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Annual Report on Progress of Geoff Stoneman Towards the Degree of Doctor of Philosophy at Murdoch University on the Topic

'Factors Affecting the Germination, Establishment, Survival, Growth and Form of *Eucalyptus marginata* Seedlings'

A series of field experiments were established in winter 1989 (see attached Research Project Plan). Results from the emergence phase of these experiments are reported in the attached paper 'Factors affecting the emergence of jarrah (*Eucalyptus marginata* Donn. ex Sm.) seedlings in the northern jarrah forest of Western Australia'. One of the major findings was that there was a great deal of seed harvesting by vertebrates. This has impacted on my plans for the future of the field experiment because as a result of seed harvesting there was not enough emergents on some sites to do the planned series of harvests. I now plan to reestablish these experiments in autumn 1990 with bird netting over all plots. Consequently, I will only be able to look at survival and growth in the following 18 months and not 30 months as previosly planned. However, I will be able to contrast seasonal effects on the two sets of emergence, growth and survival data.

The first of a series of glasshouse experiments was on the effect of soil temperature and soil type. Results are reported in the attached paper 'Effect of soil temperature and soil type on growth of jarrah (*Eucalyptus marginata* Donn. ex Sm.) seedlings'. I am awaiting results of chemical analysis of the soils to complete the paper. I had intended to compare three soils, but unfortunately the bauxite pit site was fertilised and it was pointless to include that soil in the experiment.

Further laboratory studies will investigate the effects of water supply and water relations on the growth of jarrah seedlings (winter/spring 1990). The effects of soil nutrition and light may follow. I also intend to do laboratory experiments on the effect of temperature and moisture on germination of jarrah seed.

The effects of soil temperature and soil type on the growth of jarrah (*Eucalyptus marginata* Donn ex Sm.) seedlings.

Abstract

The effects of soil temperature and soil type on the growth of jarrah (*Eucalyptus marginata* Donn ex Sm.) seedlings was studied experimentally in a glasshouse on plants grown for 33 days. Both soil temperature and soil type had significant effects on the growth of the seedlings. Total plant growth was highest at 25-35^{0}C and on the P soil. Root growth was less on the P soil and higher at soil temperatures of 25-30^{0}C. Above ground growth was highest on the P soil and at soil temperatures of 25-35^{0}C. The optimum soil temperature for growth of jarrah seedlings is quite high in comparison to other temperate tree seedlings. Cotyledon growth was independent of soil temperature. Low and high soil temperatures resulted in smaller root:shoot ratio's because more of the plant biomass was accumulated in the cotyledons than in other plant parts at these soil temperatures.

Total root length was strongly related to root dry weight for plants grown at 20-35^{0}C, but those grown at 15^{0}C had less total root length for a given root dry weight. The maximum relative growth rate of jarrah seedlings was

similar to that of other species generally considered to be faster growing.

The optimal soil temperatures found in this study are unlikely to occur when soil water is readily available in the northern jarrah forest. Treatments to jarrah forest stands which increase soil temperature when soil water is available will increase the growth rate of jarrah seedlings.

Introduction

The northern jarrah (*Eucalyptus marginata* Donn ex Sm.) forest of Western Australia experiences a mediterranean climate with hot dry summers and cool wet winters (Gentilli 1989). Jarrah seed germinates in the forest in the cool wet winter months (Abbott 1984). Mortality of seedlings is greatest in the first year before a lignotuber has developed and after that survival is high (Abbott 1984, Abbott and Loneragan 1986). Growth of the seedling in the nutrient deficient soil (Havel 1975) is slow and 15 - 20 years usually elapses before the ground coppice stage is reached (Abbott and Loneragan 1984), although the growth rate of seedlings can be increased by fertilising (Abbott and Loneragan 1986, Barrow 1977, Dell *et al.* 1983, Dell *et al.* 1985, Koch *et al.* 1988, Wallace 1978, Wallace *et al.* 1986). Growth of the ground coppice into a sapling may then occur if conditions are suitable

(Abbott 1984) as the ground coppice has developed a substancial root system which enables it to remain physiologically active over the summer drought (Abbott and Loneragan 1986). Root growth follows a seasonal pattern with most growth in May/June and September/October (Dell and Wallace 1983) when soils are moist and soil temperatures moderate. Dell and Wallace (1983) also observed rapid root growth in February, when soil temperature is high (Shea 1975, Shearer and Tippett 1989), following unseasonal rainfall. Thus, three major environmental factors; nutrients, water and soil temperature; are known to affect the growth and development of jarrah.

For many other tree species soil temperature has been shown to affect the growth of roots (Andersen *et al.* 1985, Barney 1951, Bowen 1970, Deans 1979, Grant and Byrt 1984, Grossnickle 1987, Hellmers 1963, Heninger and White 1974, Kaufmann 1977a, Kuhns *et al.* 1985, Larson 1967, Nambier *et al.* 1979, Rook and Hobbs 1976, Teskey and Hinkley 1981, Tryon and Chapin 1983), shoots (Andersen *et al.* 1987, Brand and Janas 1988, Heninger and White 1974, Kaufmann 1977a) and the root:shoot ratio (Heninger and White 1974, Barney 1951). However, there has been only one study on the effect of soil temperature on root growth of eucalypts (Grant and Byrt 1984) and no studies on the effect of soil temperature on the shoot growth or root:shoot ratio of eucalypts.

The soil temperature regime in the jarrah forest varies from site to site because of differences in factors such as canopy and litter cover, aspect and slope (Christensen 1975, Shea 1975, Shearer and Tippett 1989). Therefore, forest operations may affect the soil temperature regime at a given site by changing canopy or litter cover and fire can also change the soil temperature regime of a site for several years (Raison *et al.* 1986).

In this experiment the effects of five soil temperatures and soil from two site-types on the growth and development of jarrah seedlings is investigated.

Methods

Havel (1975) has described characteristics of site-types in the northern jarrah forest. 'T' site-types generally regenerate readily whereas regeneration of jarrah on 'P' site-types is much more variable.

The experiment was designed to examine the effect of (i) soil temperature; 15^{0}C, 20^{0}C, 25^{0}C, 30^{0}C and 35^{0}C: and (ii) soil from two site-types; a 'T' and a 'P' site-type: on the growth and development of jarrah seedlings. Thus, there were 10 treatments with five replicates of each for each of four harvests in a randomised block design. Pots were randomly allocated to a position in the soil cooling/warming tank and these positions were randomly changed on a weekly basis.

