		2.65		12.25		10.62		9.50					
	(68	4	3.85	Yes	FTA 1981	1.57		1.78		6.25		5.00		6.87					
Trees well watered Old leaves used	25	4	3.85	Yes	FTA 1981	1.22	(0.54 (1.90	1.58	(1.32 (1.85	11.05	(11.03 (11.07	12.41	(11.63 (13.19	4.73	(4.71 (4.75				
	26	4	3.85	Yes	FTA 1981	0.92	(0.60 (1.23	1.51	(1.47 (1.56	13.59	(12.63 (14.56	7.40	(7.37 (7.44	2.68	(2.25 (3.12				
	35	4	3.85	Yes	FTA 1981	0.30	(0.09 (0.51	2.51	(1.55 (3.47	3.64	(3.12 (4.16	14.29	(10.50 (18.09	12.74	(11.73 (13.75				
	25	4	3.85	Yes	FTA 1981	1.25		0.43		13.50	4.28			6.50					
	1 BL	4	3.85	Yes	Jam Paddock	1.75		0.80		13.48		5.00		4.75					
	5 BL	4	3.85	Yes	Jam Paddock	1.16		0.37		11.98		4.13		4.63					
	6 BL	4	3.85	Yes	Jam Paddock	1.51		0.46		13.73		6.62		7.13					
Previously cultivated area PO4 may blow from surrounding lands	1 (A)BL	4	3.85	Yes	Jam Paddock	1.72	(1.69 (1.75	0.82	(0.80 (0.83	12.71	(11.47 (13.96	5.45	(5.42 (5.49	2.95	(1.37 (4.53				
	2 (B)BL	4	3.85	Yes	Jam Paddock	1.42	(1.27 (1.57	2.18	(0.40 (3.97	11.79	(11.39 (12.19	6.64	(6.49 (6.80	2.89	(1.47 (4.32				
	3 (C)NL	4	3.85	Yes	Jam Paddock	0.84	(0.82 (0.86	1.52	(0.29 (2.80	21.22	(19.85 (22.60	5.92	(5.80 (6.04	3.14	(1.45 (4.84				
	4 (D)NL	4	3.85	Yes	Jam Paddock	1.24	(1.19 (1.24	2.00	(0.41 (3.60	16.16	(14.83 (17.50	7.12	(6.04 (8.21	3.55	(1.56 (5.55				
	5 (E)BL	4	3.85	Yes	Jam Paddock	1.16	(1.15 (1.16	0.57	(0.35 (0.79	13.36	(11.86 (14.86	4.40	(4.12 (4.69	3.09	(1.35 (4.84				
	6 89 BL	4	3.85	Yes	Jam Paddock	1.73		0.40		15.50		3.70		6.88					
	7 129BL	4	3.85	Yes	Jam Paddock	1.75		0.37		13.88		2.32		6.38					
	8 153NL	4	3.85	Yes	Jam Paddock	2.50		0.51		17.75		5.73		4.50					
	9 143NL	4	3.85	Yes	Jam Paddock	2.81		0.96		4.00		3.95		10.25					
		52	4.12.82	Yes	Dryandra	1.70	± 0.37	0.34	± 0.05	17.45	± 2.86	8.40	± 3.38	7.28	± 2.62	1.8 ± 0.40	4.51 ± 10.0	7.2 ± 2.8	14.2 ± 5.9
		52	1.4.83	Yes	State	1.02	± 0.27	0.33	± 0.08	13.52	± 2.98	9.52	± 3.35	6.45	± 1.95	1.03 ± 0.31	58.4 ± 11.9	4.6 ± 2.6	10.0 ± 2.2
		52	21.8.83	Yes	Forest	1.39	± 0.30	0.71	± 0.16	12.28	± 1.49	7.39	± 2.64	8.21	± 3.26	1.90 ± 0.53	85.0 ± 47.0	6.5 ± 2.8	8.7 ± 3.6

ammonium sulphate (779 kg ha-1), sodium phosphate (571 kg ha-1) or a mixture of the above gave the best growth and did not look chlorotic. Interestingly, shoots of these plants did not contain the highest levels of N nor of P although levels were higher than in studies on non-fertilised plants. If optimum levels of nutrition are exceeded the excess may not be utilised or may hinder development.

All sandalwoods with hosts, with one exception, showed low growth and low harvest weights relative to controls and lost weight throughout the experiment. The exception was a seedling with an Acacia host, both treated with ammonium sulphate at a rate of 779 kg ha-1. The shoot of this plant had amongst the highest N and P concentrations of those recorded by Sawyer. All plants given iron grew well. In contrast Struthers (1983) found iron addition had no effect on growth of his seedlings.

Phosphorus Treatments

Crossland (1982) and Keesing (unpublished report) experimented with superphosphate. After trials on seedlings involving applications of between 0 and 680 kg ha-1 of superphosphate for periods up to 240 days, it was concluded that this fertiliser was not suitable for young sandalwoods. In a few cases the controls had greater concentrations of the mineral than the treated plants. In general the N, P and K concentrations were increased above the controls and were indeed higher than in untreated sandalwoods of the same age. Keesing reported decreasing concentrations with the duration of experiment. Crossland states that the treated plants were smaller with less leaves and less roots than the controls.

Varying Ca and K Levels in an Otherwise Balanced Solution

Struthers (1983) found that he could not draw many firm conclusions from this set of studies. Treatment response was probably reduced because the seedlings were originally grown with osmocote. However increasing the Ca concentration did appear to stimulate growth whereas increasing K gave a much lower response. The level of increase of these minerals appeared to have little effect. Controls had higher levels of N, P, Fe and Zn than treated plants.

Hydroponic Omission Studies

Two hydroponic studies have been made in which seedlings were grown in standardised nutrient deficient solutions. It was found that a lack of Ca dramatically reduced the growth of plants and led to their death within three to six weeks. A lack of N and micronutrients resulted in obvious reduced growth by an age of 2 months.

Conclusions

There appears to be a large variation in some elemental concentrations. This may have resulted from one or more of the following three phenomena.

* such differences reflect large leaf concentration variations (therefore standardised sampling is very important for comparative work),

* the trees have inherently different characteristics in this respect because for example, they are derived from seed of different stock or they have different host relationships. The latter point may well be important.

* analytical inaccuracies.

Whatever the cause of the observed variations, the number of samples used (Table 2) has nonetheless been sufficient to allow overall trends to be apparent.

The growing seedling relies heavily on its mineral seed reserves for perhaps a year. But seed reserves and sandalwood root intake are not sufficient to reverse a decline in mineral concentrations as the seedling develops its shoot and root system. Since concentrations peak by two years it is suggested that haustorial connections must be made not later than the time of minimum concentrations. As nutritional intake from the host occurs concentrations rise. The levels of nutrient in healthy, vigorously growing two and four year old sandalwoods are N, 25 mg/g; P, 2 mg/g; Ca, 8 mg/g; K, 14 mg/g; Na, 6 mg/g. These concentrations should provide a guide as to fertiliser requirements.

The large number of fertiliser trials and variation in level and length of treatments with plants of different ages generally makes specific deductions difficult. Results sometimes appear conflicting. More studies will be needed to estimate which treatments result in plants with optimum nutrition levels as indicated from the studies described above.

From the above studies it may be concluded that ammonium sulphate (779 kg ha-1) - especially in combination with an Acacia host - sodium phosphate (571 kg ha-1), or a combination of these fertilisers, is a promising treatment for young sandalwoods. Osmocote 90 day release (50 kg ha-1) was also beneficial but superphosphate was not.

The Ca and N in the endosperm cannot support the young plant for long but increased Ca levels stimulate growth of seedlings, whereas lack of Ca and N is soon lethal. Obviously uptake of these minerals and Na if available occurs via the plants' own root system. Any treatment which increases root growth (especially osmocote and possibly sodium phosphate) may encourage this early uptake of limiting minerals.

The best insurance for continued vigorous growth to maturity appears to be early attachment to strong and healthy hosts.

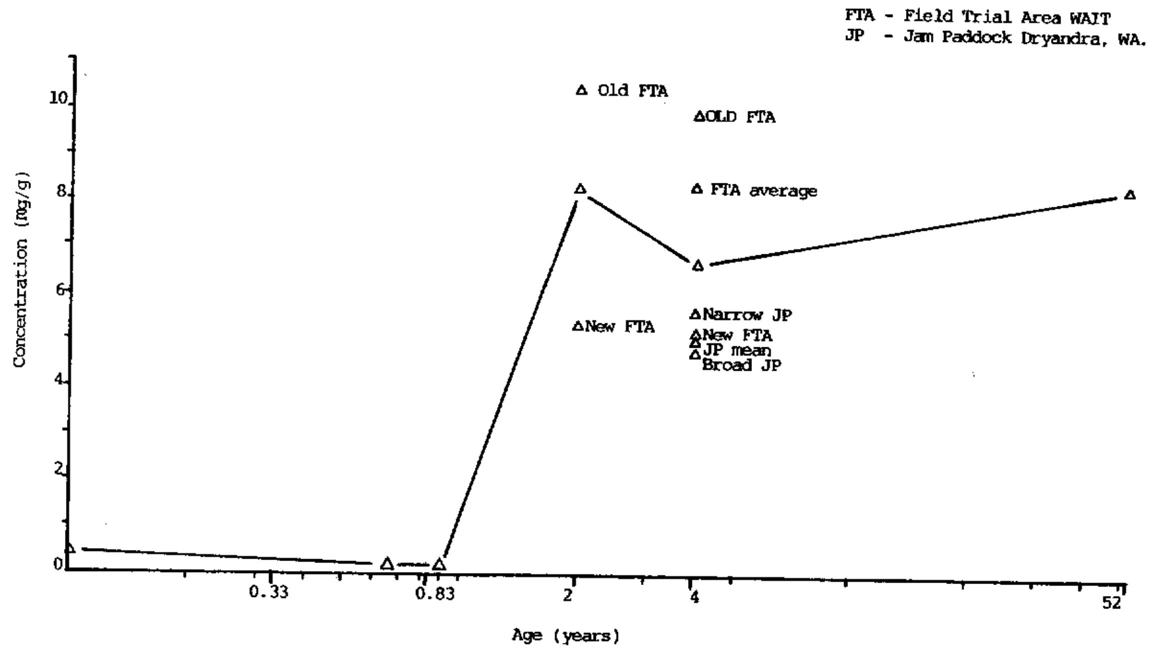

FIGURE 5. Calcium concentration in leaves from Santalum spicatum of different ages.

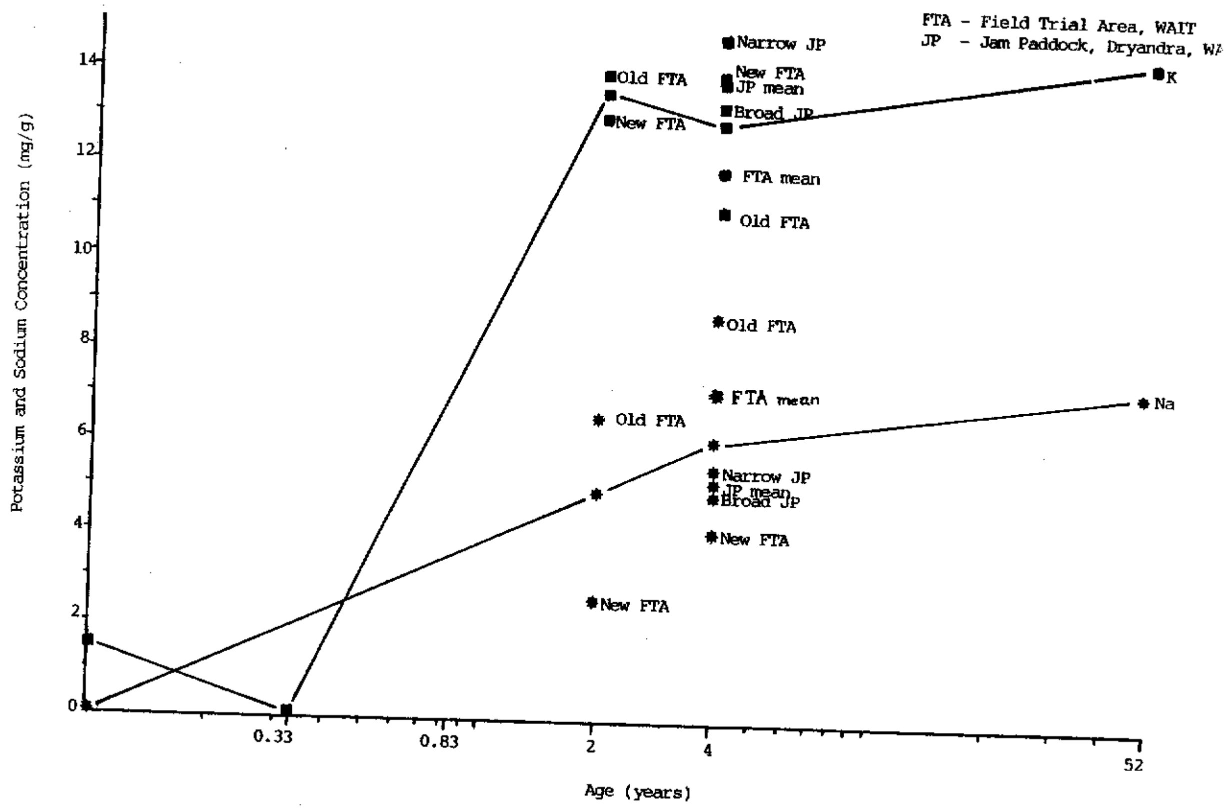

FIGURE 6. Potassium and sodium concentration in leaves from Santalum spicatum of different ages.

TABLE 2. Mineral concentrations of various categories of leaves. Figures averaged from Table 1.

Sample Description			Mineral Content - Leaves/Shoots									
			mg/g						ug/g			
Origin	Age (years)	Shoot or Leaf Age/ Shape	N	P	Ca	K	Na	Mg	Fe	Cu	Zn	No. of Different Samples Analysed
Dryandra & Kalgoorlie		Endosperm	24.4	1.54	0.40	1.59	<0.01	1.97	0.14	13.1	40.6	2
Leinster Downs, Narrogin & Bullock Hills	0.33	Shoot	13.4	0.13		0.08						3
Kalgoorlie	0.66	Shoot			0.31							2
Leinster Downs & Narrogin	0.83	Shoot	6.6									2
Kalgoorlie	0.90	Shoot			0.31							2
FTA	2.0	Mixed	24.6	1.86	8.30	13.56	4.99					7
		Old	25.4	1.99	10.49	13.96	6.74					4
		New	23.6	1.68	5.38	13.02	2.65					3
FTA	4.0	Mixed	17.8	2.05	8.33	11.98	7.18					12
		Old	14.4	2.06	9.91	11.07	8.75					8
		New	24.6	2.03	5.17	13.80	4.03					4
Jam Paddock	4.0	Mixed	16.31	0.91	5.08	13.80	5.01					12
		Broad	15.25	0.75	4.78	13.30	4.84					8
		Narrow	18.43	1.25	5.68	14.78	5.36					4
FTA & Jam Paddock (all above)	4.0	Mixed	17.06	1.48	6.70	12.89	6.09					24
Dryandra	52.0	Mixed	13.7	0.46	8.44	14.4	7.31	1.58	62.8	6.1	10.97	3

Further Work

It would appear desirable to pursue nutrient investigations along the following lines.

* Analyses of leaves from various localities and of different ages, particularly in the range 4 months to two years for as many minerals as possible including trace elements. Use of isotopes as traces may be useful.

* Studies of leaf development from young immature to senescent - how long do leaves stay on the tree - when are they fully expanded - when do new leaves form etc.

* Further fertiliser trials especially involving treatments which indicated some effectiveness - Ca addition, ammonium sulphate, sodium phosphate, osmocote and possibly iron. Investigate importance of fertilising host.

* More information on the best methods of encouraging early host attachment to suitable healthy hosts.

Acknowledgements

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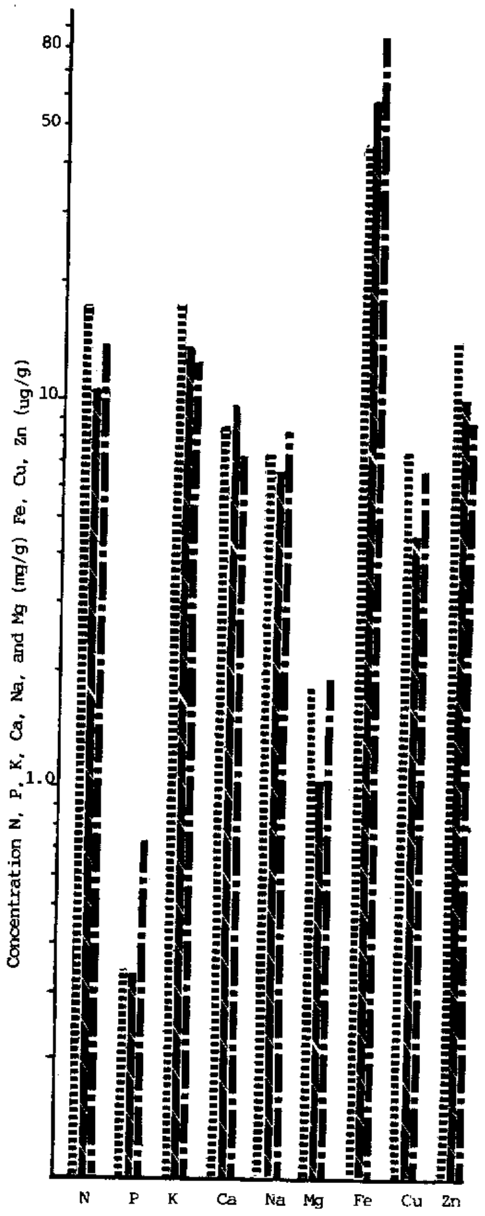

FIGURE 7. Mineral concentrations in leaves of 52 year old Santalum spicatum harvested in December 1982 ▪▪▪▪▪▪▪, in April 1983 ▬▬, and in August 1983 ▪▪▬.

