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VARIATIONS OF GROWTH RATE OF *EUCALYPTUS DELEGATENSIS* R.T. BAKER SEEDLINGS AT FIVE ELEVATIONS

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ABSTRACT

Eucalyptus delegatensis R.T. Baker, from a single seed source, was grown at five sites over a range of elevations from 260 m to 600 m on two soil types, in the Surrey Hills district of North West Tasmania. Seedlings were harvested twice, after 26 and 74 weeks of growth. Dry weight and leaf area were measured and at the second harvest the net assimilation rate was calculated for each elevation.

The seedlings at the five elevations formed three significantly different populations, as discriminated on the basis of dry weight and leaf area. The differences in NAR can best be explained by variation in the length of the growing season, and the severity and duration of frosts over the altitudinal range.

The population with the highest NAR (4.16gm sq dm $^{-1}$ week^{-1}) was grown below 300 m, in an area where *Eucalyptus obliqua* is the dominant wet sclerophyll forest species. The population with medium NAR (2.03 gm sq dm $^{-1}$ week $^{-1}$) was grown at three sites between 300 and 600 m, in an area where *E. delegatensis* wet sclerophyll forest is the major vegetation type. The poor growth of the third population (NAR = 0.72 gm sq dm $^{-1}$ week $^{-1}$), grown above 600 m, corresponds to an area in which *E. delegatensis* grassy woodlands, and *Nothofagus cunninghamii* rainforest are the predominant vegetation types.

INTRODUCTION

Eucalyptus delegatensis R.T. Baker is the major eucalypt species in the Surrey Hills District of North West Tasmania (fig. 1) and is being utilised extensively for paper and timber production by Associated Pulp & Paper Mills Pty. Ltd., at Burnie. As part of an investigation into methods of increasing tree productivity and improving regeneration, a study was carried out into the natural optimum growth rates of *E. delegatensis* over a range of elevations within the Surrey Hills forest area of Associated Forest Holdings Pty. Ltd.

Five experimental sites were chosen at elevations of 850 ft, (260m), 1180 (360), 1560 (475) 1780 (540) and 2000 (600m) respectively (fig. 1). The sites lie roughly along a N-S line, and were chosen to have comparable aspects (N) and slopes (less than 2^{o}) and to be free of shade at all times of the day. *E. delegatensis* seedlings were grown from a single local seed source, in the two soil types predominant in the area, one from Devonian granite and the other from Tertiary basalt (table 1).

A number of additional observations were also made on the vegetation types over the altitudinal range and on the growth rates of mature trees and natural regeneration. These observations, combined with rainfall and temperature measurements from each site, were used to interpret the results of the major experiment.

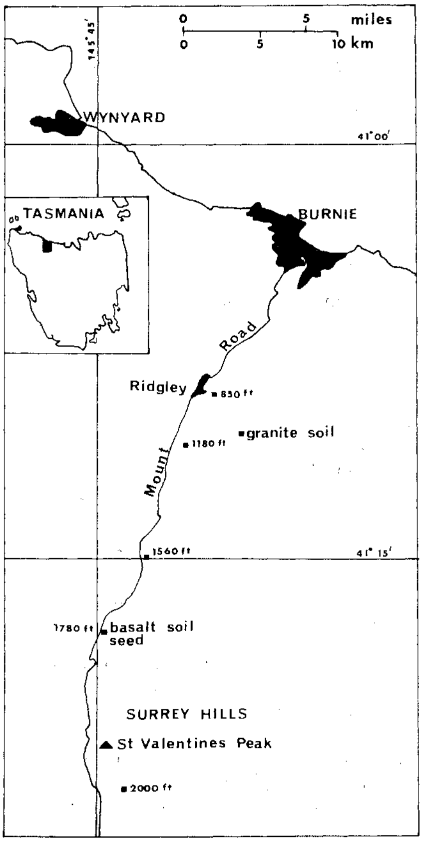

FIG.1. - Map of Surrey Hills District of N.W. Tasmania. (Inset shows location of detailed map). Experimental soil and seed collection sites are shown.