The experiment took place in a glasshouse. Daily minimum air temperature ranged from 11°C to 21°C and daily maximum air temperature ranged from 27°C to 37°C. There was a general trend of increasing air temperature over the course of the experiment due to prevailing weather conditions.

The experiment was designed to give four harvests of the plant material, at (i) day 15 i.e. 15 days after sowing, (ii) day 21, (iii) day 27 and (iv) day 33. The height of all seedlings was measured prior to a harvest. Plants were harvested by washing the soil from the pot, thus leaving the roots and top behind. Taproot length was measured with a rule as the length from the root collar to the end of the longest root, the roots were then cut up and total root length estimated using a Comair root length machine. The tops of the plants were divided into (i) stem + leaves and (ii) cotyledons. Dry weight was measured after the plant material had been oven dried at 70°C for 24 hours.

Soil was collected from the top 15 cm of each site type, sieved through a 4 mm sieve and air dried for 10 days in a plastic tunnel hot house. 1580 g of soil was placed into a plastic liner inside each pot. The pots were made of PVC sewer pipe and had a diameter of 82 mm and a depth of 232 mm. The pots were sealed at the base.

Jarrah seed (Department of Conservation and Land Management seed-lot D797) was sieved and seed from the 2.0 mm - 2.8 mm size class was germinated in aerated deionised water in a flask in the laboratory. The seed was sorted into two groups depending on how well advanced germination was. One of the more advanced germinants (radicle ~ 3 mm) and two of the less advanced germinants (radicle ~ 1 mm) were sown in each pot on 19/10/1989 (day 0) at a depth of 7 mm and covered with soil. The soil was watered and pots covered with paper to reduce evaporation until seedlings emerged. The pots had been previously placed in the soil cooling/warming tanks several days previously to allow the soil to stabilise at the pre-determined temperature. Seedlings were thinned to one per pot on day 11.

The pots were watered to 90% of field capacity of the soil, by weighing, once each week. The soil was watered every other day to keep the topsoil moist.

Soil nutrition ....

Data were analysed using the ANOVA and REGression procedures of the SAS statistical package (SAS 1985).

Results

Plant growth

Above ground growth

Plants grown on the P soil had significantly more above ground biomass at day 15, 21, 27 and 33 than the plants grown on the T soil (Figure 1 and Table 1). There was significantly higher above ground biomass at temperatures of 25^0-35^0 at day 21, 27 and 33.

The cotyledons responded differently to soil temperature than did the stem + leaves. Temperature did not have a significant effect on the growth of the cotyledons, unlike all other plant parts (Table 1). Cotyledon dry weight was significantly higher for the P soil than the T soil at day 15, 21, 27 and 33 (Figure 2 and Table 1).

There was significantly higher dry weights of stem + leaves on the P soil than on the T soil at day 15, 21, 27 and 33 (Figure 3 and Table 1). Ther were significant effects of temperature on dry weight of stem + leaves at day 15, 21, 27 and 33. Maximum dry weight of stems + leaves was attained at 30^0-35^0C.

Below ground growth

There were lower root dry weights on the P soil than the T soil at day 15 but not at later harvests (Figure 4 and Table 1). Temperature had significant effects on root dry weight at day 15, 21, 27 and 33 with maximum root dry weight being attained at 25^0-30^0.

Temperature had a significant effect on taproot length with longer taproots being grown at 20^0-30^0C than at 15^0 or 35^0C (Figure 5 and Table 1). Soil type did not affect total root length (Figure 6 and Table 1). Temperature had a significant effect on total root length at day 15, 21, 27 and 33 (Figure 6 and Table 1). Maximum root length was achieved at 25^0-30^0C.

Total plant growth

There were significantly higher dry weight's on the P soil than the T soil at day 27 and 33 (Figure 7 and Table 1). Temperature had a significant effect on total dry weight at day 21, 27 and 33 with maximum dry weight being attained at 25^0-35^0C.

The cotyledons initially accumulate most biomass followed by the roots and then the stem + leaves (Figure 8). The cotyledons continued with a steady rate of biomass accumulation over the period of the experiment, whereas roots accumulate biomass at an increasing rate and stems

+ leaves accumulate biomass at an exponentially increasing rate. By day 33 biomass is being distributed preferentially to the stem + leaves, then the roots and then the cotyledons.

Root:shoot ratio

The root:shoot ratio was significantly higher on the T soil than the P soil at all harvests (Figure 9 and Table 1) i.e. plants on the T soil allocated relatively more of their dry matter to roots than to shoots than did plants on the P soil. Temperature had a significant effect on the root:shoot ratio at each harvest. Temperatures of 20^0-25^0 resulted in higher root:shoot ratio's than temperatures of 15^0 or 30^0-35^0. The root:shoot ratio was more responsive to temperature for plants grown on the T soil than for plants grown on the P soil.

Relationship between total root length and root dry weight

For the regressions between total root length and root dry weight at the five soil temperatures (Figure 10) the regression for the plants grown at 15^0C is significantly different ($p=0.0418$) to the regression for all other soil temperatures. There are no significant differences between any of the other regressions. Thus, for plants grown at soil temperature from 20 - 35^0C total root length can be estimated from root dry weight. Plants grown at

15^{0}C have less total root length for a given root dry weight.

Relative growth rates

Both time since emergence and soil temperature affect the relative growth rate, with relative growth rate being maximal (0.15) during days 15 - 21 at a soil temperature of 30^{0}C (Table 2).

Discussion

The optimal soil temperature for growth of jarrah roots in this experiment i.e. 25 - 30^{0}C, is similar to the optimum of 28 - 31^{0}C found for root extension rates for jarrah and marri (*E. calophylla*) by Grant and Byrt (1984). These temperatures are quite high in comparison with those reported for other species. Optimal soil temperature for *Pinus taeda* root growth was 25^{0}C (Barney 1951), 23^{0}C for *P. ponderosa* (Larson 1967), 19^{0}C for *Picea glauca*, 27^{0}C for *Pinus banksianna*, 15 - 27^{0}C for *Pseudotsuga menziesii*, 23^{0}C for *Betula papyrifera* and 19^{0}C for *Ailanthus altissima* (Heninger and White 1974). Kaufmann (1977a) found 15^{0}C to be optimal for two-year-old *Pinus radiata* whilst Nambiar *et al.* (1979) found that root growth increased as soil temperature increased over the range 5 - 20^{0}C for 8-month-old *P. radiata*.