APPENDIX

Samples used and references to analyses performed. Note that (in 1982) etc. refers to the year of analysis.

Endosperm

Seed ex Kalgoorlie and Dryandra. (Struthers 1983).

Young Shoots

4 month old (0.33 years) shoots grown from seed from Leinster Downs, Narrogin, Bullock Hills. Crossland (in 1982).

8 month old (0.66 years) shoots grown from seed from Kalgoorlie. Wijesuriya (in 1985).

10 month old (0.83 years) shoots grown from seed from Leinster Downs, Narrogin. Crossland (in 1982).

11 month old (0.9 years) shoots grown from seed from Kalgoorlie. Wijesuriya (in 1985).

Two Year Old Trees

Planted 1983 at FTA, WAIT. Numbers 1-13 seed ex Tom Price. No. 84 seed ex Kalgoorlie. Sellars (in 1985), and Stomber (in 1985).

Four year old trees planted 1981 at FTA, WAIT

No 52 seed ex Yeelirie.

No's 53, 57, 68, 25, 26 & 35 seed ex Kalgoorlie area.

Trees 52, 53, 57, 68 are considered vigorous growers and, at mid-1985, had an average height of just over 2 m.

Trees 25, 26 and 35 are more slow growing and had an average height of about 1.2 m.

Trees 53, 68, 26 and 35 received foliar spray applications from the time of planting - there has been no treatment in the past year for trees 52, 57 and 25. The spray per tree was 80 ml of a solution containing 1.5% Thrive and 1% Sequestrine. The treatment was discontinued as it effected no difference in visible parameters (growth rate etc) nor in mineral composition compared with untreated trees. The section of the FTA in which all the above sandalwood trees are growing is regularly irrigated throughout the summer. Acacia aneura and other potential hosts are in close proximity and the Acacia were fertilised with osmocote a year after planting. All sandalwoods appear healthy and there are no signs of any deficiencies. All leaves are a deep green with blue overtones perhaps best considered as a blend of R.H.S. leaf colour no's 146B and 133B.

New Leaf and Old Leaf Samples

All leaves taken from trees growing at WAIT Field Trial Area. Four years old when sampled.

New Leaf (Young, fully expanded, dark green
(Picked from second fifth of branch from tip

Old Leaf (Mature, thicker than new leaf and
(showing incipient yellowing
(Picked from fourth fifth of branch from tip

Jam Paddock (JP) Dryandra, Western Australia.

(Four year old trees planted 1981)

No's 1, 2, 5, 6 and 7 seed ex Narrogin.

No's 3, 4, 8 and 9 seed ex Kalgoorlie.

Trees 1 and 2 are considered vigorous growers and in early 1985 had an average height of 1.25 m. Trees 34 and 5 are slower growing and had an average height of about 0.7 m. All trees appeared to be growing well and looked healthy. The leaf colour was assessed as 146B on the R.H.S. leaf colour chart.

Broad Leaf (BL) and Narrow Leaf (NL) Samples

All leaves taken from trees growing at Jam Paddock, Dryandra. Four years old when sampled.

Broad leaf plants grew from Narrogin seed.

Narrow leaf plants grew from Kalgoorlie seed.

Dryandra

54 year old trees planted 1931 (sampled in 1983 when 52 years old) in plantation designated PU 8324. All trees are healthy. The trees ranged in height from 2.9 m to 6.2 m. Many potential hosts grew nearby but only Acacia accuminata could be confirmed as a functioning host.

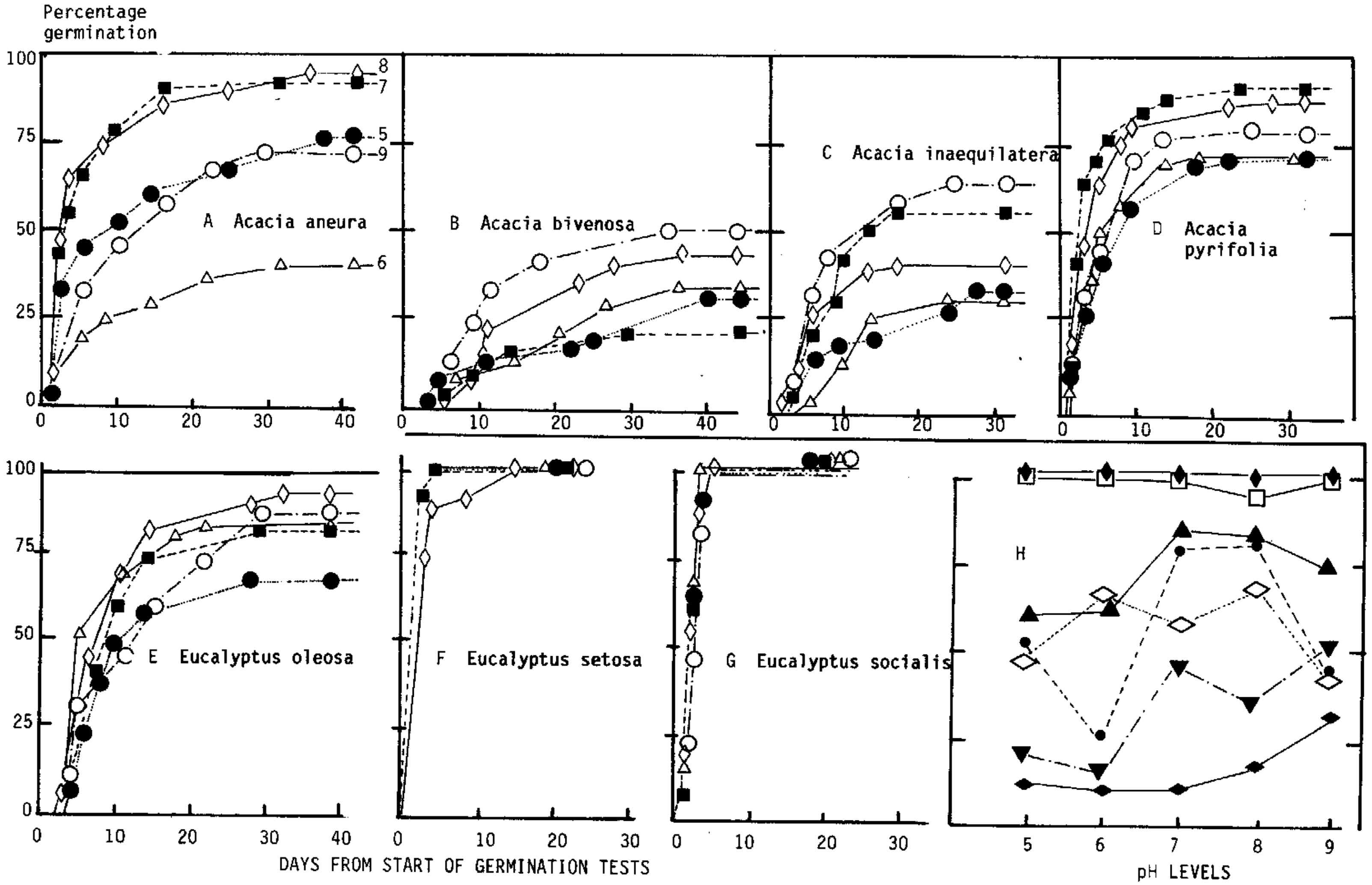

FIGURE 1. Germination results. Time course of germination A-G for seven species as shown, with pH levels 5 (closed circles), 6 open triangles, 7 closed squares, 8 open diamonds, and 9 open circles. H is a summary for all species with germination attained at 10 days for each of five pH levels: closed diamonds E. setosa, open squares E. socialis, open rhomboids E. oleosa, filled upright triangles A. pyrifolia, filled inverted triangles A. inaequilatera, closed circles A. aneura, and filled rhomboids A. bivenosa.

TABLE 2. Germination measurements for 7 species observed for up to 60 days at five pH levels.

SPECIES	**A. aneura**				**A. bivenosa**				**A. inaequilatera**				**A. pyrifolia**				**E. oleosa**				**E. setosa**				**E. socialis**			
GERMINATION MEASUREMENT	Via	GR	GV	Vig	Via	GR	GV	Vig	Via	GR	GV	Vig	Via	GR	GV	Vig	Via	GR	GV	Vig	Via	GR	GV	Vig	Via	GR	GV	Vig
pH level of test																												
5	74	8.8	8.0	0.9	30	18	1.7	0.5	32	11.5	2.4	2.4	74	7.1	21	0.7	64	9	5.3	0.2	100	3.0	383	0.9	100	3.7	190	0.4
6	46	9.7	9.3	1.6	30	17	0.9	-	28	11.6	2.2	0.2	74	5.9	21	0.9	80	7	12.5	<0.1	100	3.1	365	0.8	100	3.5	166	0.5
7	92	6.2	16.2	0.8	22	11	0.8	-	56	6.8	14.3	0.7	94	5.6	37	0.8	78	8	8.1	0.2	100	3.1	358	0.8	100	3.5	186	0.5
8	96	6.9	21.6	0.7	46	16	2.5	0.1	42	6.6	11.5	1.7	90	5.3	25	0.8	90	13	7.8	0.1	100	4.1	88	0.8	100	3.3	180	0.6
9	84	9.5	8.5	0.7	50	12	3.2	0.2	64	8.7	14.3	0.8	82	6.5	24	0.7	86	11	8.1	-	100	3.1	350	0.8	100	3.5	180	0.5

Via - Viability of seed, total germination percentage attained by 60 days; GR - germination rate; GV - germination value; Vig - vigour. These expressions are explained in the text. Lack of recordings under vigour indicate that no germination attained by 6 days in Acacia or 3 days in Eucalyptus and hence a comparable energy value could not be calculated.

These measures may be taken as providing objective values to contrast germination. Viability is an inherent property of a seed batch, and its expression may be reduced by environmental conditions. We may hypothesise, for convenience, that the highest viability could have been attained by all batches of seed of the species. Germination rate is a measure of rapidity of germination, with lower values indicating faster germination. Germination value weights the rate of germination with the stage of most rapid germination such that high values accrue to batches which have germinated most rapidly in the region of highest germination. Vigour may be considered as an objective measure of the strength of the seed, at least for seed of high viability. Low values indicate rapid, early germination.

Figure 1 illustrates the time course of cumulative germination over the period of the germination tests.

In the **Acacia** species seed was not equally viable. **A. aneura** and **A. pyrifolia** had seed of higher viability than the other two species, and in both cases highest germination was attained at pH 7-8. Only in **A. aneura** was viability below 50 percent in a batch, and this was at pH 6. Germination was least at pH 5-6 for both **A. aneura** and **A. pyrifolia**. Fastest germination (low value for germination rate) was at pH 7 for **A. aneura** and pH 8 for **A. pyrifolia**. These positions were reversed for germination value. There were few differences of note in vigour, in these two species, apart from a poor value (highest level) in pH 6 for **A. aneura**, coinciding with the poorest viability recorded.

In contrast the other two **Acacia** species produced most germinants at the highest pH level used. For **A. bivenosa**, pH 8-9 were similar, with lower viability for the three more acid media. In **A. inaequilatera** pH 7, 8 and 9 gave better germination than pH 5 and 6. Fastest germination was at pH 7 and 9 in **A. bivenosa**, and at pH 7 and 8 in **A. inaequilatera**. Germination values were equal in pH 7 and 9 for the latter species, and highest at pH 9 for **A. bivenosa**. Vigour values were similar for pH 7 and 9 in **A. inaequilatera** and pH 8 and 9 in **A. bivenosa**.

Of the 3 **Eucalyptus** both **E. setosa** and **E. socialis** were highly viable. All seed of **E. socialis** had germinated within 5 days, most of the **E. setosa** (with the exception of pH 8) germinated in 4 days of the start. The **E. oleosa** seed was not quite as viable, though it had a higher overall viability than all the **Acacia** species except for **A. aneura**. No effect of treatment can be imputed in the cases of both **E. socialis** and **E. setosa**.

In **E. oleosa** germination was highest at pH 8 and 9, lowest at pH 5. Germination rate was faster at pH 6, reflecting the shortest time to completion at 21 days versus 28-32 at other pH levels. Germination value was highest at pH 6 and this level also had the lowest value for vigour.

Emergence and germination from amended soils are recorded in Table 3. **E. oleosa** and **E. setosa** produced highest total emergence overall, all final percentages tended to be lower than the petri dish results, with a few exceptions. For example, the performance of **A. aneura** at pH 6 was considerably better from soil than in the petri dish, suggesting the low level recorded for the former may be put down to experimental error. As the germination recorded at pH 9 was high and similar to pH 7, we impute no effect of pH on germination and emergence in this species.

Only in the case of pH 9 with **A. bivenosa**, where germination appears enhanced and at pH 9 with **E. oleosa** and pH 5 with **E. socialis** where, in both cases, emergence appears to be depressed, can strong indications of a possible effect on germination be countenanced. In a number of other experiments (see for example Fox & Black 1982) germination is not affected by soil chemical status.

Mean harvest values for the seedlings after 84 days growth in the amended soils are given in Table 4. **A. aneura** grew best at pH 6 and was poor at the higher pH levels. **A. bivenosa** showed the reverse with best growth at pH 8 and 9.

In **A. aneura** seedling height and leaf area were greatest at pH 5. RGR decreased throughout the trial for pH 8 and 9, while it increased for pH 7. RGR for pH 5 and 6 fluctuated between harvests but generally increased.

Conclusions

Of the results presented those pertaining to germination and emergence tend to confirm field observations on species distributions rather more precisely than do the aspect comparisons.

The effects of aspect on the growth of plants as seedlings may be of little importance. Species may show a preference to a particular aspect in terms of growth but be able to grow and survive elsewhere. Dominance of one species on a particular aspect may be a result of its ability to grow faster and thus compete with other species more successfully. Under glasshouse conditions it was not possible to closely mimic resultant temperature and moisture regimes which probably follow field differences in aspect. Despite the lack of confirmatory evidence from this work there is probably a real difference in the case of **Acacia aneura** in distributions related to aspect. Further examination of the coincident edaphic characteristics accompanying stands of **A. aneura** on south facing slopes is warranted. Seedlings of this species can persist in shade, in nature, but this is not indicative of late successional status. The species will respond to light when other conditions are favourable. Our results suggest that acidity of the medium may be more important in terms of influence on growth than shade.

Eucalyptus setosa and **E. socialis** grew well in shade, partly a reflection of soil moisture being non-limiting in the experiment. If all conditions had been more closely investigated it may well have proved the case that these species would have shown better correlation of growth with light. Perhaps only in the example of **Acacia bivenosa** were the experimental results reasonably consonant with field observations. This species shows a clear preference for basic soils in the region and the germination and emergence data confirm a clear advantage accruing to this species when it is grown under basic conditions. However it often occurs as an early coloniser after fire, and while it has been noted as particularly prevalent on some south facing sites, we cannot say for certain that it tends to avoid north facing sites.

The sustained emergence performance of **Eucalyptus setosa** through pH 6-9 levels is probably a reflection of comparatively large seed size in this species. The final dry matter production indicates clearly that it can attain best early seedling growth at the more acidic end of the range. **Eucalyptus socialis** dry matter production on the basic soils was similar in magnitude of difference to that of **Acacia bivenosa**. Both these species are able to utilise growth media of alkaline tendency better than more acid media.

The related species **A. inaequilatera** and **A. pyrifolia** occupy distinctive micro-habitats in the field. We find the former to be more widespread as a shrub in **Triodia** grassland, on a range of soil materials, but consistently on skeletal soils where moisture stress must be severe. **A. pyrifolia** on the other hand appears to favour stream beds and banks, and other sites where soil moisture stress is probably less severe. Further comparative study of these two species, and also the less common, but very similar, **Acacia marramamba**, is suggested.

Acknowledgements

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NOTES ON EUCALYPTUS TODTIANA F. MUELL.

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Summary

Field observations of clumps of **Eucalyptus todtiana** growing at Eneabba indicated that some species are absent beneath its canopy whereas others are positively associated with the clumps.

A study was undertaken to examine the possible causes of this apparent selective growth of species under the clumps. Hypothetical explanations were: less light, allelopathy, lower or higher water and nutrient availability, and thicker litter. Field and experimental attributes were studied along transects under the clumps and outside the clumps.

Percent soil moisture, depth of litter and levels of some nutrient elements were significantly higher under the clumps than in adjacent heath. No significant differences were detected with pH, soil texture and percent organic matter. Environmental parameters examined were more favourable in the clumps. Allelopathy was not adequately determined as a causative mechanism in suppression. It is possible that under clumps the presence of some elements at higher levels than in the heath could act to disadvantage the suppressed species. In contrast higher moisture content and litter depth in the clumps may be favourable to species associated with clumps.

Introduction

Eucalyptus todtiana F. Muell. (prickly bark) is common on coastal sandplains from Eneabba to Jandakot. It is usually a mallee 3-4 m high but in the south of its range it may attain 10 m as a tree. At the study site 15 km south of Eneabba, the plants were mallees with 2-6 major stems, occurring as isolated clumps 3-7 m tall in an open heath vegetation, generally less than 2 m tall.