METHOD AND MATERIALS

At each experimental site an excavation of 1.5x6x0.6m deep was prepared. Each excavation was lined with plastic sheeting, and divided into one hundred compartments 0.3x0.3x0.6m deep with black painted hardboard sheeting. Each set of 100 compartments in each block were randomly filled with granitic soil, the remainder with basaltic soil.

The soils used at all five sites came from the same two sources, the basaltic from the top 0.6m of a kraznozem at 540m, and the granitic from the top 0.3m of a yellow podzolic (Stephens 1962) soil at 335m. Some chemical and physical properties of these soils are shown in table 1. Soils were sieved to remove stones and roots. The soil in the compartments was allowed to settle, then topped up to a uniform distance below the tops of the hardboard divisions.

Meteorological stations were set up at each experimental site, and weekly maximum and minimum screen temperatures, together with weekly rainfall measurements were made throughout the experiment. Part way through the experiment, an additional thermometer was installed at each site, at ground level, so that soil surface minima could be measured weekly.

E. delegatensis seed collected in December 1969 from a large number of young trees in a plantation at 535m was used for the experiment. The moistened seed was stratified at 1°C for two weeks prior to broadcasting over all soil compartments at each elevation in the first week of October, 1970. Germination started in the first week of November and by the end of the month, through thinning and transplanting, each compartment contained a single seedling.

An initial harvest of ten seedlings from each soil/site combination was made in the second week of May 1971, and a second harvest of 20 seedlings from each combination in the first week of April 1972. At each harvest, leaf area and seedling oven dry weight were measured.

RESULTS

The means and standard errors for oven dry weight and leaf area at each soil/site combination are given in tables 2 and 3. For seedlings at each elevation, "t" tests were carried out on dry weight and leaf area results to determine whether there were significant differences between plants grown on the two soil types. With one exception (at 475m) in the first harvest) differences in soil type were not reflected by significant differences in either dry weight or leaf area production.

New elevation means were calculated combining results for both soil types, and "t" tests between elevations carried out. The results of these tests are summarised in table 4. At 475m, the difference in both seedling dry weight and leaf area were highly significantly different between soil types, hence each is treated separately in comparisons with other elevations (table 4a).

TABLE 1

Some chemical and physical properties of the two soil types used in the experiment.

Granitic = top 300mm of a yellow podzolic developed on Devonian granite.

Basaltic = top 600mm of a kraznozem developed on Tertiary basalt.

Characteristic	Granitic	Basaltic
pH	4.8	5.0
Sand and Gravel Content		
% Gravel (2mm + in diam)	14	18
% Coarse Sand (2 - 0.2 mm)	58	26
% Fine sand (0.2 - 0.2 mm)	17	12
% Clay and silt (by subtraction)	12	44
Water Stable Soil Aggregates		
% 4mm + in diam	5.8	20.9
% 4mm - 2 mm	14.2	22.1
% 2 - 1.003 mm	26.2	16.5
% 1.003 - 0.500 mm	24.3	10.2
% 0.500 - 0.250 mm	13.6	5.4
pF (wilting point)	4	28
Colour	Grey	Red-brown
P ppm (HCl extractable)	59	741
N % (Kjeldahl)	0.14	0.21
N/P	28.5	4.3

TABLE 2

Seedling dry weight (g) means and standard errors for each soil/elevation combination at each of two harvest times.

First harvest - 26 weeks after germination

Second harvest - 74 weeks after germination

Soil	Granitic		Basaltic	
Elevation mm	1st Harvest	2nd Harvest	1st Harvest	2nd Harvest
260	7.78 ± 2.14	76.2 ± 13.5	6.81 ± 1.87	94.3 ± 23.0
360	3.25 ± 1.14	50.2 ± 5.1	0.93 ± 0.47	38.0 ± 6.1
475	7.21 ± 2.08	31.9 ± 3.6	1.60 ± 0.43	42.4 ± 6.9
540	2.78 ± 1.13	48.3 ± 5.3	1.20 ± 0.43	38.0 ± 10.2
600	1.10 ± 0.28	17.3 ± 1.7	0.71 ± 0.14	26.0 ± 4.4

TABLE 3

Seedling leaf area (sq dm) means and standard errors for each soil/elevation combination at each of two harvest times.