The optimal soil temperature for growth of jarrah shoots in this experiment i.e. 30^{0}C, is also quit high in comparison to that found for other tree species. Heninger and White (1974) found 19^{0}C optimal for *Picea glauca* and *Ailanthus altissima*, 27^{0}C for *Pinus banksianna*, 15 - 27^{0}C for *Pseudotsuga menziesii* and 31^{0}C for *Betula papyrifera*. For *Pinus radiata* 15^{0}C was optimal for needle and terminal leader extension (Kaufmann 1977a). Shoot growth has been found to be more responsive to air temperature than to soil temperature in some studies (Larson 1967, Hellmers 1963).

The effect of temperature on root:shoot ratio is similar to that reported for *Pseudotsuga menziesii* and *Betula papyrifera* (Heninger and White 1974) i.e. root:shoot ratio is small at low and high temperatures and largest at intermediate temperatures. *Pinus taeda* (Barney 1951) and *Picea glauca* (Heninger and White 1974) showed the opposite pattern i.e. root:shoot ratio was small at intermediate temperatures and large at low and high soil temperatures. The results for jarrah also conflict with the conclusion of Cooper (1973), who in a review of the effects of soil temperature on plant growth concluded that the root:shoot ratio is largest at high and low soil temperatures, with a minimum in the range 20 - 25^{0}C. The reason for jarrah's root:shoot ratio being small at low and high soil temperatures was because cotyledon dry weight was independent of soil temperature and at low and high soil temperatures more of the plant dry weight was accumulated in the cotyledons and less in other plant parts. At later stages of plant growth when the cotyledons are insignificant the response of root:shoot ratio to soil temperature may be quite different.

The response in plant growth to soil temperature is likely to be related to a number of physiological factors. Low soil temperatures increase root resistance to water uptake (Kaufmann 1977b, Running and Reid 1980), increase plant water stress (Kaufmann 1977a,b), reduce transpiration (Babalola *et al.* 1968, Rook and Hobbs 1976) and reduce photosynthesis (Turner and Jarvis 1975, Babalola *et al.* 1968, Rook and Hobbs 1976, Lawrence and Oechel 1983). Reductions in photosynthesis at low temperature can be attributed to cold soils reducing water transport in roots, which increases root resistance and the viscosity of water, which in turn results in greater water stress and potential stomatal closure (Lawrence and Oechel 1983a). Uptake of phosphorus is also low at low soil temperatures (Apple and Butts 1953, Power *et al.* 1963). At high soil temperatures increased root respiration may reduce root growth (Hermann 1977, Lawrence and Oechel 1983b).

Nielsen and Humphries (1966) found that roots are generally thicker at low temperatures. This also seems to be true for jarrah roots as plants grown at 15^{0}C have less total root length for a given root dry weight.

The pattern of biomass accumulation (Figure 8) shows that jarrah has a similar pattern to that reported for *E. pilularis* by Mulligan and Patrick (1985a), except that the early exponential growth of cotyledons was not observed. This may be because the sampling interval was too long to determine a short period of exponential growth in the jarrah experiment. *E. pilularis* cotyledons rapidly developed photosynthetic capacity and were the major sink for assimilated phosphorus in the first week (Mulligan and Patrick 1985a). They then became phosphorus exporters to enable growth of other parts when phosphorus supply was limited. The cotyledons made an essential contribution to the growth of the *E. pilularis* seedlings up to about day 32 (Mulligan and Patrick 1985a), increased their leaf area up to about day 45 and dissappeared by about day 130 (Mulligan and Patrick 1985b). Field observations (Stoneman unpublished data) indicate that the longevity of jarrah cotyledons is at least as long as those of *E. pilularis*. There have been no studies on the role of jarrah cotyledons in photosynthesis and mineral nutrition of the seedling, however from the pattern of biomass accumulation it seems likely that jarrah cotyledons will be important for both the storage and subsequent provision of reserve materials and the development of photosynthetic capacity.

The early growth of jarrah cotyledons seems to be genetically controlled as dry weight of the cotyledons did not respond to soil temperature. However, total dry weight did respond to soil temperature, thus the jarrah seedlings had to change their biomass distribution pattern so that cotyledon growth could continue unabated. At the low and high soil temperatures a larger proportion of total biomass was allocated to cotyledons than at the intermediate soil temperatures. This is also why the root:shoot ratio is small at low and high soil temperatures.

The maximum relative growth rate of the jarrah seedlings (0.15) is similar to the maximum relative growth rate for *E. pilularis* (0.17) (Mulligan and Patrick 1985a), and *E. grandis* (0.205) (Doley 1978). This is greater than the relative growth rate for many temperate zone tree species (Jarvis and Jarvis 1964, Grime 1966, Pollard and Wareing 1968, Loach 1970, Grime and Hunt 1975) and similar to the relative growth rate of some tropical tree species (Coombe and Hadfield 1962, Okali 1971, Ampofo and Lawson 1972). A repeat of this experiment with more frequent harvests may well find the maximum relative growth rate of jarrah is higher than that found in this study.

The highest growth rates of jarrah seedlings are at relatively high soil temperatures, which will usually be experienced in the northern jarrah forest when soil water is limiting to plant growth. The mediterranean climate of the northern jarrah forest is characterised by strongly seasonal patterns in climatic variables. About 80 per cent of rainfall falls between May and October with little over the summer months. Evaporation has the opposite pattern with 80 per cent between November and April. Soil temperature is at a minimum of about 10^0C in winter and at a maximum of about 20^0C in summer (for a stand with 60 per cent canopy cover and soil temperature measured at 25 cm depth)(Shearer and Tippett 1989). Soil temperatures of about 27^0C (at 25 cm depth) may be reached where there is little canopy cover (Shearer and Tippett 1989) and soil temperatures of 35^0C may be reached at 7.5 cm depth in openings (Shea 1975). Soil water content peaks in late winter / early spring following the winter rains and reaches a minimum in autumn before the winter rains recommence (Sharma *et al.* 1982, Schofield *et al.* 1989). Soil water is near wilting point for many months over the summer drought period. Thus, in summer when soil temperatures are optimum for growth of jarrah seedlings soil water is usually limiting to plant growth and so the growth rates observed in this experiment are unlikely to be found in the forest.