The clumps studied were located on Flora Reserve 31030, currently being mined for mineral sands. The area containing **Eucalyptus todtiana** is expected to be mined in the future. It is thus important that the ecology of this species be studied as the aim of rehabilitation after mining is to restore the original vegetation.

Preliminary observations suggested that very few species of the surrounding heath grew under the canopy of the **Eucalyptus todtiana** clumps. It was hypothesised that **Eucalyptus todtiana**

1) suppresses its own seedlings,
2) suppresses growth of most of the available species, and
3) provides a favourable microclimate for a distinctive associated flora.

Explanations for this apparent selective growth of species under the clumps include

a) less light (Lodhi & Rice 1971; Del Moral et al. 1978),
b) presence of inhibitor chemicals (allelopathy) in the soil (Del Moral & Muller 1970; Del Moral et al. 1978; Al Mousauri & Al-Naib 1975),
c) lower or higher water and nutrient availability, and
d) thicker litter.

A study was undertaken to explore which of these possible explanations is most important in respect of **Eucalyptus todtiana**. It was considered useful to undertake transect studies through clumps and adjacent heath and to measure relevant environmental and soil characteristics. In addition, species associated with **Eucalyptus todtiana** were categorised according to their attributes for use in rehabilitation of refilled mine pits.

Site Characteristics

Flora and Fauna Reserve 31030, 15.3 km south of Eneabba, falls within the rectangle prescribed by latitudes 29°5'-29°55'S, and longitudes 115°15'-115°18'E. The clumps studied were located east and west of Brand Highway, which runs through the Reserve.

The area is on the Eneabba Plain, immediately to the west of the Gingin Scarp. It is underlain by Cainozoic rocks of aeolian and sedimentary origin. Laterization and subsequent dissection of the younger sediments have resulted in subdued topography of lateritic hills with some break-aways, separated by sandy valleys (Lamont 1976). Heavy minerals are present in the marine sediments deposited along the ancient coastline. The study site is on the crest of an old sand dune, consisting of deep grey and yellow sands over lateritic gravels at a depth of 4-5 m (Lamont 1976).

The present climate may be described as warm mediterranean with an annual rainfall of 450 to 600 mm with an average rainfall at Eneabba of 534 mm. Hot, dry summers occur with some days in January and February reaching 47°C (screen temperature) and pan evaporation up to 18 mm. Ground temperatures may reach 60-70°C (Hopkins & Hnatiuk 1981). From August to April, periods of strong, warm easterly winds occur. Rainfall only exceeds evaporation for the months of June, July and August. Average summer temperature is 27.3°C and that for winter, 13.5°C (Table 1).

The area lies within the Irwin Botanical District. Vegetation in the vicinity is low heath with occasional stands of **Eucalyptus todtiana** (low woodland) and **Xylomelum angustifolium** (high shrubland). This is sometimes termed Kwongan (sandplain), and has a fairly uniform scrub-heath assemblage. The low open woodland of **Eucalyptus todtiana** rises above open or closed heath cover, dominated by **Banksia hookerana**, **Conospermum triplinervium**, **C. incurvum** and **Xylomelum angustifolium**. The open herb layer is dominated by geophytes (e.g. **Drosera stolonifera**) and grass-like species (e.g. **Mesomelaena** spp., **Conostylis** spp.).

Mulga Research Centre Journal No. 8
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Average height of tallest plants under the clump was 67.3 cm which increased in the heath to an average of 77.5 cm. This difference was significant at the 1 percent level.

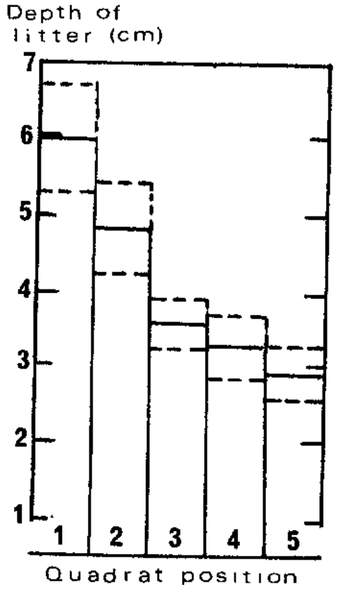

FIGURE 1. Litter depth. Values shown are means and standard deviations for all quadrats at each position from centre of clump (1) to out in the heath (5).

TABLE 4. Contrasts in litter and cover.

a) Average thickness of litter (cm).

Under Canopy	Outside Canopy
4.8 ± 1.2	3.1 ± 0.3

b) Percent ground cover of plants. (mean 10 clumps)

Under Canopy	Outside Clump
47.3 ± 8.9	45.5 ± 14.1

TABLE 5. Mean heights, number of plants and species per m quadrat under the clumps and in the surrounding heath.

	Under Clump	Heath
Mean height (cm)	53.1 ± 7.0	75.5 ± 0.2*
Number of plants	6.7 ± 0.1	7.8 ± 0.4*
Total number of species	5.4 ± 0.4	6.1 ± 0.2*

* significant at 1% level.

Plant density per square metre was highest outside the clump. There was an average of 6.7 plants under the clump and 7.8 in the heath. Species richness was also higher in the heath than under the **Eucalyptus todtiana** clumps, with an average of 5.4 species under the clump compared to 6.1 species per square metre in the surrounding heath. Figure 3 gives more detail on species richness. There appears to be a slight reduction in the number of species at the edge of the canopy. Differences in mean values for number of plants and species were significant at the 1 percent level using the Mann Whitney test.

Table 6 provides results for the environmental attributes measured underneath the clump canopy and outside the clump. Humidity was highest underneath the clump ranging from 35 to 68 percent (average 54) whereas outside the clump humidity ranged from 25 to 52 percent (average 41). This was again significant at the 1 percent level.

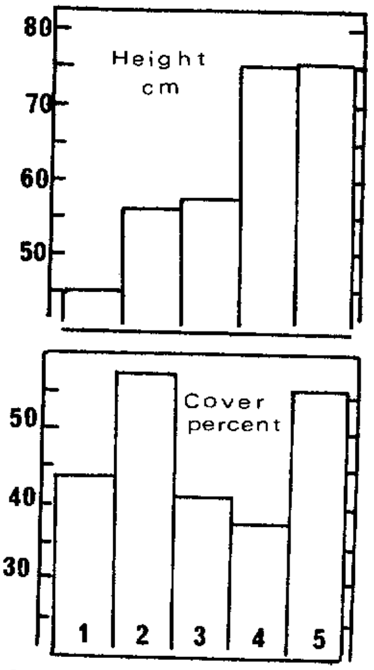

FIGURE 2. Mean heights of understorey plants and percentage ground cover due to understorey plants. Transect positions as in Figure 1.

Soil temperature was highest in the heath. Table 6 shows that the average temperature of the ground outside the clump was 37.2°C compared to 30°C under the canopy. The temperature of the canopy leaves was 6.3°C lower than the air temperature. Wind speed was reduced to 1.3 m s-1 under the canopy and increased to an average of 1.7 m s-1 outside the clump.

Soil Attributes

Munsell colour of the five transect soils (Table 7) shows little difference in colour between clump and heath soils. Both were sands. Surface soil colour ranged from light brownish grey to a light yellowish brown, with no apparent trends within and outside the clumps.

TABLE 6. Environmental attributes measured underneath the E. todtiana canopy and outside the clumps. (Means and, in brackets, standard deviations). Measurements taken at 20cm (ground) and 2m (canopy).

Attribute	Height	Under Clump	Heath
Humidity (percent)	ground	58 (13)	43 (9)
	canopy	54 (11)	41 (10)
Wind speed (m/sec)	ground	1.0 (1.0)	1.7 (0.7)
	range	(0-3.5)	(1.0-3.6)
	canopy	1.3 (0.7)	2.1 (0.7)
	range	(0.5-3.0)	(1.5-4.1)
Temperature (°C)	ground	32.0 (7.8)	37.2 (6.1)
	canopy	26.3 (6.4)	32.6 (5.9)

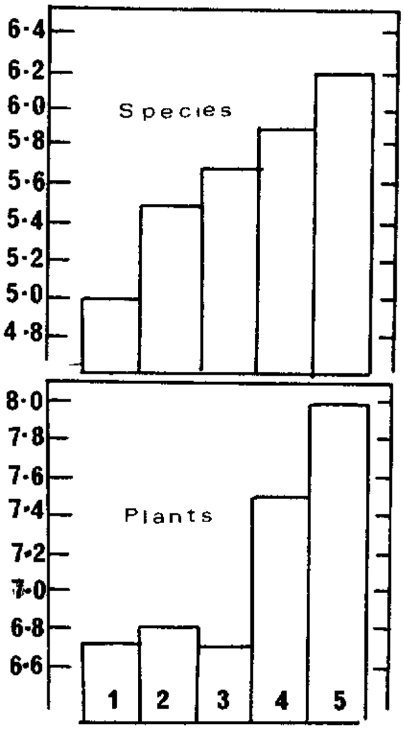

FIGURE 3. Mean number of species and number of individual plants. Transect positions as in Figure 1.

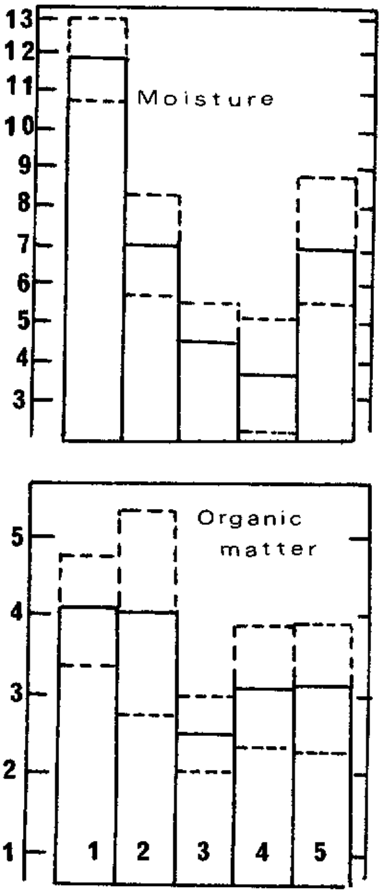

FIGURE 4. Percentage organic matter and soil moisture, from quadrat samples. Values shown are means and standard deviations for all quadrats at each position from centre of clump (1) to out in the heath (5).

TABLE 7. Munsell colour of five soils, taken at 15 cm depth. Soils 1, 2 and 3 were under the canopy and soils 4 and 5 occur in the heath. Soils were collected on 5 March 1983.

Soil Number	Code	Colour
1	5Y 7/1	Light grey sand
2	10YR 6/2	Light brownish grey sand
3	5Y 7/1	Light grey sand
4	10YR 7/3	Very pale brown sand
5	10YR 6/4	Light yellowish brown sand

TABLE 8. Nutrient concentrations and physical attributes of soils from under the E. todtiana clumps and from the heath soils collected 5 March 1983. (Standard deviation in brackets)

Soil Factor	Under Clump E. todtiana	Heath
Nutrients (ppm)		
Nitrogen	670 (150)	640 (10)
Phosphorus	342 (84)	134 (45)*
Calcium	1676 (97)	247 (24)*
Sodium	144 (18)	91 (48)
Potassium	364 (66)	305 (67)*
Organic Matter (%)	3.0 (0.9)	3.1 (1.1)
Moisture Content (%)	7.8 (3.7)	5.3 (2.3)*
pH	4.9 (0.2)	5.1 (0.1)
Soil Conductivity	0.12 (0.02)	0.11 (0.05)

* Significant at 1% level.

TABLE 9. Growth of E. todtiana (means from four replicates) in soil from five sites. (Standard deviations in brackets).

a) Mean dry weights (mg)

Soil Source	Site Number 1	2	3	4	5
Control deionised water	267	370	302	256	276
	(104)	(99)	(63)	(123)	(131)
Leachate	315	322	358	190	292
	(53)	(93)	(96)	(50)	(54)

b) Mean values of Top/Root ratio.

Soil Source	Site Number 1	2	3	4	5
Control rain water	0.56	0.82	0.47	0.43	0.53
	(0.22)	(0.36)	(0.16)	(0.18)	(0.19)
Leachate	0.51	0.60	0.63	0.44	0.52
	(0.18)	(0.26)	(0.24)	(0.14)	(0.20)

Table 8 gives nutrient levels and soil physical attributes of the five soils. Moisture content, percent organic matter and soil conductivity were slightly higher under clumps compared to heath but the last two attributes were not significant at the 5 percent level using the Mann-Whitney U-test. The zone under the clump canopy was slightly more acidic than the heath soils. Figure 4 shows a slight decrease in moisture content and percent organic matter from the centre of the clump to the heath soils. Total potassium, calcium, sodium, phosphorus and total nitrogen were generally much more concentrated in clump than heath soils. However, the only significant differences were between the levels of K, Ca and P using the Mann-Whitney U test. In all cases but sodium, there was a decrease in nutrient concentrations from the centre of the clumps into the heath.

Germination and Growth

Seed of Eucalyptus todtiana responded to lower (15-20°C) rather better than higher temperatures (25-30°C). Figure 5 shows the time course of germination.

The dry weights and top/root ratios obtained for Eucalyptus todtiana seedlings are given in Table 9. Watering with Eucalyptus todtiana leaf leachate instead of rainwater caused no reduction in growth of the seedlings. There was also no significant difference in growth between plants grown in soils from the five sites in the transect. The greatest top/root ratio occurred in the middle of the clump using rainwater.

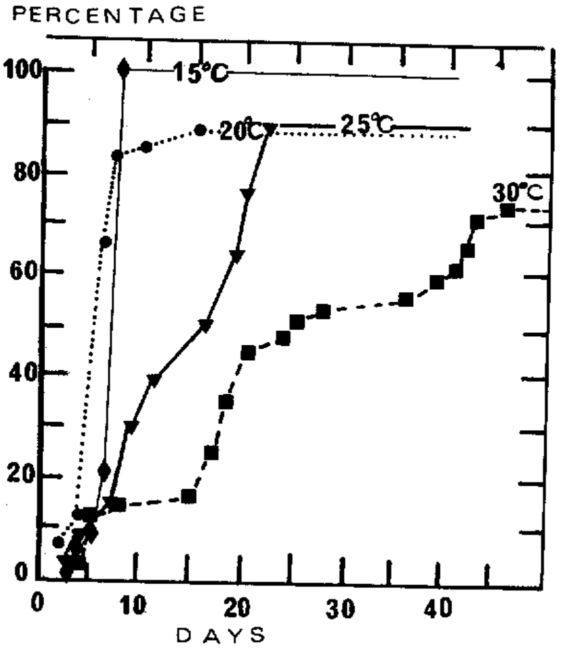

FIGURE 5. Time course of germination for fresh seed of Eucalyptus todtiana incubated at 4 controlled temperatures, in darkness. Viability is high and germination most rapid at 15-20°C.

Table 10 gives summarised germination results for **Banksia hookerana**. In no soil was germination prevented, but germination occurred at a slower rate in the presence of **Eucalyptus todtiana** leaf leachate (Figure 6). There was reduced germination in the soil from site 5 (6 m outside the clump) by 33 percent, using leaf leachate compared with deionised water.

TABLE 10. Germination of **B. hookerana** over 3 weeks in 5 potted transect soils in the presence of deionised water or **E. todtiana** leaf leachate.

	Percentage Germination	
Sampling Point	Control (water)	Leaf Leachate
1	92	92
2	100	92
3	83	83
4	92	100
5	92	67

Table 11 gives the growth results for **Banksia hookerana** seedlings, all of which survived the period of the experiment. A two-way analysis of variance on dry weights of shoots showed no difference between the five sampling sites but there was a significant difference at the 1 percent level when leachate was applied. There was an overall drop of 11 percent dry weight in the presence of leachate. This was most marked for site 5 soil with a 20 percent reduction in dry weight.

The mean number of leaves was slightly higher on plants grown with deionised water than with leachate, however this was not significant at the 1 percent level (Table 11).

Phenols were present in the leaf leachate used in germination growth studies. The leaf leachate had an absorbance value of 2.0 compared to 0.66 for rainwater.

Table 12 lists species (names after Beard, 1970) recorded in the 5 quadrats in the transect for the 10 clumps studied. 59 species were recorded, 49 were under the clump and 41 in the heath. Included in this table is the position in the transect where each species was found. Two species stand out: **Banksia hookerana** only found in heath and **Lomandra hastilis** only found under the clumps.

Table 13 shows the growth habit of the 59 species found. Also shown is a summary of species occurrence, whether in the heath or under the clump. Species found to be exclusively with or very much more abundant under **Eucalyptus todtiana** were Lomandra

TABLE 11. Dry weights and leaf numbers for **Banksia hookerana** grown in five soils.

a) Dry weights (mg) of tops.

Source of Soil	Centre	Midpoint	Edge	Scrub 1	Scrub 2	F Value
Control (deionised water)	265 ± 47	259 ± 19	289 ± 41	266 ± 49	263 ± 59	20.0
Leachate	221 ± 18	211 ± 52	210 ± 44	269 ± 33	177 ± 6	1.9

F(0.001) [1,40] = 14.4

b) Number of leaves.

	Centre	Midpoint	Edge	Scrub 1	Scrub 2
Control (deionised water)	8.4 ± 0.9	7.4 ± 1.9	8.1 ± 1.6	7.2 ± 2.6	7.8 ± 0.8
Leachate	7.7 ± 0.7	6.2 ± 2.6	6.4 ± 1.1	5.6 ± 3.1	7.0 ± 1.7

TABLE 12. Species occurrence in the 10 clumps studied. Presence in quadrat number is indicated where 1 is at centre, 2 at halfway across canopy, 3 at edge of canopy, 4 is 3 m north of canopy edge and outside it, 5 is a further 3 m to the north.