First harvest - 26 weeks after germination

Second harvest - 74 weeks after germination

Soil	Granitic		Basaltic	
Elevation m	1st Harvest	2nd Harvest	1st Harvest	2nd Harvest
260	4.31 ± 1.15	24.07 ± 4.43	4.17 ± 1.12	30.08 ± 7.44
360	1.84 ± 0.21	15.42 ± 1.51	0.59 ± 0.27	13.44 ± 1.84
475	3.61 ± 0.92	7.47 ± 0.77	1.06 ± 0.29	11.86 ± 1.66
540	1.39 ± 0.41	13.54 ± 1.40	0.76 ± 0.25	11.92 ± 2.87
600	0.70 ± 0.18	5.10 ± 0.44	0.45 ± 0.09	7.70 ± 1.26

At the second harvest, the leaf area at 475m was significantly different (5%) between the two soil types; however, as this difference was not observed in the dry weights, the results for granite and basalt soils were combined for the purposes of further testing (table 4b).

TABLE 4A

Results of "t" tests carried out on 26 week old seedlings between sites*. Figures in the body of the table are the probabilities of the difference between sites compared being not significant.

LEAF AREA

Site Elevation m	260	360	475 B	475 G	540	600
260		0.001	0.001	NS	0.001	0.001
360	0.001		NS	0.01	NS	5.0
475 B	0.02	NS		0.02	NS	NS
475 G	NS	0.01	0.01		0.01	0.001
540	0.001	NS	NS	0.01		0.01
600	0.001	0.05	NS	0.001	0.05	

* 475m is treated twice, 475B (basalt sample) 475G (granite sample), because there was a significant difference between growth on the two soils at this site.

TABLE 4B

Results of "t" tests carried out on 74 week old seedlings between sites.

LEAF AREA

Site Elevation m	260	360	475	540	600
260		0.01	0.001	0.001	0.001
360	0.01		NS	NS	0.001
475	0.001	NS		NS	0.01
540	0.001	NS	NS		0.001
600	0.001	0.001	0.001	0.01	

In table 5, the net assimilation rate for each soil/elevation combination is shown. The net assimilation rate was calculated from the following formula:-

$$NAR = \frac{W_2 - W_1}{t_2 - t_1} \cdot \frac{\log_e A_2 - \log_e A_1}{A_2 - A_1}$$

where W_2, W_1 = final and initial dry weights (gm)

A_2, A_1 = final and initial leaf areas (sq dm)

$t_2 - t_1$ = duration of experiment (weeks)

In this case, the first harvest was that taken after 26 weeks of growth, the final harvest, that taken after 74 weeks.

TABLE 5

The net assimilation rate (g sq dm $^{-1}$ week $^{-1}$) at each elevation/soil combination between the first (26 weeks) and second (74 weeks) harvests.

	SOIL	
Elevation - m	Granitic	Basaltic
260	3.25	4.20
360	2.25	1.78
475	1.18	1.96
540	2.05	1.77
600	0.78	1.21

Seedlings at both 475 and 540 m were subject to insect attack during their second summer's growth. Insect damage was kept to a minimum by removing all insects each week; however, at both sites, nearby mature trees of *E. delegatensis* provided a source of insects for constant infestation. The main insects involved were leaf-eating Chrysomelidae larvae and sap-sucking *Amorbus* sp. (Hemiptera) adults which destroyed growth apices by feeding on their soft tissues.