Treatments to jarrah forest stands which increase soil temperatures, particularly in spring / early summer and late autumn / early winter when soil temperatures are moderate (Christensen 1975, Shea 1975, Shearer and Tippett 1989) and soil water readily available (Sharma *et al.* 1982), will increase the growth rate of jarrah seedlings. Thus, reducing canopy, understorey or litter cover by logging, clearing or burning will increase soil temperature (Christensen 1975, Raison *et al.* 1986, Shea

1975, Shearer and Tippett 1989) and increase the growth rate of jarrah seedlings. Similarly, the growth rate of jarrah seedlings will be greater on warmer sites such as those with north facing slopes (Shea 1975).

Response to soil nutrition.....

Acknowledgements

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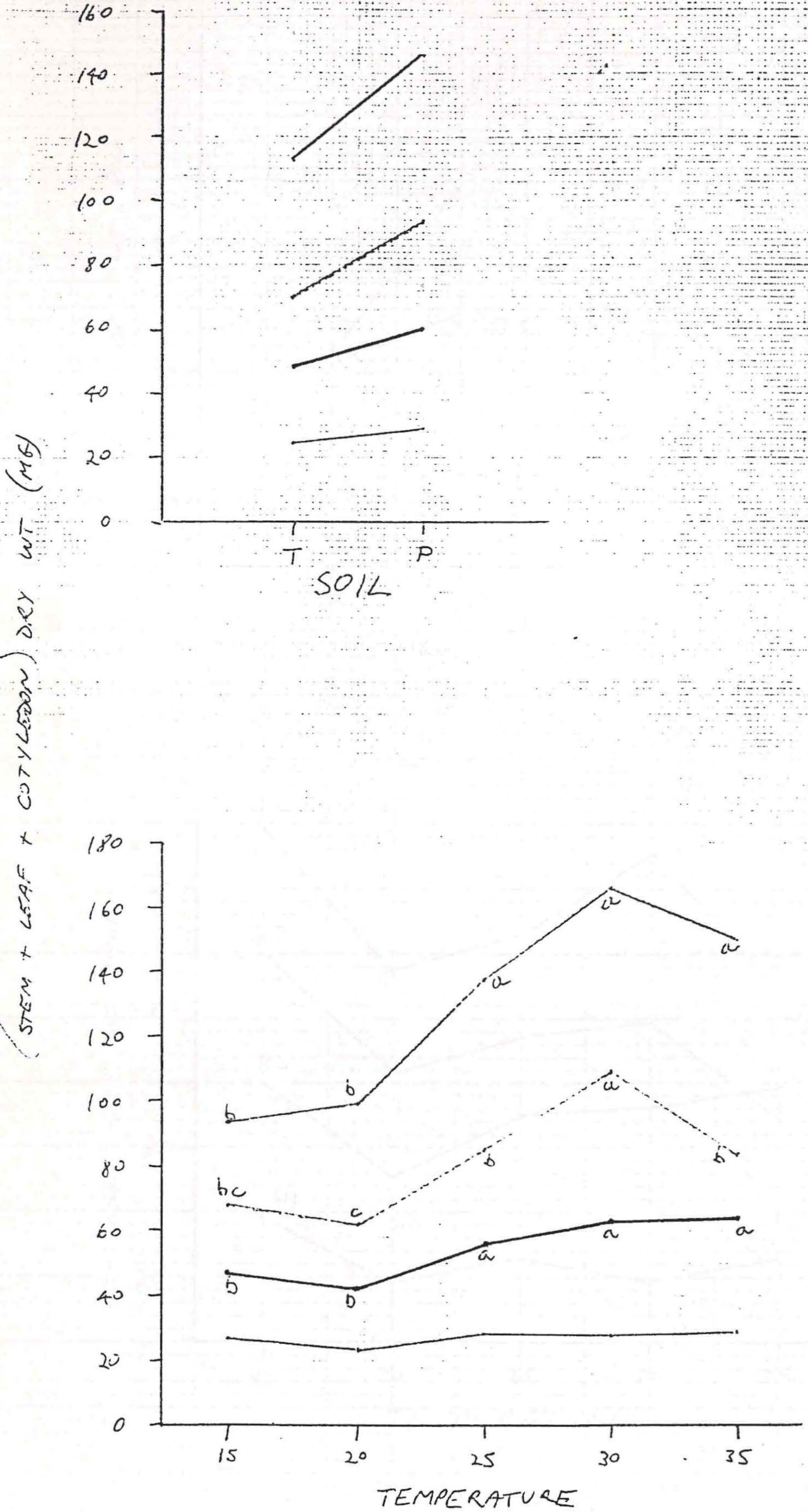
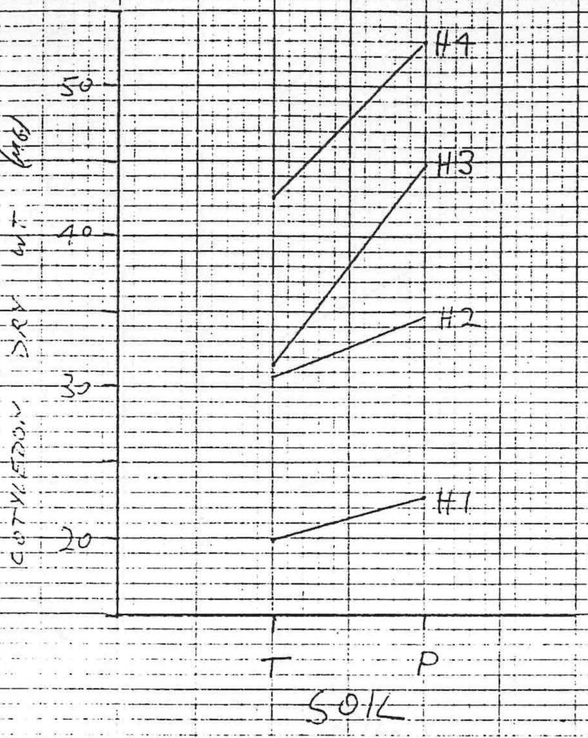
Table 1: Summary of statistical analysis of the effects of soil type (S) and soil temperature (T) on plant parts.