Species	Clump 1	Clump 2	Clump 3	Clump 4	Clump 5	Clump 6	Clump 7	Clump 8	Clump 9	Clump 10
Acacia latipes		2,3								
Acanthocarpus preissii			2,3,4		2	3	1,2	1,4	1,2	
Actinostrobus acuminatus	5		5					4		
Anigozanthos humilis		4								
Astroloma pallidum							1		5	
Banksia hookerana	4,5	5	4	5	4,5	5	4,5	5	5	5
Banksia grossa				4		4	3,4,5			3
Beaufortia elegans				4			2			
Boronia ramosa		1			1					
Blancoa canescens					4	5				4
Burchardia umbellata	1,2,4				1,2,3	1	3		3	1,3
Caladenia flava	2	1,2	1	1						
Calothamnus sanguineus	4			2					2	5
Casuarina humilis				4						
Conospermum incurvum					4	4			4	4
Conospermum triplinervium	3	4,5	2	4	3	3,5	4		3,4	4,5
Conostylis aculeata						1,5	5	3,5	1,4	1,2,5
Conostylis dielsii	3,5	5	4,5	5	5	4				
Conostylis setigera			5				4	4		5
Dampiera juncea	1,3,5						3,5	1		
Darwinia nieldiana	2			3,5		1,2		2		1
Darwinia speciosa		5	4							
Daviesia nudiflora				3	4					
Drosera leucoblasta							5		3	3
Drosera stolonifera	1	1,2,4								
Ecdeicolea monostachya	3		2,3,4		1					
Eremaea beaufortiodes	3	3	2,4	2		2,3,4	4	3,5	1,5	4
Eremaea violacea					3			4	4	5
Eucalyptus todtiana		1,3	1	1	1					
Gompholobium tomentosum					3					
Hakea costata			2	2			5			2
Hakea incrassata		3								
Hemiandra pungens				2	4	1,3				2
Hibbertia hypericoides				4	5	2,5	3	4,5		
Hypocalymma aff xanthopetalum								2		
Isopogon tridens				3					2	
Jacksonia floribunda	5	2,4	5			5	2	5	4,5	2,3
Lepidobolus preissianus	4		1							
Lepidosperma sp						2				
Leptospermum oligandrum			2							
Lomandra hastilis	1,2	2	1,3	1,2,3	1,2,3	1,2	1,2	1,2,3	1,2	1
Loxocarya cinerea						2	1,4,5	3,5	1,2,3,4	1,
Lysinema ciliatum						2				
Melaleuca scabra		4,5	3	5		5	3	3,5	3,5	
Mesomelaena stygia	2,5									
Persoonia acicularis	3	4				3				
Petrophile divaricata						4			4	4
Petrophile linearis		3				3				
Petrophile media	4									
Pityrodia sp	3									
Pterostylis vittata		2	1							
Restio aff sphacelatus	4		1,3,5	1,2,3,5	1,2,5	3		1,2		
Scaevola canescens	1	1,2,3		2			1			
Stachystemon axillaris		1,2				1				
Stirlingia latifolia									5	1
Synaphea petiolaris				2	5				5	1
Verticordia grandis		4	5				2			
Verticordia nitens						3				
Xanthorrhoea reflexa								4		

hastilis, **Stachystemon axillaris**, **Caladenia flava**, **Pterostylis vittata**, **Boronia ramosa** subsp. **arethifolia** and **Drosera stolonifera**. On the other hand, a number of species were exclusive to, or very much more abundant in, the surrounding heath, especially the large plants **Banksia hookerana**, **Xylomelum angustifolium** and **Xanthorrhoea reflexa**.

Figure 7 illustrates profiles through representative clumps. The slight suppression at the edge of the clump can be seen. The **Banksia hookerana** plants can be seen growing next to the clumps but not underneath the canopies. Also conspicuous is **Conospermum triplinervium**, more abundant in the heath than underneath the clumps.

Discussion

The field studies indicate that **Eucalyptus todtiana** clumps have a distinctive vegetation associated with them. In general terms plants under the **Eucalyptus todtiana** clump can be distinguished from those in the surrounding heath by their slightly reduced height, canopy cover and lower density and diversity. The dominant species under **Eucalyptus todtiana** is **Lomandra hastilis** whereas in the scrub heath it is **Banksia hookerana**.

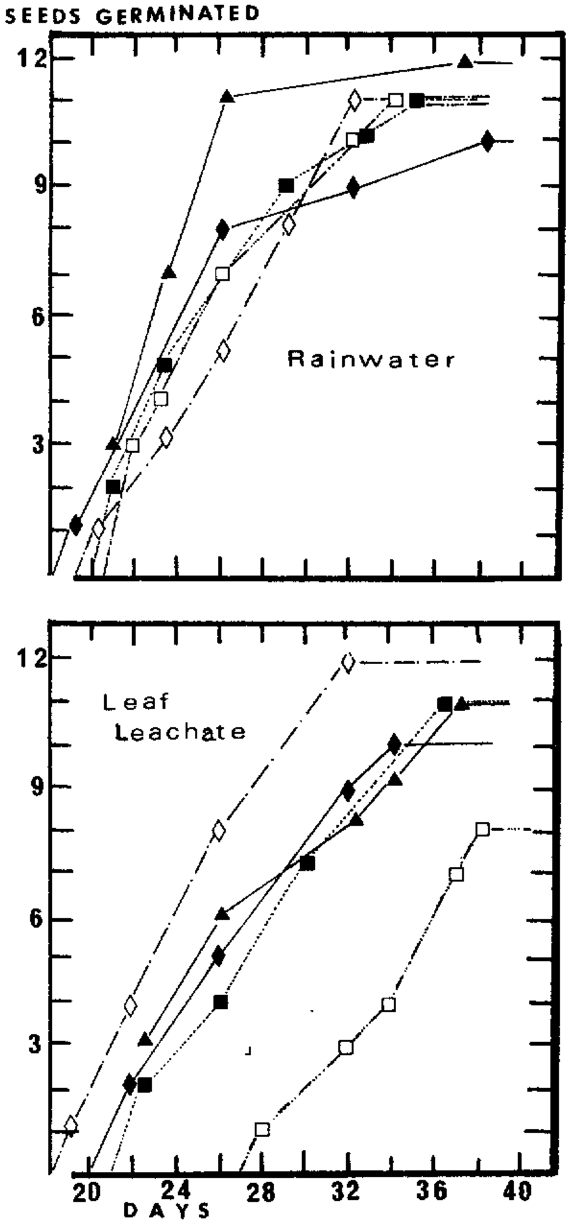

FIGURE 6. Germination trials for **B. hookerana** from a total of 12 seeds. 1■ centre; 2▲ midpoint; 3♦ edge; 4 ◊ shrub 1; 5 □ shrub 2; referring to soils used.

Eucalyptus todtiana clumps also differ in environmental attributes from the heath. The clumps have more leaf litter, organic matter, higher K and P levels, less light, and higher percentage moisture content. The increased organic matter and P and K may be due to the higher levels of leaf litter. The level of phosphorus is approximately 2.5 times higher in the clump soils than in the heath. **Banksia** are susceptible to phosphorus toxicity (Specht 1975; Heddle & Specht 1975). It is possible that the levels reported in Table 8 may be sufficient to cause phosphorus toxicity in **Banksia hookerana** seedlings thus excluding this species from establishing under the clump. This would require further testing for confirmation. It was also noted that **Banksia grossa** only grew at the edges of the canopy and in the heath.

The mechanisms by which the nutrients become higher in clump soils are probably related to the high biomass attained by **Eucalyptus todtiana**. Foliage cover would provide leachate over time and periodic fire would release nutrients. The dominant Eucalypt may accumulate more nutrients than the heath dominants which are less woody.

The open heath experiences higher soil temperatures, stronger winds and lower humidity than inside the **Eucalyptus todtiana** clumps. These factors might play a role in suppressing **Lomandra hastilis, Caladenia flava, Pterostylis vittata** and **Stachystemon axillaris** from growing abundantly in the heath, and autecological experiments may be informative in relation to such species.

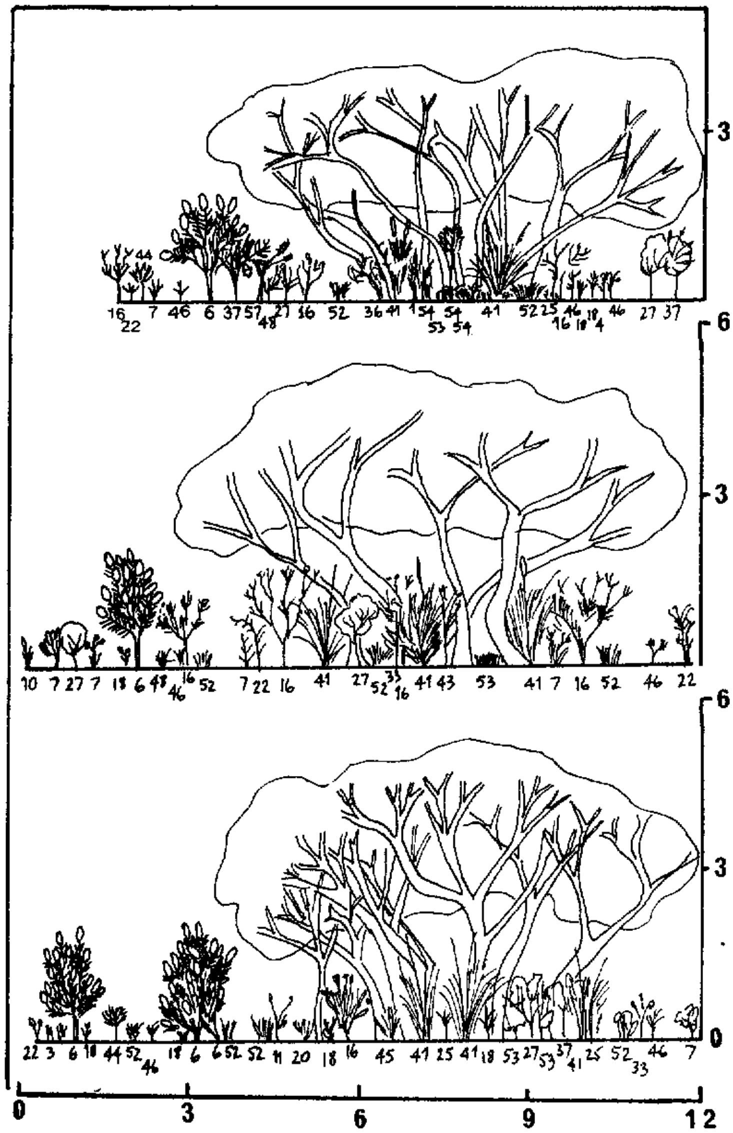

FIGURE 7. Profiles of 3 of the clumps studied. Numbers refer to the plants in Table 13.

TABLE 13. Species growth habit, form and occurrence in heath and under 10 Eucalyptus todtiana clumps. Growth symbols (Column G) are: R = Rhizomatous sand binders, L = Short-lived large seeded species, S = Short-lived small seeded native species, N = Long lived native species (after Specht 1975). Form symbols (F) are: Sh = shrub, He = herb, Res = Restionaceae, Tr = tree, GT = grass tree. (Numbers are those used in profile diagrams).

				Presence/ Absence*	
No.	Species	F	G	C	H
1.	Acacia latipes	Sh	L	+	-
2.	Acanthocarpus preissii	H	R	+	+
3.	Actinostrobus acuminatus	Sh	N	-	+
4.	Anigozanthos humilis	He	S	-	+
5.	Astroloma pallidum	Sh	S	+	-
6.	Banksia hookerana	Tr	N	-	+
7.	Banksia grossa	Sh	N	-	+
8.	Beaufortia elegans	Sh	N	+	+
9.	Boronia ramosa	Sh	S	+	-
10.	Blancoa canescens	He	S	-	+
11.	Burchardia umbellata	He	S	+	+
12.	Caladenia flava	He	S	+	-
13.	Calothamnus sanguineus	Sh	S	+	+
14.	Casuarina humilis	Sh	N	+	+
15.	Conospermum incurvum	Sh	S	-	+
16.	Conospermum triplinervium	Sh	N	+	+
17.	Conostylis aculeata	He	R	+	+
18.	Conostylis dielsii	He	R	+	+
19.	Conostylis setigera	He	R	+	+
20.	Dampiera juncea	He	S	+	+
21.	Darwinia nieldiana	Sh	S	+	+
22.	Darwinia speciosa	Sh	S	+	+
23.	Daviesia nudiflora	Sh	L	+	+
24.	Drosera leucoblasta	He	S	+	+
25.	Drosera stolonifera	He	S	+	-
26.	Ecdeicolea monostachya	Res	R	+	+
27.	Eremaea beaufortioides	Sh	N	+	+
28.	Eremaea violacea	Sh	N	+	+
29.	Eucalyptus todtiana	Tr	N	+	-
30.	Gompholobium tomentosum	Sh	L	+	-
31.	Hakea costata	Sh	N	+	-
32.	Hakea incrassata	Sh	N	+	+
33.	Hemiandra pungens	Sh	L	+	+
34.	Hibbertia hypericoides	Sh	S	+	+
35.	Hypocalymma aff. xanthopetalum	Sh	S	+	-
36.	Isopogon tridens	Sh	N	+	+
37.	Jacksonia floribunda	Sh	L	+	+
38.	Lepidobolus preissianus	Res	R	+	+
39.	Lepidosperma sp	Res	R	+	-
40.	Leptospermum oligandrum	Sh	N	+	+
41.	Lomandra hastilis	He	R	+	-
42.	Loxocarya cinerea	Res	R	+	+
43.	Lysinema ciliatum	Sh	S	+	-
44.	Melaleuca scabra	Sh	N	+	+
45.	Mesomelaena stygia	He	R	+	+
46.	Persoonia acicularis	Sh	N	+	+
47.	Petrophile divaricata	Sh	N	+	+
48.	Petrophile linearis	Sh	N	+	+
49.	Petrophile media	Sh	N	+	-
50.	Pityrodia sp	Sh	S	+	-
51.	Pterostylis vittata	He	S	+	-
52.	Restio aff. sphacelatus	Res	R	+	+
53.	Scaevola canescens	Sh	S	+	-
54.	Stachystemon axillaris	Sh	S	+	-
55.	Stirlingia latifolia	Sh	S	-	+
56.	Synaphea petiolaris	Sh	S	-	+
57.	Verticordia grandis	Sh	N	-	+
58.	Verticordia nitens	Sh	N	+	+
59.	Xanthorrhoea reflexa	GT	N	-	+

* C Clump, H Heath, + = plant species present.

It was hypothesised that the absence of Eucalyptus todtiana seedlings from underneath the clumps may be due to allelopathy. The results appear to disprove this hypothesis in relation to leaf leachate. There could, however, be a chemical inhibitor produced by the adult roots which prevents the younger plants from establishing under the canopy or nearby.

Allelopathy does not appear to adequately explain suppression of Banksia hookerana under Eucalyptus todtiana. It is possible that phenols leached from the understorey vegetation and Eucalyptus todtiana are not toxic.

Further chemical analyses are required to contrast the Eucalyptus todtiana and understorey vegetation litter and soil extracts. These may provide sources of toxicity effects on the heath plants. Del Moral and Muller (1970) suggested that allelopathic effects are optimal where soil is poorly drained, with high colloidal content or dry. Failure to detect toxicity in the germination and growth experiments could be attributed to the fact that the soils were provided with adequate water in the experiment thereby diluting the effect of toxic phenols on the plant. Both the clump and heath soils experience high water deficits during summer.

No one mechanism has emerged to be a main contributor to species suppression and enhancement under the Eucalyptus todtiana canopy. As there are certain species only found in association with Eucalyptus todtiana clumps and mining companies are obliged to return the area mined close to its original state, it is imperative that Eucalyptus todtiana be grown in the rehabilitation areas. The gazetted rare species Stachystemon axillaris is usually associated with Eucalyptus todtiana clumps.

Acknowledgements

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GERMINATION AND EARLY GROWTH OF THE DUNE WATTLES: ACACIA LITTOREA, ACACIA CYCLOPS AND ACACIA ROSTELLIFERA, IN ASH-BED SOILS, AFTER WET HEAT SEED TREATMENT

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Introduction

Much of the vegetation of Rottnest Island has been severely altered by fire, followed by heavy selective grazing by **Setonix brachyurus**, a native marsupial. The resultant vegetation consists of monocotyledonous, low, dense heath (Pen & Green 1983). This is believed to be less palatable to the quokka, than the Acacia **rostellifera** community (Storr 1957) which has shown a steady decline on the island. Burning followed by fencing is now being undertaken prior to tree planting. These operations provide the opportunity for direct seeding of native legume species into re-afforestation areas. The foliage of these legume species is considered to be high in essential amino acids. Deferred grazing of such areas, while the plants become established, may help stabilise the island quokka population. This should also lead to an increase in plant species richness, which may in turn promote stability of the revegetated areas.

The present report deals with some experimental work undertaken in the winter/spring of 1984. Tests were conducted to determine the response of seed of three **Acacia** species occurring on Rottnest (**A. cyclops**, **A. littorea** and **A. rostellifera**) to conditions prevalent during and following fire. Germination tests sought to determine optimum germination temperature following the breaking of dormancy by heat treatment for each of the three species. Plants were also grown on ash-bed and non ash-bed soils.

Seed treatment and planting commenced in early August, and observations continued for a period of 110 days, concluding in late November.

Historical Summary

The present status of Rottnest vegetation and historical changes have been reported by O'Connor et al. (1977) and Pen & Green (1983).