DISCUSSION

First Harvest

The results of the first harvest (tables 2, 3, 4A, 5) are difficult to interpret, due in part to the small number (10) of replicates of each soil/elevation combination. In general, dry weight and leaf area production decrease with increase in elevation, with only one notable exception; on the granite soil at 475m, growth was comparable with that at 260m, whereas the growth on the basalt soil was similar to that at 360, 540 and 600m. Probably this superior growth was due to particularly favourable establishment conditions in the granite soil. In terms of major plant nutrients (P and N), the basalt soil is far superior to the granite (table 1); however, structural attributes are also markedly different between soils. Glasshouse trials using a range of tree species, including *E. delegatensis*, have shown that growth is consistently superior on basalt soil, which suggests that soil structure, probably in relationship to establishment, may have been the differentiating factor in the field.

Second Harvest

The results of the second harvest are more clear-cut than for the first, in part due to the increase in sample size to twenty. The significant differences between dry weight on granitic and basaltic soils at 475m have disappeared; however, differences in leaf area are present, due in this case to heavier insect grazing on the granite grown seedlings.

The tendency for dry weight and leaf area production to decrease with increase in elevation is very marked. However, rather than a directly linear relationship, the five elevations can be divided into three groups on the basis of "t" tests between sites. The growth characteristics of seedlings in each group can be summarised as follows :-

Population A

Including all seedlings at 260m

Good dry weight and leaf area production

High net assimilation rate

Population means :

DW : 85.2 $\pm$ 13.4 g

LA : 27.08 $\pm$ 4.34 sq dm

NAR : 4.16 g sq dm $^{-1}$ week $^{-1}$

Population B

Including all seedlings at 360, 475 and 540m

Medium - poor dry weight and leaf area production

Medium - low net assimilation rate

Population means :

DW : 41.4 $\pm$ 2.7 g

LA : 12.27 $\pm$ 1.01 sq dm

NAR : 2.03 g sq dm $^{-1}$ week $^{-1}$

Population C

Including all seedlings at 600m

Poor dry weight and leaf area production

Low net assimilation rate

Population means :

DW : 21.6 ± 2.5 g

LA : 5.95 ± 0.65 sq dm

NAR : 0.72 g sq dm $^{-1}$ week $^{-1}$

In tables 6 and 7, monthly and annual mean temperatures, and annual rainfall are summarised, for the 74 weeks of the experiment. The mean annual temperatures show a similar type of grouping to that found for seedling growth response, whereas rainfall increases more evenly with increase in elevation. Components of the mean annual temperature most important in reducing plant growth are frequent frosts, and their time of occurrence, and the shortness of the growing season. The growing season is defined as a period of time with mean air temperatures greater than 5.5°C (Baker 1950). If the NAR is to be regarded as the most informative parameter of plant growth measured, the relationship between the populations A: B: C is 6: 3: 1. If the length of the growing season alone is considered for these same elevation populations (based on records kept during the experiment), the corresponding ratios for A: B: C are 4: 3: 2. Clearly, the length of the growing season alone is unsufficient to account for all the variation between populations. In addition the number of frost free months (no temperature below 2.2°C) can be considered for each elevation population. For population A, 5 months are frost free; for population B 2 months, and for population C, no months are frost free. For 11 months of the year population C (600m) was likely to receive a heavy frost (less than 0°C), whereas for population B heavy frosts are likely in 9 months of the year, and for population A for 2 months. At 600m air temperatures below -5°C were likely to be received for two months of the year. During the experiment, individuals at 600m were visibly damaged by frost, once through loss of new spring growth, and twice by the loss of mature leaves in autumn. Both these types of damage severely retard growth.

TABLE 6

Mean monthly temperatures (°C) throughout the experiment (October 1970-May 1972) at each elevation.