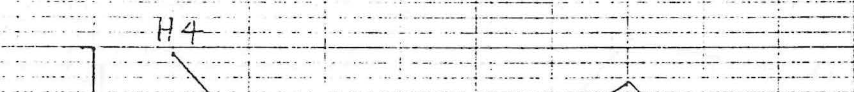
Dependent variable		Response to variable		
		S	T	S*T
Above ground dry weight	@ day 15	.0097	ns	.0375
	@ day 21	.0001	.0001	ns
	@ day 27	.0003	.0001	ns
	@ day 33	.0005	.0001	ns
Cotyledon dry weight	@ day 15	.0276	ns	.0132
	@ day 21	.0323	ns	ns
	@ day 27	.0003	ns	ns
	@ day 33	.0056	ns	ns
Dry weight of stem + leaves	@ day 15	.0360	.0001	ns
	@ day 21	.0001	.0001	ns
	@ day 27	.0039	.0001	ns
	@ day 33	.0007	.0001	ns
Dry weight of roots	@ day 15	.0021	.0322	ns
	@ day 21	ns	.0001	.0006
	@ day 27	ns	.0046	ns
	@ day 33	ns	.0008	ns
Taproot length	@ day 15	.0216	.0001	ns
	@ day 21	ns	.0001	.0297
	@ day 27	.0113	.0001	ns
	@ day 33	ns	.0001	.0001
Total root length	@ day 15	ns	.0001	ns
	@ day 21	ns	.0001	.0027
	@ day 27	ns	.0001	ns
	@ day 33	ns	.0001	ns
Total dry weight	@ day 15	ns	ns	.0353
	@ day 21	ns	.0001	ns
	@ day 27	.0162	.0006	ns
	@ day 33	.0097	.0001	ns
Root to shoot ratio	@ day 15	.0001	.0064	ns
	@ day 21	.0002	.0001	.0001
	@ day 27	.0001	.0001	.0005
	@ day 33	.0004	.0002	.0309

Table 2: Effect of soil temperature (^{0}C) and time since emergence (days) on relative growth rate (g g^{-1} day^{-1}) of dry weight of jarrah seedlings.

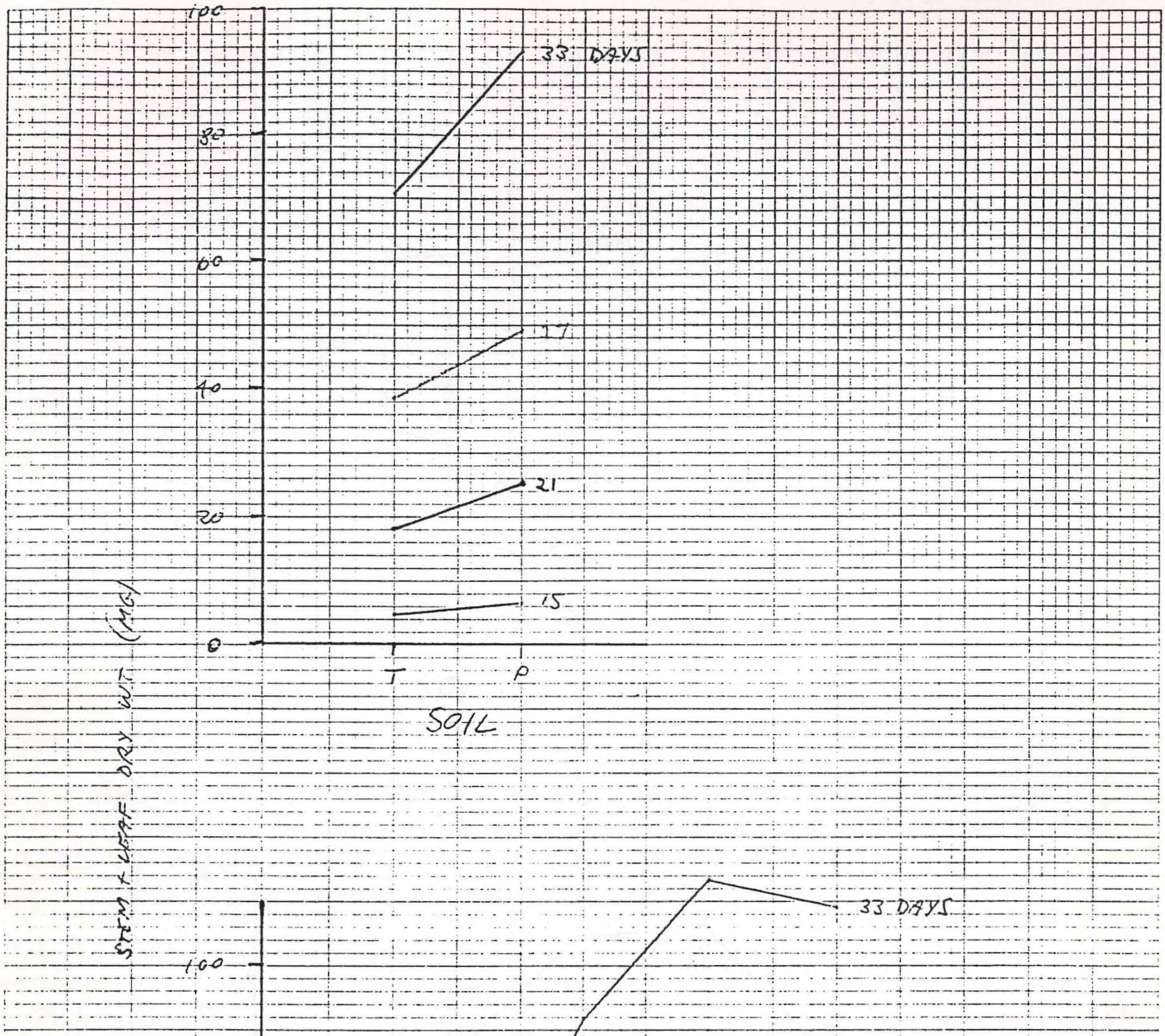
Time since	Soil temperature				
emergence	15	20	25	30	35
15 - 21	0.07	0.11	0.13	0.15	0.14
21 - 27	0.05	0.06	0.05	0.07	0.04
27 - 33	0.05	0.07	0.09	0.07	0.10