The vegetation of Rottnest Island formerly consisted of an extensive cover of low closed forest and scrub including **Callitris preissii**, **Melaleuca lanceolata** and **Acacia** species (Pen & Green 1983). The total area of this type of vegetation has dwindled from an estimated 1000 ha to less than 150 ha at present. It has been largely replaced by low shrubland or heath dominated by **Acanthocarpus preissii**. The changes are related to the effects of woodcutting, fire, coastal erosion and grazing by the quokka.

The change in the vegetation began with the advent of a greater frequency of fire once permanent settlement of the island began in 1838. A large fire followed by others at close intervals could easily destroy seedlings and deplete the soil seed bank, leading to the elimination of fire-sensitive species over much of the island. **Acacia rostellifera** is a relatively fire-tolerant species, owing to its ability to produce numerous suckers after burning. It was able to re-establish itself and form dense thickets in place of other species (Pen & Green 1983).

By 1919 **Acacia** scrub covered two thirds of the island, but in the 1920s the quokka became a protected species and consequently the population increased, putting a large strain on the islands' food resources. The green bark and suckers of **Acacia rostellifera** are very palatable and by the 1940s most of the **Acacia** scrub had been depleted. A severe fire in the summer of 1955 severely burnt 730 ha of the central, western, part of the island. Further fires and extensive quokka grazing since then has led to the decline of **Acacia** scrub to a total of only some 8 percent of the island. The majority of the island is now predominantly covered by a low dense heath of **Acanthocarpus preissii** and **Stipa variabilis**.

Acacia rostellifera occurs in communities as a small tree in sheltered localities on the eastern half of the island. On the windward slopes of dunes, particularly in the remaining western half, it occurs as an extensive, low, suckering scrub. Its growth appears favoured by deep fine sands over Tamala limestone and is further enhanced by accumulation of leaf litter. The low dense scrub propagates from suckers as well as seed, and where it is not foraged by the quokka, it advances outward by stages of sucker growth (O'Connor et al. 1977).

The small tree form of **Acacia rostellifera** is most evident on the eastern half of the island.

It consists mainly of mature stands, and isolated trees are showing signs of decay with little evidence of replacement by younger plants. A woody climber, **Clematis microphylla**, can top the tree canopy of dense thickets. Most patches contain dead wood, and large portions of the canopy are apparently unhealthy.

Acacia littorea, a much smaller shrub species than **A. rostellifera**, is found in dense heath communities in coastal areas over Tamala limestone. Along the south coast the vegetation is dwarfed and hedge-like, due to the combination of very shallow soil over the limestone and exposure to wind and salt. In the north **Acacia littorea** appears as larger and denser thickets, due to deeper sands over the limestone. Dense stands tend to die out from the centre. Regeneration is by seed. The understorey of the heath community may include several low species such as **Acanthocarpus** and **Guichenotia ledifolia**.

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Acacia cyclops, though at present a scarce species at Rottnest, can be associated with Acacia littorea on the shallow soil over limestone communities. **A. cyclops** has the potential to grow into a bushy shrub of 2 m height, with a wide spread. This species has been grown in many countries for animal fodder.

Experimental Methods

Germination Temperature

Sets of 400 seed of each of the three Acacia species were counted in lots of 50 seed each.

Two hundred seeds of each species were placed in boiling water for one minute. The heat-treated seeds were placed in 4 petri dishes (50 seeds in each) containing vermiculite moistened with benlate solution. Dishes were then incubated in one of 4 different temperature cabinets. These were set at 15, 20, 25 and 30°C. Untreated seeds were used as a control and incubated similarly. Germination was recorded daily and germinants, defined as seed with 2 mm of radicle protruding, were removed. Tests were terminated at 50 days from the start.

Response to Ash

To assess the germination and growth of heat-treated seeds on ash-bed soils, 180 seeds of each species were sown in 60 jiffy pots, 3 to a pot. The jiffy pots were filled with standard horticultural soil (1/3 fine sand, 1/3 coarse sand and 1/3 peat). Five g of ash, derived from Veldtgrass, leaves and twigs was mixed into the top cm of soil for 20 pots per species. 2.5 g of ash was mixed into the top cm of another 20 pots and the remaining 20 pots per species were used as a control.

The pots were kept moist and germination was recorded. The pots were thinned to one good plant per pot and this entailed transplanting seedlings to those pots where no seeds had germinated. Seedlings were transplanted to pots of the same ash level. After thinning out heights and leaf (phyllode) numbers of 4 plants per treatment were recorded on a fortnightly basis.

An intermediate harvest was conducted at 77 days, when the plants from 10 pots in each ash level and the control were harvested. The whole plant was removed from each pot by washing the soil away from the roots. Fresh weights were taken of the roots and tops, lengths of roots and stems were recorded. The plants were then placed in a 60°C oven for 24 hours when dry weights were recorded.

Plants were then ground. A sample from each treatment was used to determine potassium and calcium content of plants for each treatment. Solutions were made up containing 10 ml of plant aliquot, 1 ml of lanthanum chloride at 10,000 ppm, 2.5 ml of 10 percent sulphuric acid and 2.5 ml of hydrochloric acid. These were then made up to 25 ml with deionised water. The solutions for each treatment were then analysed by flame photometer.

At 110 days a final harvest was taken. The remaining plants of each treatment were removed from soil by washing. The number of root nodules was scored and weights obtained as described for the intermediate harvest.

Results

Germination Temperature

Figures 1, 2 and 3 show the time course of cumulative germination for **Acacia rostellifera, A. cyclops** and **A. littorea** respectively.

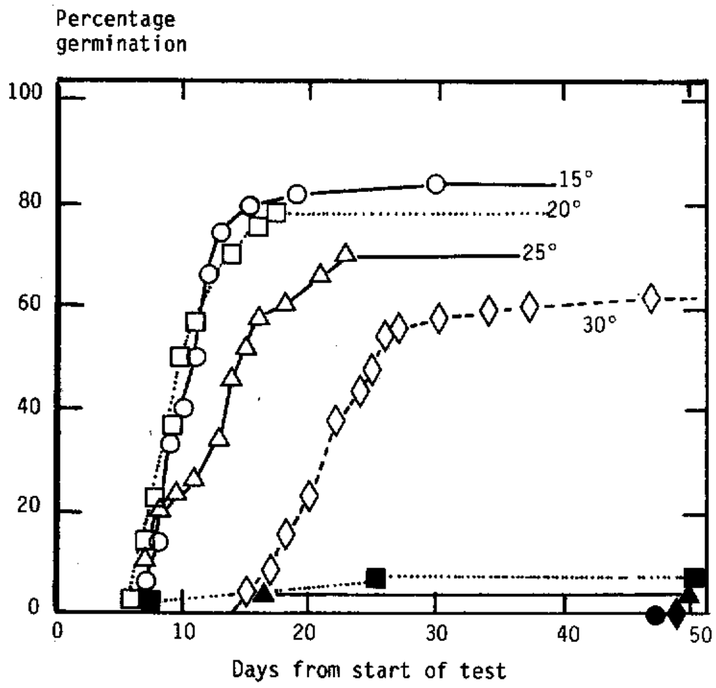

FIGURE 1. Cumulative percentage germination for Acacia **rostellifera**. Open symbols represent heat treated seeds, closed controls. Circles incubation at 15°C, squares at 20°C, triangles at 25°C, and diamonds at 30°C.

In the case of **Acacia rostellifera** seeds required exposure to heat before they would germinate. Untreated seeds at 15 and 30°C did not germinate over the 50 day period. Those at 20 and 25°C had very few germinants. The heat-treated seeds responded best to low temperature incubations, where more seeds germinated earlier. The seeds at 15, 20 and 25°C all commenced germinating on the 6th day, scoring very highly for the first 2 days after which germination at 25°C slowed down. Twelve days after the first germination 78 percent of the seeds at 20°C had germinated and no more were recorded. At 15°C a total of 82 percent had germinated thirteen days after the first germination. No more germinations were recorded for another 12 days, when one additional seed germinated bringing the total germination to 84 percent. Sixteen days after the first germination 70 percent of the seeds at 25°C had germinated and no more germinations were recorded. The seeds at 30°C incubation temperature did not start to germinate until the 14th day. Germination continued steadily over the next 16 days by when 58 percent of the seeds had germinated. A few late germinations were recorded over the remaining 20 days to give a final score of 62 percent.

The first **Acacia cyclops** seed to germinate was a heat-treated seed incubated at 30°C on the 17th day after treatment. Over the next 12 days all the samples started to germinate. The highest score was 46 percent recorded by heat-treated seeds at 20°C incubation temperature. The next highest score was 30 percent recorded by the untreated set also at 20°C. All other treatments gave poorer germination. The untreated seeds at 30°C incubation temperature scored 20% germination, this was higher than for the heat-treated seeds at 15, 25 and 30°C where germination totals were 17, 10, and 14 percent respectively. The control seeds at 15°C also gave 14% germination and no germination was recorded for the control set at 25°C. It would seem that **Acacia cyclops** required a specific germination temperature of around 20°C for maximum germination, and that heat treatment was of little or no importance in respect of the seeds used for this species.

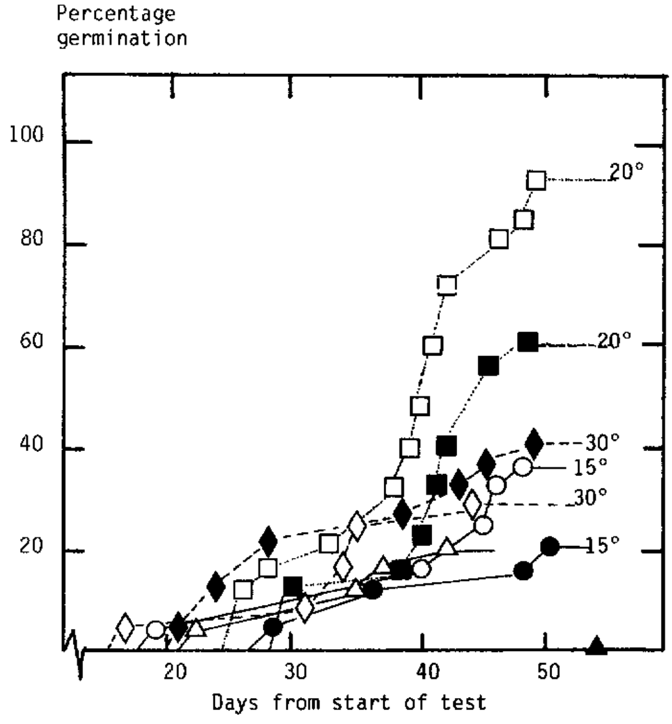

FIGURE 2. Cumulative percentage germination for **Acacia cyclops**. Open symbols represent heat treated seeds, closed controls. Circles incubation at 15°C, squares at 20°C, triangles at 25°C, and diamonds at 30°C.

Heat treatment and low temperatures produced best germination results for **Acacia littorea**. Figure 3 shows that the heat-treated seeds at 15°C incubation temperature germinated fairly rapidly from the 10th day until the 23rd day by when 70 percent germination had been recorded. After this germination fell away with only 4 percent more by the 35th day, bringing the total to 74 percent. Heat-treated seeds at 20°C incubation gave a total germination of 76 percent, reached after a steady rate of germination from the 9th to the 48th day from the start. Though the percentage was higher for the 20°C set, the 15°C temperature gave more rapid germination. Treated seeds incubated at 30°C recorded total germination of 30 percent, but first germination was delayed until the 28th day. Heat-treated seeds at 25°C gave only 8 percent germination, recorded on the 13th day. The control seeds showed very low germination. Those at 15°C gave 8 percent, those at 20°C 4 percent and those at both 25 and 30°C only 2 percent, with the 30°C set having one seed germinating on the last day. It seems for **Acacia littorea** that both heat treatment and low incubation temperatures were necessary for maximum germination.

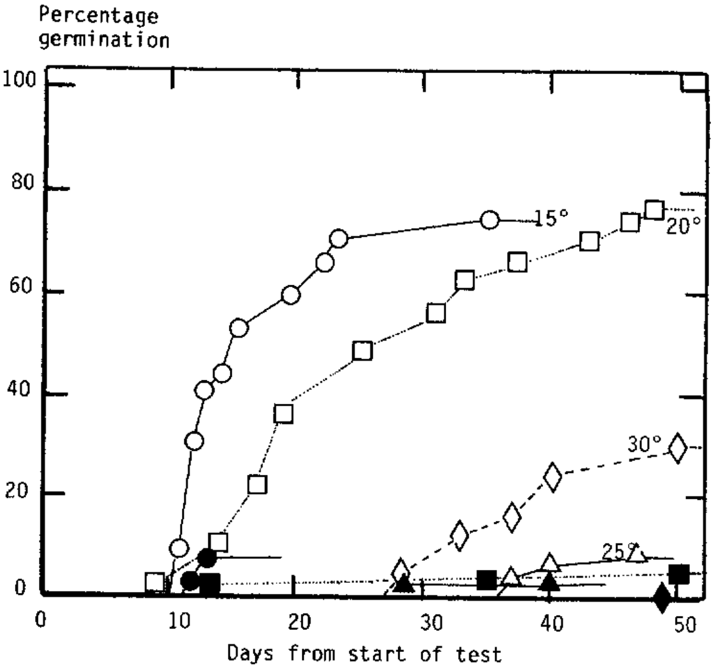

FIGURE 3. Cumulative percentage germination for **Acacia littorea**. Open symbols represent heat treated seeds, closed controls. Circles incubation at 15°C, squares at 20°C, triangles at 25°C, and diamonds at 30°C.

Response to Ash

Tables 1 and 2 summarise mean heights and leaf (phyllode) numbers for each of **Acacia rostellifera**, **A. cyclops** and **A. littorea** over the growing period.

TABLE 1. Mean heights (cm) of seedlings in three ash treatments.

	Acacia rostellifera			Acacia cyclops			Acacia littorea		
Ash Level	0	2.5	5	0	2.5	5	0	2.5	5
Weeks From Sowing									
8	1.8	0.8	1.0	4.8	6.3	4.5	3.5	6.5	4.8
10	2.3	2.8	3.6	8.0	11.1	9.5	4.5	9.3	8.9
11	2.8	3.4	3.4	9.3	11.6	12.1	4.5	9.6	9.5
12	3.3	4.3	4.3	10.4	14.0	11.9	4.9	10.6	10.6
14	3.0	4.3	5.3	12.4	16.5	13.3	5.4	12.6	11.5
16	5.7	7.5	6.5	9.0	16.4	12.9	6.4	11.1	14.8

TABLE 2. Mean leaf number of seedlings in three ash treatments.

	Acacia rostellifera			Acacia cyclops			Acacia littorea		
Ash Level	0	2.5	5	0	2.5	5	0	2.5	5
Weeks From Sowing									
8	-	-	-	-	-	-	5.3	5.8	5.8
10	9.0	11.0	11.0	4.5	6	5.5	6.5	8.5	8.3
11	9.7	12.4	11.9	4.7	5.5	5.6	6.6	8.2	7.9
12	10.0	12.0	12.5	6.0	7.8	6.5	6.5	9.5	10.0
14	10.5	14.8	14.8	6.0	8.5	7.8	7.8	10.8	10.8
16	10.7	16.8	16.9	5.9	8.6	7.9	8.2	13.5	12.3

Initially there was little difference between samples for **Acacia rostellifera**, with control plants tallest. The effect of ash on plant height started to become evident at 10 weeks from sowing when the mean height for plants in the 5 g ash soil had increased by 2.6 cm and in the 2.5 g ash soil by 2.0 cm, whereas the control plants increased in height by only 0.5 cm. During the rest of the measurement period the mean height of plants in 5 g ash soil continued higher than that of plants in 2.5 g ash soil, which was in turn higher than for the control set, until the final harvest when the 2.5 g set were tallest. Leaf number seemed to be related to height and plants in 5 g and 2.5 g ash soil had more foliage per plant than control plants.

Acacia cyclops showed evidence of an ash level effect on plant growth from the first set of measurements. The mean height for plants in the 2.5 g ash soil was higher than those for the other two groups. This was maintained throughout the period. Mean height of 5 g ash soil plants was in turn higher than the control group. Leaf number was again related to plant height and the order corresponded to that for plant height.

Acacia littorea showed evidence of increased growth with ash. Mean heights for both 5 g and 2.5 g ash soil sets were similar. Leaf number for both was also similar throughout. The control set gave slower growth, with the final mean height about half that for both ash soil sets.