	Month												
Elevation	J	F	M	A	M	J	J	A	S	O	N	D	Annual
260	15.5	17.1	14.8	13.9	9.6	7.6	6.5	6.4	6.9	9.9	12.3	14.0	11.2
360	13.9	16.1	14.1	11.5	7.6	6.0	4.9	4.3	5.4	7.6	11.0	13.1	9.6
475	14.3	16.1	13.5	11.3	7.2	6.5	6.3	4.7	5.2	7.9	10.8	12.7	9.7
540	13.9	15.9	13.7	11.4	7.1	6.0	5.1	4.5	5.6	7.7	11.2	13.1	9.6
600	12.5	14.5	12.4	7.9	5.2	3.9	3.1	2.3	4.0	5.2	9.3	12.8	7.7

TABLE 7

Mean annual rainfall (mm) over the period of the experiment (October 1970 - May 1972) at each elevation.

Elevation (m)	Annual Rainfall (mm)
260	1424
360	1470
475	1530
540	1730
600	1860

At all population B sites, some autumn purpling of mature leaves was seen with the first heavy frost. However, these leaves survived, (and, presumably, functioned) well into the following summer. During the last ten months of the experiment, minimum temperatures were recorded at ground level, as well as under screens. The ground minimum at 600m when spring growth was killed, was -10°C, though the screen minimum was only -2°C. Likewise, death of mature leaves in autumn occurred when a ground minimum of -12°C was recorded, with a screen minimum of -4°C. Ground minima as low as this were not recorded elsewhere, though -6°C was common during the winter months at population B sites. Ground minima at 260m even in mid-winter, never fell below -4°C; -1°C was the common winter ground minimum here. The fact that low ground and screen minima are not restricted to the winter season over 600m means that tender spring growth, and mature autumn growth, can both experience low temperatures without the gradual acclimatization of gradually lowering minima, which is the usual situation for populations B and A. Thus it appears that the occurrence of unseasonable frosts over 600m may be sufficient to explain the greater reduction in the growth rate of population C seedlings than might be expected from data on the length of the growing season considered alone.

GENERAL DISCUSSION

The three growth populations of *E. delegatensis* described in this paper can be broadly correlated with the length of the growing season and the degree and duration of frostiness in the Surrey Hills area. Both of these factors are directly influenced by the increasing elevation of the sites under study. The boundary between populations is not clearly defined, due to the limited number of sites used. At least one boundary, between populations B and C, corresponds with a change in physiography from a gently sloping N facing basaltic slope, to an undulating poorly drained basaltic plateau. Along this boundary a change in dominant vegetation type also occurs. On the gentle basaltic slope mixed eucalypt-*Nothofagus cunninghamii* forests are the main plant community, whereas on the plateau top though this community type does occur, pure *Nothofagus* rainforest, or *E. delegatensis* grassy woodlands predominate.

Below 300m, *E. delegatensis* becomes increasingly uncommon, being replaced by *E. obliqua*. Also, *Nothofagus cunninghamii* tends to be restricted to valleys below this elevation. Thus, in a general sense, the boundary between populations A and B marks the transition from wet sclerophyll forests dominated by *E. delegatensis*, to those dominated by *E. obliqua*.

The growth responses observed for seedlings of population B are typical of *E. delegatensis* in areas where it is a successful forest dominant. Over 600m, despite its natural occurrence in mixed forest (eucalypt-*Nothofagus*), wet sclerophyll forest and grassy woodland, evidence is present from poor tree form, poor rates of tree growth (based on stem analyses), infrequency of successful seed set and the poor quality of natural regeneration, to support the hypothesis that *E. delegatensis* in this area is growing near the edge of its natural range. The very poor growth of the experimental seedlings of population C lends further support to this hypothesis.

Although there were no differences in dry weight and leaf area production between soil types at the time of the second harvest, evidence from glasshouse trials suggests that ultimately, growth rates on the granitic soil will fall behind those on basaltic soil. The equal, and occasionally superior, rates of establishment of *E. delegatensis* on granitic soil is an observation of importance in terms of forest management. Much poor tree form and heart rot, which make trees unsuitable for timber production, are probably initiated very early in tree growth, often by heavy insect attack. Vigorous early growth, even on a poor soil type, may counteract the effects of insect damage, so that ultimately good quality timber is produced, although taking longer to reach maturity than on more nutrient-rich soils.

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