Shoot
(STEM + LEAF + COTYLEDON) DRY WT (MG)
160
140
120
100
80
60
40
20
0
T
P
SOIL
180
160
140
120
100
80
60
40
20
0
a
a
a
b
b
a
b
b
c
bc
a
a
a
b
b
15
20
25
30
35
TEMPERATURE

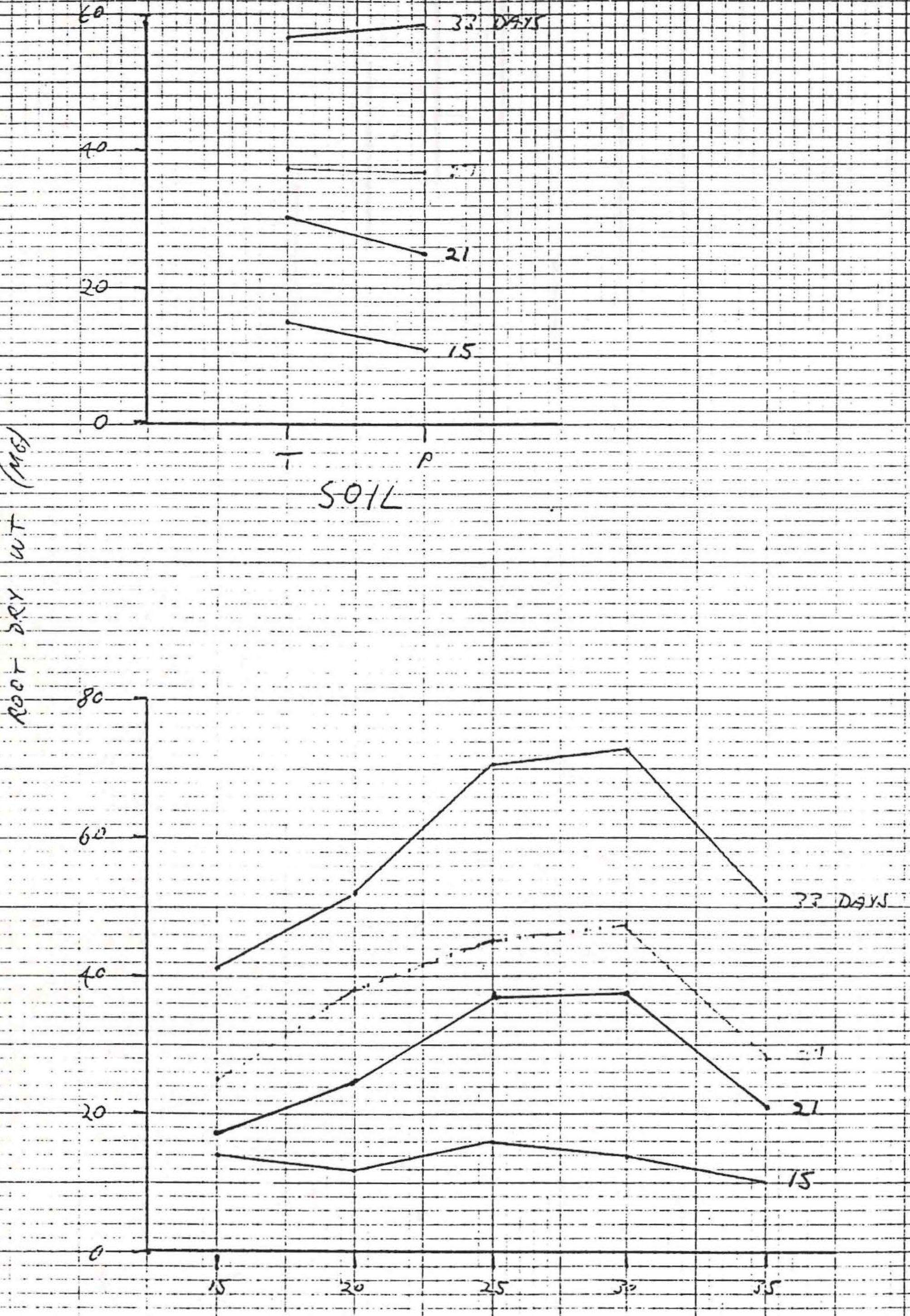

COTYLEDON DRY WT (MG)
50
40
30
20
H4
H3
H2
H1
T
P
SOIL


COTYLEDON DRY WT (MG)
50
40
30
20
H4
H3
H2
H1
15
20
25
30
35
TEMPERATURE

2


100
80
60
40
20
0
33 DAYS
27
21
15
T
P
SOIL
STEM + LEAF DRY WT. (MG)
100
80
60
40
20
0
33 DAYS
21
15
15
20
25
30
35
TEMPERATURE