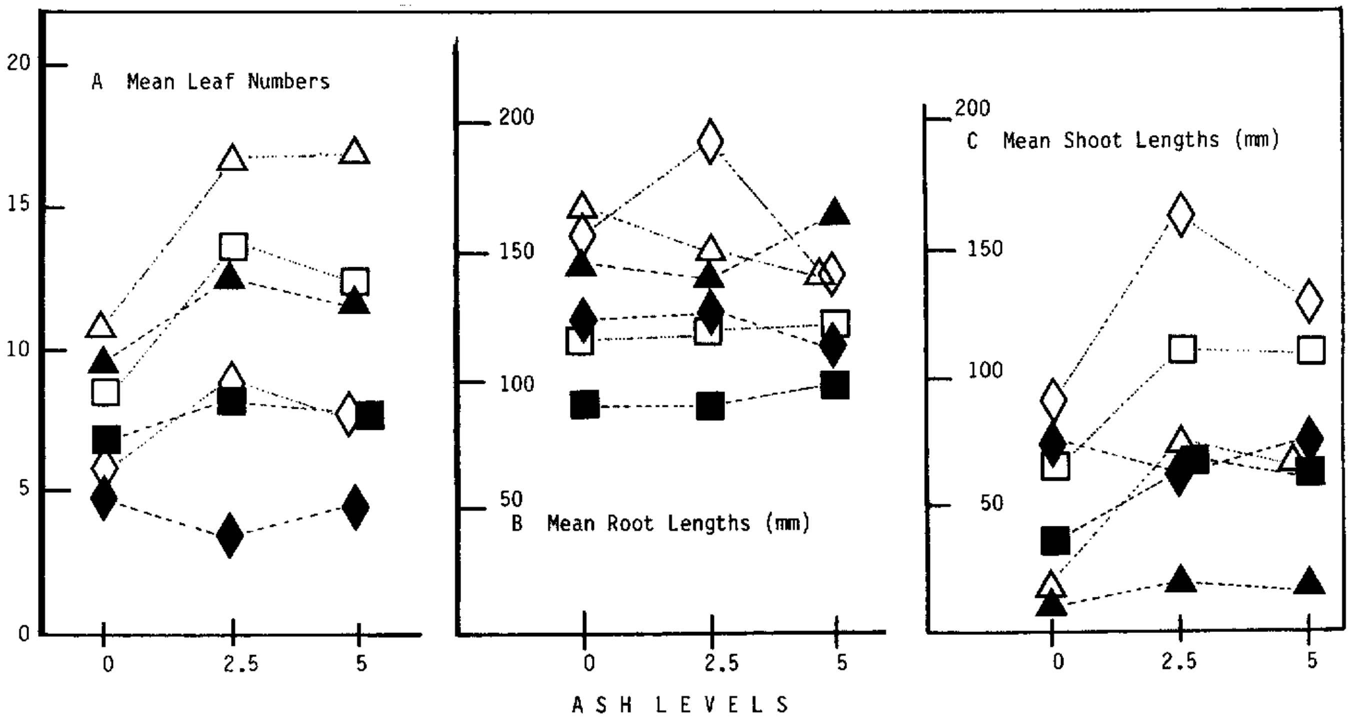

FIGURE 4. Mean values for harvests: A leaf numbers, B root lengths, C stem lengths. Open symbols refer to second harvest at 110 days, closed symbols first harvest at 77 days. Diamonds **Acacia cyclops**, squares **Acacia littorea**, and triangles **Acacia rostellifera**.

Figure 4 illustrates harvest values for mean leaf number, stem and root length. The mean foliage numbers recorded in control sets of both **Acacia rostellifera** and **Acacia littorea** were the lowest for these species. In general the highest mean leaf number was in the 2.5 g ash soil set. Mean numbers for the 5 g ash tended to be slightly lower than the 2.5 g ash soil sets but higher than for the controls. **Acacia cyclops** at 77 days showed a different trend, where control and 5 g ash soil sets had similar mean leaf numbers and the 2.5 g set was lower than both.

A similar pattern was evident in relation to mean stem lengths. **Acacia cyclops** at 77 days had similar stem lengths for the control and 5 g ash sets, with the 2.5 g ash soil set shorter. **Acacia rostellifera** and **Acacia littorea** had shortest lengths in the control set, the 2.5 g set had longest stems and the 5 g ash soil set was slightly shorter. **Acacia littorea** showed a large difference between control and the treatments at both harvests.

Root length of the 2.5 g ash soil set in **Acacia cyclops** was longest for this species, in contrast to the shortest mean stem length. This was only slightly longer than control at first harvest. The mean length for the 5.0 g ash soil was shorter than the other two at both harvests in **A. cyclops**. The stem length here, in contrast, was greatest of the 3 species. In **Acacia rostellifera** the 2.5 g ash soil set with the longest mean stem length had the shortest mean root length (at 77 days). It is of interest to note here that nodules were present on roots of 3 of the plants from the 2.5 g ash soil group, the only root nodules recorded at the intermediate harvest. The 5 g ash set had long roots but stem length was not much different to that of the control set. By 110 days root length at 5 g had declined. **Acacia littorea** had similar mean root length for both control and 2.5 g ash soil, but there was a wide range. The 5 g ash soil had the longest mean root length for this species, only marginally so at 110 days.

Fresh weights are illustrated in Figure 5, and dry weights are summarised in Table 3. Fresh weights of the tops in all three species showed a marked difference between control and treatment sets. **Acacia rostellifera** had a much greater fresh weight in 2.5 g ash than in control. The 5 g ash fresh weight was slightly greater than the 2.5 g set at both harvests. **Acacia littorea** also showed a large difference in weight between control and the 2.5 g ash set, but the 5.0 g ash fresh weight was only slightly lower than that for the 2.5 g ash set. **Acacia cyclops** on the other hand showed a lower fresh weight in the 2.5 g ash soil at 77 days than it did in the control. The 5 g ash soil weight was higher than the 2.5 g and halfway between it and the control. By 110 days **A. cyclops** top fresh weight was greatest at 2.5 g ash and the 5 g level was also considerably greater than the control.

The mean fresh weights of roots, for all three species, also showed a marked difference between control and the treatments. **Acacia rostellifera** had a big difference between control and the 2.5 g ash set with the 5 g set largest at 77 days, but rather less than 2.5 g level at 110 days. This species produced the greatest root mass throughout.

TABLE 3. Dry weight mean (g) of seedlings in three ash treatments.

	Acacia rostellifera			Acacia cyclops			Acacia littorea		
Ash Level	0	2.5	5	0	2.5	5	0	2.5	5
Harvest 1 at 77 days									
Tops	.031	.056	.052	.049	.032	.052	.011	.021	.022
Roots	.020	.026	.027	.014	.008	.011	.004	.008	.008
Totals	.051	.083	.079	.063	.040	.063	.015	.029	.030
Harvest 2 at 110 days									
Tops	.067	.198	.189	.133	.292	.172	.051	.068	.071
Roots	.044	.072	.073	.035	.072	.045	.012	.027	.022
Totals	.111	.269	.263	.167	.363	.218	.052	.094	.093

Acacia littorea recorded a modest increase between the control and 2.5 g ash with the 5 g ash set showing a similar fresh weight for roots as that for 2.5 g ash set. **Acacia cyclops** had a lower mean fresh weight in the 2.5 g ash at 77 days, compared to the control. The 5 g ash, though heavier than the 2.5 g ash set, was also lower than the control at 77 days. By 110 days, the 2.5 g set was best, and the 5 g set poorest.

Considering plant total fresh weight there were marked differences in both Acacia **rostellifera** and A. cyclops. In **A. rostellifera** at 77 days the 5.0 g ash set had greater fresh weight than the 2.5 g set, in turn more than the control. At 110 days both treatment levels were much greater than control, with the 2.5 g set marginally better.

TABLE 4. Ratios of weights for seedlings from three ash treatments.

	Acacia rostellifera			Acacia cyclops			Acacia littorea		
Ash Level	0	2.5	5	0	2.5	5	0	2.5	5
Harvest 1 at 77 days									
Top/roots dry weight ratio	1.7	2.4	2.0	3.7	4.2	3.8	3.1	3.0	2.8
Fresh/dry total plant weight ratio	2.7	3.0	3.5	2.4	2.9	2.3	1.7	3.1	2.7
Harvest 2 at 110 days									
Top/roots dry weight ratio	1.6	2.8	2.6	4.5	4.0	3.9	2.3	2.8	3.3
Fresh/dry total plant weight ratio	3.5	4.0	4.1	3.3	3.0	3.1	2.7	2.9	2.6

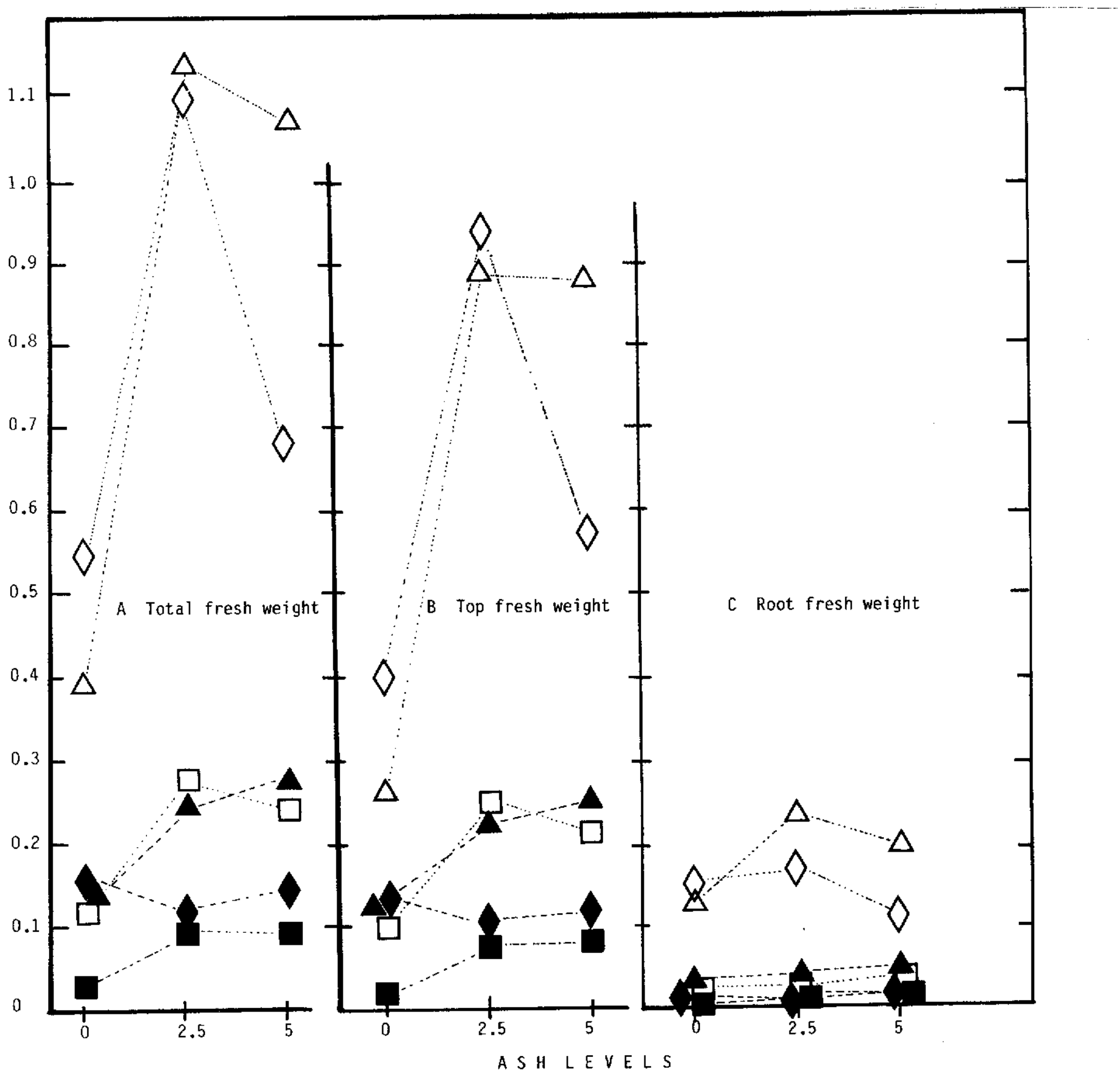

FIGURE 5. Mean fresh weights (g) at harvests: A total, B tops, C roots. Open symbols refer to second harvest at 110 days, closed symbols first harvest at 77 days. Diamonds Acacia cyclops, squares Acacia littorea, and triangles Acacia rostellifera.

Acacia cyclops had about the same weight for both the control and the 5.0 g ash set. The 2.5 g ash had a lower mean fresh weight at 77 days, but was clearly the largest at 110 days. **Acacia littorea** showed a similar difference in mean fresh weight between the control and the 2.5 g ash as **Acacia rostellifera**, though the 5.0 g ash soil had a lower weight than the 2.5 g ash set.

In top dry weight **Acacia rostellifera** exhibited a dramatic increase in weight between the control and the ash treatments (Table 3). The 5 g treatment gave slightly smaller weight throughout than the 2.5 g ash whereas at first harvest, the fresh weight was slightly greater.

Top dry weight at 77 days for **Acacia cyclops** was smallest for the 2.5 g ash soil with both 5 g and control similar. This pattern followed that for fresh weight (Figure 5). By 110 days the 2.5 g treatment clearly outstripped both the others, again following the fresh weight pattern. In **Acacia littorea** top dry weight for both ash treatments was similar, and both were clearly better than control.

The mean dry weights of roots showed no significant change in the positions of the treatments within each species. In all cases control root weights were less than treatments and ash treatment root weights were similar for both treatments. **Acacia cyclops** differed most, with lower weight for the 2.5 g ash at first harvest than the control. However at 110 days this species showed a much greater root dry weight than control and the 5 g ash treatment.

Analysis of variance for the plant total dry weights at harvest gave the following results.

Harvest 1. Mean dry weights (g), underlined results do not differ with LSD test.

Acacia rostellifera	F significance
2.5 g > 5 g > 0 0.083 0.079 0.051	p > 0.10
Acacia cyclops	
0 < 5 g > 2.5 g 0.063 0.040	NS
Acacia littorea	
5 g > 2.5 g > 0 0.030 0.029 0.015	p > 0.05

Harvest 2. Mean dry weights (g), underlined results do not differ with LSD test.

Acacia rostellifera	F significance
2.5 g > 5 g > 0 0.269 0.263 0.111	p > 0.01
Acacia cyclops	
2.5 g > 5 g > 0 0.363 0.218 0.167	p > 0.05
Acacia littorea	
2.5 g > 5 g > 0 0.094 0.093 0.052	p > 0.05

The 5 g ash treatment in **Acacia rostellifera** was intermediate in position for both harvests. At 77 days the 2.5 g ash showed a marginally significantly greater weight than the control. At 110 days both ash treatments were significantly greater than control at the p 0.01 level.

The 5.0 g ash weight for **Acacia cyclops** was the same as the control at 77 days and differences were not significant. The 2.5 g ash showed a much greater weight than the other two sets at 110 days, and this difference was significant. The 5.0 g ash of **Acacia littorea** gave a weight slightly higher than that of the 2.5 g level at 77 days. This difference was not significant, but both were significantly greater than control. The pattern at 110 days was similar with both ash treatments significantly greater than control, but with the 2.5 g set slightly larger than the 5 g set in mean dry weight.

Table 4 shows the mean ratio of the dry weights of the tops to the roots and the fresh/dry weight (total) ratio, for both harvests. For the top/root ratios **Acacia cyclops** had the highest values throughout, for all treatments. At 77 days the 2.5 g ash gave the highest value for this species, whereas at 110 days the control set was highest, with little difference between the ash treatments. **Acacia littorea** had the next highest values for top/root ratio with control highest at first harvest and the 5.0 g ash highest at second harvest. The control group in **Acacia rostellifera** showed the lowest value, at both harvests, of all 3 species. The 2.5 g ash soil group gave the highest values and the 5 g ash ratio fell between the control group and the 2.5 g ash.

In the case of the ratio of total fresh weights to total dry weights values were generally highest in **Acacia rostellifera**. In this species the pattern was consistently

5 g > 2.5 g > control.

The 2.5 g ash ratio in **Acacia cyclops** was much higher than both the control and the 5.0 g ash at 77 days, but at 110 days the control was greatest. **Acacia littorea** at 77 days showed larger ratios for ash soils compared to the control. However at 110 days there was little difference between treatments.

The control group of **Acacia rostellifera** contained 16.1 ppm calcium. The 2.5g ash set contained 17.8 ppm as did the 5 g ash set. **Acacia cyclops** had 9.1 ppm in control, 5 in the 2.5 g ash, and 13.1 ppm in the 5.0 g ash set. **Acacia littorea** recorded 5, 16.9 and 10 ppm calcium for control, 2.5 g and 5.0 g ash treatments respectively.

These results multiplied by respective mean dry weights give an estimate of the amount of calcium, in milligrams, that the plants took up from the soil. **Acacia rostellifera**, in control took up 0.83 mg of calcium. The 2.5 g ash plants took up 1.43 mg of calcium and the 5 g ash soil group took up 1.4 mg. The control set of **Acacia cyclops** took up 0.57 mg, the 2.5 g ash took up 0.19 mg, and the 5.0 g ash plants took up 0.82 mg of calcium. All three treatments of **Acacia littorea** took up small amounts of calcium, 0.076 mg, 0.48 mg and 0.3 mg for the control, 2.5 g and the 5 g ash treatments respectively.

The control set of **Acacia rostellifera** had 19 ppm of potassium, the 2.5 g ash 33.25 and the 5 g ash contained 50 ppm. **Acacia cyclops** had 17.5, 9 and 29 ppm for the control, 2.5 g and 5 g ash treatments respectively. The control of **Acacia littorea** had 8.5 ppm, the 2.5 g ash 18.5 and the 5 g ash contained 24.25 ppm of potassium.

The amounts of potassium in plants of **Acacia rostellifera** were 0.97, 2.74 and 3.94 mg in the control, 2.5 g and 5 g ash soil groups respectively. **Acacia cyclops** contained 1.09, 0.35 and 1.82 mg for the control, 2.5 and 5.0 g ash soil groups and **Acacia littorea** recorded 0.13, 0.53 and 0.73 mg for the control, 2.5 and the 5.0 g ash soil groups respectively.

Discussion and Conclusions

The experiments suggest that, after a bush fire, there would probably be an increase in the number of Acacia plants. After soil moisture is adequate **Acacia rostellifera** would probably be the first to appear, with **Acacia littorea** germinating over the next few days. **Acacia cyclops** is less sensitive to fire and would not commence germinating until 2 weeks after **Acacia rostellifera**; this would be approximately 20 days after adequate soil moisture is available. The **Acacia** species probably do not require extreme temperatures to break dormancy and a mild burn during the cooler seasons would probably provide enough heat to condition the seeds. Available rainfall and seasonal temperature would provide suitable conditions for a large number of germinations.