3


60
40
20
0
33 DAYS
27
21
15
T
P
SOIL
ROOT DRY WT (MG)
80
60
40
20
0
33 DAYS
27
21
15
15
20
25
30
35
TEMPERATURE

Q 4

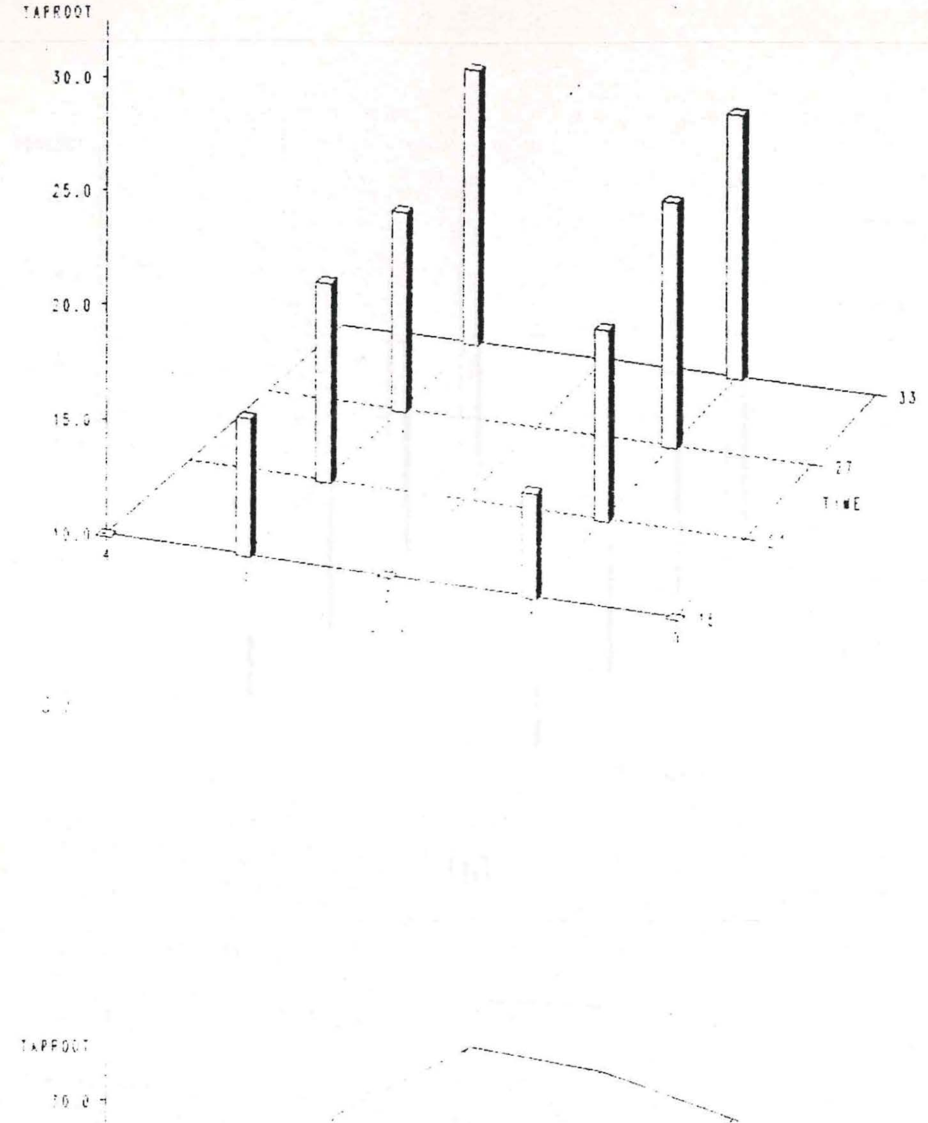


Figure ~~4~~5: Response of taproot length (mm) to (a) soil type and time (days), and (b) soil temperature (C) and time (days)