Initial plant growth is generally slow and the seedlings are quite delicate and would need to be protected from herbivore grazing or trampling.

The presence of ash in soil had a marked effect on growth in all three species **Acacia rostellifera, A. cyclops** and **A. littorea**. The **Acacia** species responded well to ash bed soils and the growth rate was increased. Initial slow growth of seedlings occurred in all treatments and is probably characteristic of **Acacia**. In most cases the 2.5 g ash soil gave either the best or similar results to the 5 g ash treatment. **Acacia cyclops** did not seem to respond as well to the ash soils as did the other species. The control group recorded either similar or larger growth results at the first harvest. The 2.5 g ash in particular recorded very low results at 77 days but mean dry weights increased considerably by the second harvest when the 2.5 g set gave the largest mean weight recorded for the species tested. Perhaps initially growth was retarded by the presence of ash in the soil. However by the end of the experiment this initial retardation had gone.

The nutrient analysis shows that by 77 days more potassium and calcium had been taken up by the plants in ash soils than by the plants of the control group, although amounts were small.

Although we did not analyse plant tissues for nitrogen the dry weights recorded suggest that the presence of ash in the soil would lead to an increase in the amount of plant protein synthesised. As the 2.5 g ash generally gave best growth, at least for the later harvest, there may be a limit to the amount of nutrients the plants can incorporate. Too much ash in the soil may inhibit growth.

This experiment has shown that **Acacia rostellifera, Acacia cyclops** and **Acacia littorea** benefit from both heat treatments of the seeds and an ash bed soil. In a re-afforestation programme seeds should be heat-treated and then sown into a mild ash bed soil, during Autumn or early Spring, and the seedlings protected from any forms of stress, such as grazing and trampling.

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SANDALWOOD PLANTING WITH PROPERTY OWNERS

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Introduction

The notion of supplying sandalwood (**Santalum spicatum**) seedlings to farmers and other property owners was first mooted in 1981. Interest was stimulated by publicity placed in the rural weeklies, metropolitan dailies and through growers' organisations. In addition to farmers, several metropolitan council Parks and Gardens Departments showed interest. A number of pastoralists were prepared to have seedlings planted on their properties but they were not able to care for them. In contrast many farmers suggested they were able to plant in areas protected from grazing and also to provide supplementary watering if required. Despite this enthusiasm and a great deal of effort, the results have been generally disappointing. This paper summarises the effort and success achieved.

Initial Procedure

The bulk of cooperating planters were farmers, or farmers' wives from agricultural areas. Initially participants were asked to report on survival and growth of their plants after planting, at 6 monthly intervals. For the second full year (1983) participants were asked to make a first report at the time of planting. The recording sheet supplied included spaces to provide information for each sandalwood including

date of planting; soil type
identification number; host
position - full sun/part shade/full shade
height; leaf number; branch number
comments on general health

In 1982 seedlings were sent by road or rail freight, in 1983 most people came to WAIT and collected the plants personally. The programme was wound down in 1984.

1982 Planting Season

By June 1982 some 610 potted sandalwoods had been delivered to a total of 95 sites. In addition to some 80 farmers, mainly in the wheatbelt, 4 metropolitan councils, 2 Department of Agriculture stations and several metropolitan householders received plants. By the end of the 1982 winter planting season a total of 132 farmers in 80 districts had been sent plants. In all 1120 seedlings were distributed. All participants had agreed to report on growth at 6 monthly intervals.

At June 1983 a set of 58 reports had been received on the 1982 planting, representing some 350 planted sandalwood. Of those planted and reported on there were 18 survivors, i.e. 5.1 percent. Survival did not appear to be related to any obvious factor. Neither host plant used, soil type, or location appeared to influence survival. One person who achieved success searched for roots of the host plant, then planted the sandalwood immediately next to them. In this way the sandalwood would have had a good chance of attaching itself to roots of the host plant before the following summer. This approach was subsequently recommended as a useful procedure to follow.

The reports sent in included space to suggest reasons for failure. The following replies were received. The number of times each category was mentioned by property owners is indicated in brackets:

1. Wind damage (3)
2. Clay soil (3)
3. Lack of water (3)
4. Locusts/Grasshoppers (3)
5. Poor potting mix (too sandy) so that roots disturbed when planting (5)
6. Poor quality of seedlings, generally due to damage in transit. (Total West/Rail) (6)
7. Planted too late (late July) (3)
8. Accidental damage (3)

It was also frequently mentioned that the summer of 1982-83 was a particularly hard one for young seedlings, being particularly long. Reports were received of the death of many native plants, including both seedlings and mature specimens.

Five of the participants successfully grew their own plants from seed put directly in the ground. These also agreed to send reports on the growth of these seedlings.

By the end of 1983 a total of 88 reports covering some 520 of those originally planted had been received. Survivors were 27 (5.2 percent) with all those surviving to mid 1983 still alive (Table 1). If we assume that those persons who did not report at all were unsuccessful, then the worst possible result in terms of overall survival would have been 27 from 1120 planted, or a survival rate of 2.4 percent over the first summer.

During the first 6 months of 1984 24 reports covering 137 planted sandalwood were received. Of these there were 6 survivors, with mean height about 67 cm. A further 19 property owners who planted 102 sandalwood reported no survivors. By the end of 1984 it is believed that at least 9 of the original 1982 plantings had survived to the beginning of the 1984/85 summer. These had attained heights from 25-300 cm (Table 1). Most were growing well.

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TABLE 1. Successful planters of sandalwood from the 1982 planting season

PLANTER LOCATION	SOIL TYPE	PRESUMED HOST	NO PLANTED	SUN(S) PART-SHADE(PS)	SURVIVORS (and heights attained cm)		
					12 months	24 months	36 months
Mrs F.Betts	Clay	**Melaleuca** Horse manure mulch	5	1 each	2 : 60,86	2 : 100	2 : 300
Mrs D.Boddington Yandanooka	Sandy loam	**Acacia acuminata**	5	–	1 reshooting*	1 : 45	1 : 83
Mr D.Cochrane Duranillin	Gravel loam	Wandoo, blackboy and scrub	5	PS	1 growing well	1 : 34	1 : 36
Mr B.Davey Wongan Hills	Sandy loam over laterite	**Acacia acuminata**	5	PS	1 growing	1 : 107	1 : 135 (at 30 months,no report at 36mths)
Mr R.Mussared Cunderdin	Medium loam	?	15	PS	3 growing well	1 : 17	Died
Mr B.Sturges Bulyee	Clay	**Acacia acuminata**	5	–	2 growing well	1 : 90	No report
Dr P.Wycherley Toodyay	Red clay over granite	**Acacia saligna/ Eucalyptus**	5	–	3 : 1 good, 2 struggling (An **A.acuminata** host died which was supporting the good plant)	2 : 25,75	2 : 26,80

NOTE: Other participants with at least one survivor over the first twelve months came from Corrigin, Darkan, Kalannie, Kendenup, Mogumber, Mundaring, Mt Madden, Northam, Pingaring and Wagin.

*Top damaged by children first year, then burnt in second year.

By mid 1985 reports had been received in respect of 7 of the 9 survivors. Of these all were alive, apart from one at Cunderdin which had been the shortest survivor (at 17 cm) by mid 1984. Mrs Betts at Kenwick had been the most successful participant with two well grown trees. She mulched the seedlings at planting, with horse manure, and has been able to provide summer watering throughout. The nearest host trees to her sandalwood are **Melaleuca** of about 3 m height.

Of the original 1120 plants then we know of at least 7 possibly 8 that have survived for three years, and three summer seasons.

1983 Planting Season

The cooperative programme was extended geographically in 1983. Seedlings were requested by the Forests Department nursery at Broome and 10 were subsequently air freighted. They survived the ordeal of travelling upside down to be planted next to local species of **Acacia, Grevillea** and **Cassia.** The nursery also planted a number of their own seedlings germinated from seed collected from the Pilbara (near Tom Price). The District Agricultural Officer at Meekatharra also participated in the programme.

By mid-1983 47 people had expressed the wish to participate in the 1983 programme. Between May and August 320 seedlings were distributed to a total of 52 people, of whom 18 were new to the programme, with 34 repeaters. Following the low survival results with the 1982 plants efforts were intensified to provide good, healthy, stock and the following recommendations were made to planters

1. Locate a root of the host and plant the sandalwood close by.
2. Plant in shade/semi-shade if possible.
3. Plant carefully with as little root disturbance as possible in the dug hole, then slit the bag down each side and carefully remove it.
4. Provide wind and insect protection.

In an effort to reduce the numbers of plants damaged in transit (road and rail freight) it was stressed that collection of plants from WAIT was advisable. Early reports indicated fewer deaths in the months immediately following transplanting. Better plants and a wetter winter/early spring in 1983 may also have been contributory factors.

By mid-1984 35 of the 52 participants had reported, covering 246 sandalwood. There were 47 survivors reported by 15 property owners from 96 planted seedlings. The unsuccessful participants (20) had received 150 sandalwood all of which died. If we assume that persons who did not report were unsuccessful (i.e. 17 persons, 74 plants) then the survival over the first summer was 47/320 or 14.7 percent, a considerable improvement on the 1982 planting success rate.

Fewer reports were received in the second half of 1984. These included many of those who had reported survivors by mid year, such that the 20 survivors reported to late 1984 came from 31 of those that had survived to mid year, from 76 planted. This decline was disappointing especially if it is assumed again that non-reporters were unsuccessful, suggesting a net survival of 20/320 or 6.3 percent. There were however, a few more than 20 alive, as two persons subsequently confirmed that they had one survivor each to mid 1985. By mid 1985, after two summers we know definitely that 10 plants survived, with a reasonable possibility that up to 18 may have. That would give the net survival into the 3rd year of 10-18/320 or between 3 and 6 percent.

The most successful grower was Ms J. Brown of Pingelly. From 10 plants 6 survived one year, one more died over the winter/spring of 1984 and by June 1985 4 remained alive with heights between 28 and 140 cm. Survivals to date are given in Table 2.

1984 Planting Programme

By 1984 it had become apparent that a number of inherent problems existed in the programme. Perhaps because seedlings were provided free of charge to growers, they may have received less careful attention than had they been paid for. The fact that persons new to planting tended to achieve low success is discouraging to them. Simultaneously evaluation of direct seeding had clearly suggested that this was a promising avenue to further explore. It was also felt that concentration of plantings could provide a more satisfactory approach to developing experience and confirming the value of preferred techniques.

For various reasons then the planting programme for 1984 was wound down, with emphasis to be re-directed elsewhere. Nevertheless the efforts made in the previous years had stimulated a lot of interest in the concept of planting sandalwood and a number of persons wished to continue or enter the programme. In order to accommodate enthusiastic persons, plants were provided, but increasing emphasis was placed on encouraging the direct planting of seed by seed distribution.

TABLE 2. Successful planters of sandalwood from the 1983 planting season

PLANTER LOCATION	PRESUMED HOST	NO. PLANTED	SURVIVORS (and heights attained cm) JUNE 1984	OCTOBER 1984	JUNE 1985
Ms J.Brown Pingelly	**Acacia lasiocalyx** **E.wandoo, loxophleba**	10	6 : 10-30	5 : 10-60	4 : 28-140
Mr D.Cochrane Duranillin	Scrub and **Acacia**	6	2 : 6.5	1 : 9	1 : 12
Mr B.Davey Wongan Hills	**Acacia** and **Callistemon**	5	2 : 59	2 : 75,90	No report
Mrs G.Fiegert Cunderdin	**Eucalyptus camaldulensis**	5	1 : 14.5	1 : 8	No report
Mrs I.Hall Narembeen	**Acacia, Eucalyptus,** **Hakea**	10	4 : 25	1 : 56 (survivor near **Eucalyptus**)	1 : 80
R.Mandry Collie	?	5	-	-	1 : 145
Mr B.Rudeforth Mundaring	**E.calophylla**	5	1 : 15	1 : 15	Dead
Mr G.Souness Borden	**E.wandoo, decipiens**	10	8 : 16	-	1 : 45
S. I. Stewart Pingaring	?	5	3 : 20	3 : 12-26	1 : 15
Mrs B.Sturges Bulyee	?	5	5 : ?	2 : 18-121	No report
Mr N.Turner Corrigin	**E.botryoides** and lucerne	5	3 : 16-30	3 : 16-40	Dead
Dr P.Wycherley Toodyay	**Acacia** **acuminata**	5	?	1 : 44	1 : 49

TABLE 3. Successful planters of sandalwood from the 1984 planting season

PLANTER LOCATION	PRESUMED HOST	NO. PLANTED	SOIL	SURVIVORS (and heights attained cm) October 1984	June 1985
Ms L.Alcorn Karridale	Sallow wattle	7	Sandy loam	7 : 8-13	2 : 20-25
Ms W.Bradshaw Tambellup	**A.acuminata**	6	Sandy loam	6 : 11-18	1 : 25
Ms I.Hall Narembeen	Various	10	Clay loam	10 : 8-20	1 : 24
Mrs F.Martin Mosman Park	**A.acuminata** and jacaranda	5	Sand	-	2 : 11-25
Mr R.Shaw Geraldton	**Acacia**	5	?	3 : 15	1 : 10
Mr N.Turner Corrigin	**A.acuminata** and lucerne	12	Sand over clay	11 : 14-30	2 : 37-40

A total of 108 potted plants were distributed to some 16 property owners. By late 1984 ten of these reported 55 survivors from 86 planted. Figures to mid 1985 of those who reported survivors (6 property owners) show that their numbers had fallen from 39/45 to 8/45 for the first one year after planting. It is unlikely therefore that of the 55 from 86, any more than 15 would have survived. We assume therefore that between 8-15/108 survived one year, or a rate of between 7 and 14 percent.

Three persons had 2 surviving plants after one year:
Ms L. Alcorn of Karridale, Mrs F. Martin of Mosman Park and Mr N. Turner of Corrigin. Survivals to date are shown in Table 3.

Seed Planting

A number of interested property owners have planted seed. Some of the successful ones include Mr G. Tompkins of Padbury, Mr R. Shaw of Geraldton, and Mr R. Mandry of Collie. Mr Shaw reported from his 1984 sowing, 8/20 germinants by October 1984 of 3-35 cm in height. These had been sown near **Acacia** and **Eucalyptus gomphocephala**, all were browsed by 'mice' and died. Mr Mandry had 15/20 germinants and by June 1985 there were 14 survivors of 11-25 cm height.

From other trials that we have conducted it may be expected that survivals into the second and third years will be similar to those of seedlings. However the total effort in establishing plants from seed is very much reduced in comparison to setting out plants raised in pots, where the nursery handling expenses are relatively high.

Discussion

Why should success have improved? Clearly improvements in handling, quality of stock and planting techniques were probably all important.

Of the 35 property owners who reported on the 1983 planting, 19 were repeaters from 1982 and 16 were new to the programme. It is of interest that of the 19 who participated in both 1982 and 1983, 9 property owners had one or more survivals (Table 4). These people planted a total of 51 Sandalwood in 1983. After one year 29 survived, an apparent success rate of 57 percent. The repeaters (10) who had no success in 1983 planted 80, of these property owners only 2 had recorded one or more survivors from their 1982 efforts. Similarly of the 9 who reported survivors from 1983 only 2 had success in 1982. A total of 11 of the repeaters had success in either 1982 or 1983 or both, whereas 8 had tried in both years with no success.

TABLE 4. Persons planting in 1983 who reported after 1 year.

	Success Yes (1)	No	Percent successful	Percent survival for (1) for 1983
Participated 1982 and 1983	9	10	47	57
New in 1983	6	10	38	16
Percentage repeaters	60	50		

Those successful in 1983 who were new to the programme in 1983 planted 115 and 18 survived, a survival rate of 15.7 percent. The overall survival of 47 from 96 planted by the 15 property owners who planted seedlings and reported one or more survival was 49 percent after that first year. Thus it may be concluded that persistence is important and that those property owners who continue to show interest are likely to succeed.

By the time that the plants have survived for 2-3 years the indications are that survivors tend to remain. The first summer season is critical in terms of remaining alive, but without effective host attachment it is unlikely that many plants could persist for longer simply through careful watering and other maintenance measures.

Conclusions

The first year (1982) of a co-operative sandalwood planting programme attracted a great deal of interest with over 130 different growers involved. However survivals were poor with only 2.4 per cent of 1120 seedlings surviving the first year. Survival declined again over the second year by when 0.8 per cent remained. Three years after planting only 0.6-0.7 percent of those planted are known to have survived.

In the second year (1983) fewer people participated but many of these were repeaters. Improved quality and handling techniques would have partly accounted for a better success rate, though grower experience on the part of cooperating property owners was important. The survival rate for the first year was 14.7 percent, a six-fold improvement over the 1982 plantings. After 2 years somewhere between 3.1 and 5.6 percent of those initially planted remained alive, giving at least a four-fold improvement over the 1982 effort.

The third year saw a much diminished programme but, again many participants were repeaters. Survival over the first 12 months was between 7 and 14 per cent, reflecting a sustained improvement over the first year of the programme.

Our own experience suggests that the use of fresh seed, cut and sown directly into the ground around May should provide the most economical establishment method. The success rate is likely to be as good or better than the use of planted stock and survivals beyond the first summer following sowing will be dependent on good, early, attachment to suitable hosts.

POST-FIRE REGENERATION OF HEATHLAND, ROTTNEST ISLAND: A PRELIMINARY INVESTIGATION.

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Introduction

Reafforestation exclosures have been established as part of a five year (1984-1988), planting programme on Rottnest Island (see Figure 1). Fences have been erected by the Rottnest Island Board around reafforestation areas, to prevent grazing by quokkas (**Setonix brachyurus**) on nursery-raised planting stock of **Eucalyptus platypus** and **Melaleuca lanceolata**. The plant community prior to erection of the exclosures, was indicated by some unburnt remnants. It consisted of a dense low heath, largely of monocotyledonous species, including **Acanthocarpus preissii**, **Stipa variabilis** and **Conostylis candicans**. **Guichenotia ledifolia** and **Thomasia cognata** were also represented in this **Acanthocarpus-Stipa** community of O'Connor et al. (1977). Other dicotyledonous and woody heath species were absent.

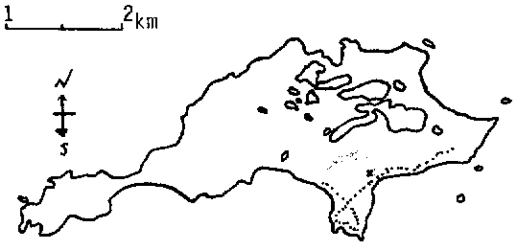

FIGURE 1. Rottnest Island reafforestation location, study site indicated by X.

During the reafforestation programme, control burning and ploughing are being used, in addition to fencing, as management tools for the **Acanthocarpus-Stipa** community. The exclosures were control burned in Summer 1983 or Autumn 1984. The exclusion fences should prevent grazing by quokkas of post-fire regenerating suckers and germinated seedlings. Germination of any fire dependent soil-stored seed, such as **Acacia rostellifera**, would be stimulated by a control burn.

Although the **Acanthocarpus-Stipa** plant community readily regenerates following fire, burning the heath initially removes the competitive effect of **Acanthocarpus preissii**. Furthermore, ploughing subsequent to the burn, breaks up the root system of **Acanthocarpus preissii** from which revegetative sprouting would otherwise readily occur.

The major purpose of the present study was to document post-fire regeneration in an **Acanthocarpus-Stipa** low dense heath community where exclosures, control burning and ploughing have been used as management tools.

A secondary aspect of the study was to sow plant species endemic to Rottnest Island in post-fire ashbeds within the exclosures. Seedling emergence was observed.

Methods

Seven 15 by 1 m2 line transects and one 16 by 1 m2 line transect were laid out during July 1984 by WAIT students of the B.App.Sc. (Biology) course. These transects were placed in four reafforestation areas. Figure 1 shows the 1984-1988 Rottnest Island reafforestation location. Figure 2 shows the relative size and position of the four study areas, with transect and slope details of each area given in Table 1.

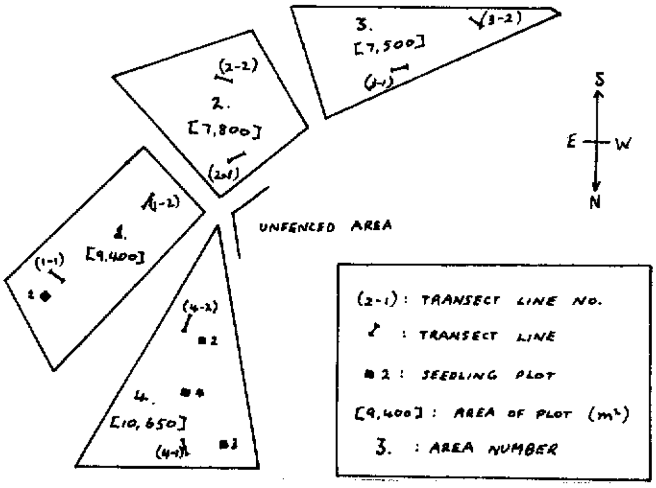

FIGURE 2. Relative size and position of the four study areas. All measurements are in metres.

In each 1 m by 1 m quadrat all plant species were recorded and number of stems were counted. Area covered by common species was recorded as negligible, less than 5 percent, less than 10 percent, or greater than 10 percent. Any planted nursery stock (**Eucalyptus platypus** or **Melaleuca lanceolata**) found in the quadrats were tagged and measured for height.

Seed of plant species endemic to Rottnest Island was sown in each of four study plots having comparable slopes. Seed was scattered and covered with approximately 1 cm of soil. Germinants emerging in these ashbed plots were counted three months after sowing. One ashbed plot (4.5m x 4.5m) was positioned on an unploughed slope, two plots (4.5m x 4.5m and 5.0m x 5.0m) were on ploughed slopes, and the fourth (5.1m x 5.1m) in an unploughed hollow.

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TABLE 1. Environmental description of the exclosure study transects.

Transect of 15 1m x1m quadrats		Control Burn Nov. 83(N) or Apr. 84(A)	Ploughed Yes (+) No (-)	Slope and Aspect
No.	Map Ref.			
1	T 1-1	N	+	Up northward slope
2	T 1-2	N	+	Up slight eastward slope
3	T 2-1	N	+	Down slight south-west slope
4	T 3-1	N	+	Slight southwest slope up hill
5	T 2-2	N	-	Crest of hill down slight south-east slope to exposed valley
6	T 3-2	N	-	Very slight east slope
7 (16 quadrats)	T 4-1	A	-	Steep southerly slope
8	T 4-2	A	-	Northerly slope

Figure 2 illustrates the relative position of these ashbed plots. A list of the sown species is given in Table 2. Seed of **Acacia cyclops**, **A. littorea**, **A. rostellifera** and **Trachymene caerulea** ('Rottnest Daisy') were given a dry heat treatment, by standing in a black enamel tray for 20 minutes in an oven preheated to 100°C.

Results

Table 3 lists plant species for each transect line in systematic family order. The number of quadrats in which each species occurred is shown with total number of plants per transect line. It is noted that four transect lines were placed in the exclosures where ploughing followed burning and four transect lines were located in exclosures undisturbed following the control burn (see Table 1 for details).

Presence/absence chi-square comparisons between ploughed and unploughed areas have been completed on statistically appropriate data. Summaries are provided in Table 4. Table 5 gives additional transect line totals and presence/absence figures.

Germinant numbers from the ashbed plots are reported in Table 6.

Discussion

A total of 26 species was recorded from the study quadrats. In the ploughed and unploughed exclosures plant species composition was similar, with 16 identified species common to both (see Table 3).

Acanthocarpus preissii-Stipa variabilis low dense heathland occurred in the study plots prior to the 1983 or 1984 control burn. Following this recent burning, pre-existing, perennial plant species have rapidly regenerated from vegetative material. **Acanthocarpus preissii** was common in both ploughed and unploughed exclosure plots, represented in 48 and 54 quadrats respectively. Fire stimulated regrowth of **A. preissii** from root stock. If ploughing in this instance did damage the root systems, regeneration has still taken place. However, **A. preissii** was more abundant in the undisturbed than in the ploughed exclosures (see Table 5).

The common tussock grass **Stipa variabilis** is believed capable of rapidly sprouting from root crowns after fire (O'Connor et al. 1977). **Stipa variabilis** was recorded from 53 unploughed quadrats and 49 ploughed quadrats. A comparison of transect-line total numbers indicates that this species was also more common in the unploughed areas (refer to Table 5).

Other perennial species previously documented as occurring within the **Acanthocarpus-Stipa** community (O'Connor et al. 1977), were recorded from both ploughed and unploughed areas. It is noted that a number of these less dominant heath community species were actually more common in the unploughed exclosures. Colonisation by **Conostylis candicans** (a tussocky, herbaceous monocotyledon), **Guichenotia ledifolia** (a dense, spreading shrub) and **Pelargonium australe** (dune geranium) was more successful in soil which had not been disturbed by ploughing. **Caladenia latifolia** (pink fairies orchid) was prevalent on the ploughed soil (see Tables 4 and 5).

TABLE 2. Weights of seed sown in each ashbed plot (g).

Species	Untreated	Treated
Acacia cyclops		5
Acacia littorea	5	5
Acacia rostellifera		5
Trachymene caerulea		2.5
+ 50 untreated seeds of Pittosporum **phylliraeoides**		

Note: number of seed per 5g **A. cyclops** 282; **A. littorea** 880; **A. rostellifera** 180.

Table 3. Species listing with total numbers and quadrats present reported - fifteen 1 m² quadrats per transect line except transect 7, 16 1 m² quadrats. Table 1 provides map references for transect lines.

	Ploughed								Unploughed							
	1		2		3		4		5		6		7		8	
Species	No	Quad	No	Quad	No	Quad	No	Quad	No	Quad	No	Quad	No	Quad	No	Quad
‡ Lagurus ovatus	14	9	12	9	16	7	24	9	10	7	16	5	31	11	21,2*	15
Stipa variabilis	32	12	39	13	50	13	22	11	57	14	51	13	146,1*	16	43	10
Lepidosperma gladiatum	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-
Scirpus antarctius	15*	15	15*	15	15*	15	14*	14	21,14*	15	15*	15	16*	16	15*	15
Acanthocarpus preissii	99	12	25	11	241	15	38	10	178,1*	14	62	14	46	12	195	14
‡ Trachyandra divaricata	8	4	43	8	34	10	49	14	62	12	60	12	2	2	73	14
Conostylis candicans	2	1	-	-	3	2	2	2	76,3*	10	56	6	102,2*	15	150,3*	11
Caladenia latifolia (a)	70	7	-	-	11	6	-	-	-	-	4	2	1	1	6	1
Rhagodia baccata	-	-	-	-	8	7	20	8	10	5	27	9	-	-	-	-
Clematis microphylla	-	-	-	-	15	9	1	1	10	7	-	-	2	2	1	1
Acacia rostellifera	2	1	-	-	1	1	-	-	-	-	-	-	-	-	-	-
‡ Erodium cicutarium	-	-	-	-	-	-	-	-	many	1	-	-	-	-	-	-
Pelargonium australe	102,4*	14	31	10	71,9*	14	52	10	66,8*	15	90,2*	11	69,11*	16	56,12*	15
‡ Euphorbia peplus	78	11	66	10	5	4	1	1	27	11	1	1	-	-	127	14
Poranthera microphylla	64	12	75,2*	14	43	13	100,1*	14	75,5*	14	90,5*	13	36,7*	14	116	10
Guichenotia ledifolia	2	2	5	3	12	6	17	10	20,7*	13	58,2*	13	20,1*	7	-	-
Thomasia cognata	-	-	-	-	-	-	-	-	-	-	-	-	1	1	-	-
Leucopogon parviflorus	5	1	-	-	-	-	1	1	13	6	1	1	-	-	-	-
‡ Solanum nigrum	79	13	47	14	5	4	67	12	98	7	140,2*	14	24,3*	6	29	7
Senecio lautus	11	6	23	11	12	7	7	5	3	1	51	14	153	16	133,2*	15
Unidentified annuals	129,5*	15	268,3*	15	243,3*	15	56,4*	15	121,5*	15	105,2*	15	229,18*	16	191,15*	15

‡ exotic species
(a) includes Eriochilus dilatatus ('round leaf' orchid)
15*, large number of plants in 15 1 m² quadrats.

Burning the pre-existing heathland has provided an ashbed for wind borne **Pelargonium australe** seed. On the unploughed sites colonisation has then readily occurred. **Conostylis candicans** sprouts from rhizomatous roots present in the soil. Ploughing appears to have damaged regenerating root stock of this species, with subsequently only 7 vegetative shoots recorded in the ploughed exclosures (see Table 5).

Thirty-seven seedlings of the volunteer species **Rhagodia baccata** were counted in the unploughed exclosures and 28 in the ploughed exclosures. **R. baccata** seed probably has been dispersed by birds into the exclosures from nearby stands. We have found **R. baccata** seed in faecal samples taken from Singing Honeyeaters (**Lichenostomus virescens**) on Rottnest Island. Only one **Acacia rostellifera** seedling was recorded in the study transects, there being no apparent soil-store of **A. rostellifera** seed. **A. rostellifera** thickets on Rottnest Island have steadily declined, due to heavy quokka grazing and the relatively short life span of the species (Storr 1963).

Reintroduction of thickets of selected **Acacia** species (e.g. **A. littorea, A. rostellifera**) by direct sowing of seed into the ashbeds, could be an additional management aspect of the 1984-1988 reafforestation programme. This present study found some heat-pretreated **A. cyclops, A. littorea** and **A. rostellifera**, emerged in the three unploughed ashbed plots (see Tables 2 and 6). One germinant was noted on the ploughed ashbed. Sowing of selected species into new exclosed seeding plots in Autumn 1986, and longer term observations, would establish the usefulness of direct seeding into these post-fire ashbeds.

The introduced herbaceous coloniser **Trachyandra divaricata** was prevalent in both the ploughed and unploughed exclosures (Tables 4 and 5).

TABLE 4. Summary of the chi-square, plant species presence/absence comparisons of ploughed and unploughed exclosures.

Species	Presence P	Presence UP	χ^2	Significance
Stipa variabilis	49	53	0.62	NS
Scirpus antarctius	59	61	-	NS
Acanthocarpus preissii	48	54	1.66	NS
Trachyandra divaricata	36	40	0.40	NS
Conostylis candicans	5	42	46.64	***
Caladenia latifolia	13	4	5.72	*
Rhagodia baccata	15	14	-	NS
Pelargonium australe	48	57	4.76	*
Euphorbia peplus	26	26	-	NS
Poranthera microphylla	53	51	0.24	NS
Guichenotia ledifolia	21	33	4.47	*
Solanum nigrum	43	34	3.32	+
Senecio lautus	29	46	9.61	**

P ploughed quadrats maximum 60, UP unploughed quadrats maximum 61.

Significance (probabilities) NS $p > 0.10$; + $P < 0.10$; * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

Seeds have been readily wind borne from surrounding plants. Further study is required to assess the extent of competition from this common dune species. Although numbers of endemic heathland species are high, **Trachyandra divaricata** is a fast growing monocotyledonous species, producing large amounts of seed. The proportion of T. divaricata plants to endemic plants is higher on ploughed surfaces. However, the data were not appropriate for statistical testing of this apparent trend.

TABLE 5. Transect line totals of plant species recorded in ploughed and unploughed enclosures.

Species	Ploughed Total	Unploughed Total
Stipa variabilis	143	297 (1*)
Acanthocarpus preissii	403	481
Trachyandra divaricata	134	197
Conostylis candicans	7	384 (8*)
Caladenia latifolia	81	11
Rhagodia baccata	28	37
Pelargonium australe	256 (13*)	281 (33*)
Guichenotia ledifolia	36	98 (10*)
Solanum nigrum	198	291 (4*)
Senecio lautus	53	340 (2*)

(1*) large number of plants in one m2 quadrat.

TABLE 6. Germinants in ashbed plots, three months after sowing.

	PLOT 1	PLOT 2	PLOT 3	PLOT 4
Acacia cyclops	-	-	1	-
Acacia littorea	1	18	3	4
Acacia rostellifera	-	2	-	1
Exposed seeds	2	12	5	11

Conclusions

Subsequent to the recent 1983 or 1984 control burn there has been regeneration of the pre-existing heathland. Exclosure fencing has prevented quokka grazing of young shoots. There is evidence that the ploughing has damaged root crowns and rhizomes present in the soil.

Considerably higher numbers of the root stock revegetating species, **Acanthocarpus preissii** and Stipa variabilis, were recorded from the unploughed exclosures. Minimal soil disturbance following control burning encourages colonisation amongst the **Acanthocarpus-Stipa** association of other endemic heath community species. **Conostylis candicans** was extremely abundant on the unploughed sites and scarce on the ploughed sites. The dense, spreading shrub Guichenotia ledifolia also colonised the unploughed soil most successfully.

These low dense heath species are not the preferred plant cover. The **Acanthocarpus-Stipa** community now covers approximately 33 percent of the total area of the island and the relatively recent and rapid increase in the distribution of the dense heath monocots has been at the expense of other woodland and scrub species e.g. **Acacia rostellifera**, **Callitris preissii** and **Melaleuca** lanceolata (O'Connor et al. 1977, Hesp et al. 1983, Pen & Green 1983).

Ploughing of the exclosure areas has damaged root stock and thus slowed regeneration of the monocotyledonous heath species. Data from this study tentatively suggests ploughing is good management policy provided it does not lead to excessive competition from opportunistic colonisers such as **Pelargonium australe** and **Trachyandra divaricata** (see Fox & Hansen 1982). Wind blown seed of the dune geranium (**Pelargonium australe**) has germinated readily in the post-fire ashbed, particularly on the undisturbed soil of the unploughed exclosures. Proportionally higher volunteer rates of **Trachyandra divaricata** were recorded from ploughed than unploughed sites. Future monitoring will assess whether colonization by these species has been detrimental to establishment of nursery stock and regrowth of woodland and shrub species.

In conjunction with exclosure erection, control burning and ploughing, another management strategy is worthy of consideration in this reafforestation programme. The establishment of dicotyledonous heath and other shrub species should be actively promoted. Selected species could be reintroduced by direct seeding in swales and hollows and by planting established seedlings onto steeper slopes exposed to water run-off. Species could include **Acacia cyclops**, **A. littorea**, **A. rostellifera**, **Diplolaena** sp and **Trachymene**. Cuttings from available parent plants could be struck in pots and then transplanted e.g. **Myoporum**, **Scaevola**, **Westringia** and **Leucopogon** spp.

This preliminary investigation has provided base-line data for future recording of long term plant establishment and survival and species succession. Other variables eg., wind velocity and direction, bird foraging and drainage patterns, should be considered in future studies.

Acknowledgements

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