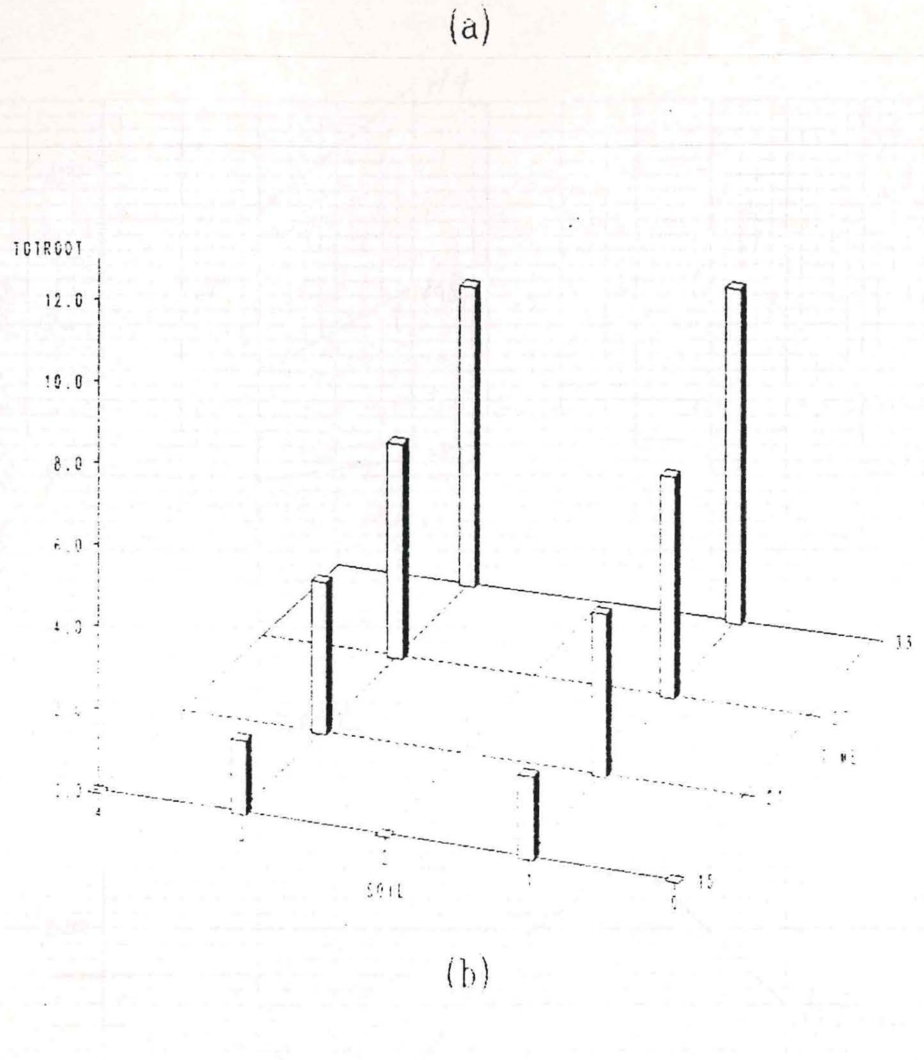
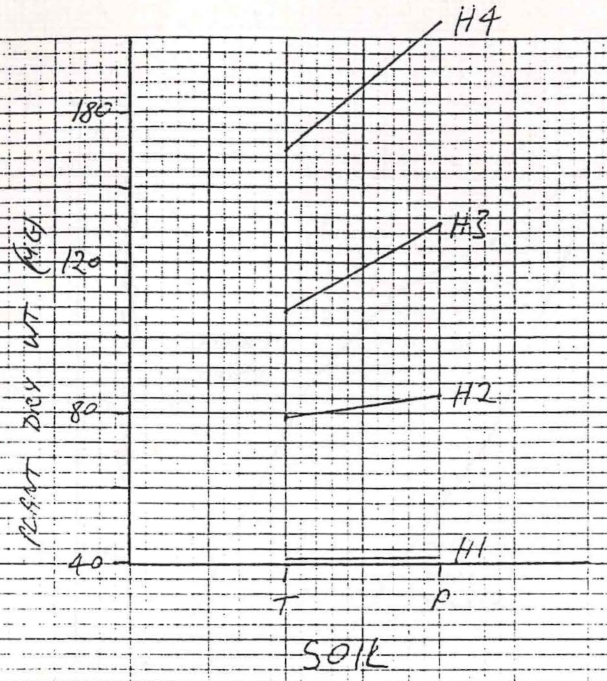
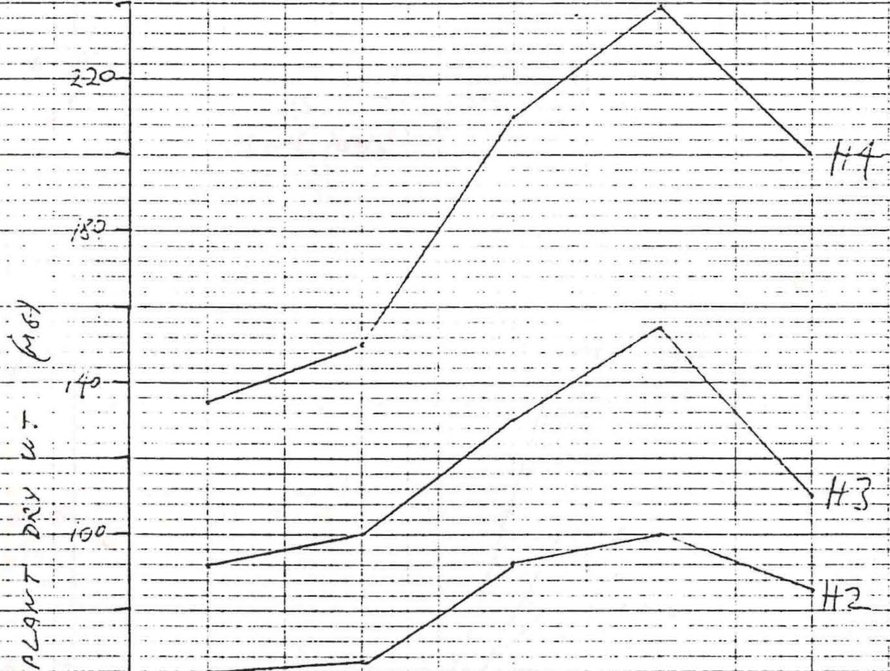
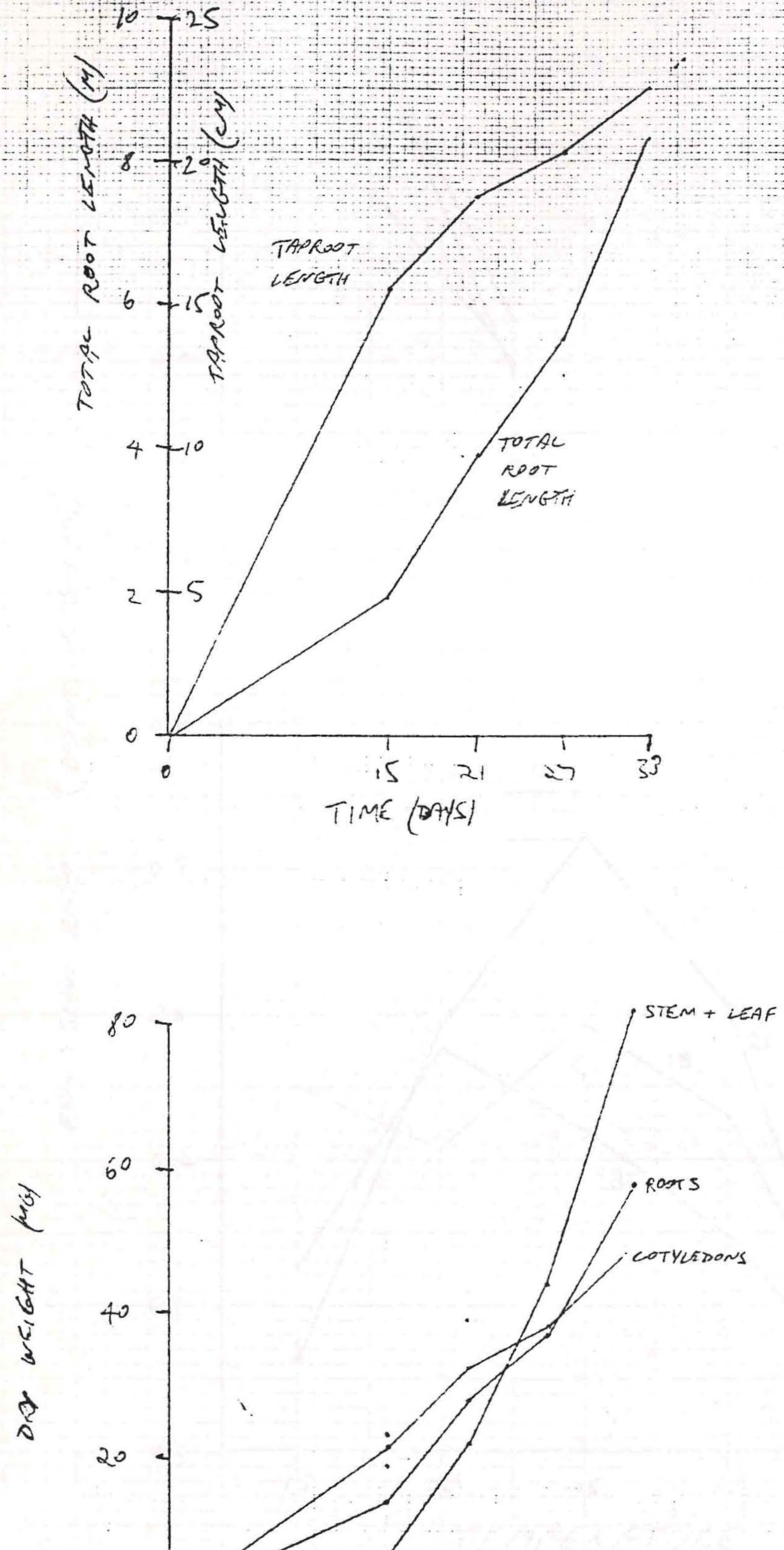


Figure 6: Response of total root length (m) to
(a) soil type and time (days), and
(b) soil temperature (C) and time (days).


H4
180
H3
120
PLANT DRY WT. (MG)
H2
80
H1
40
T
P
SOIL

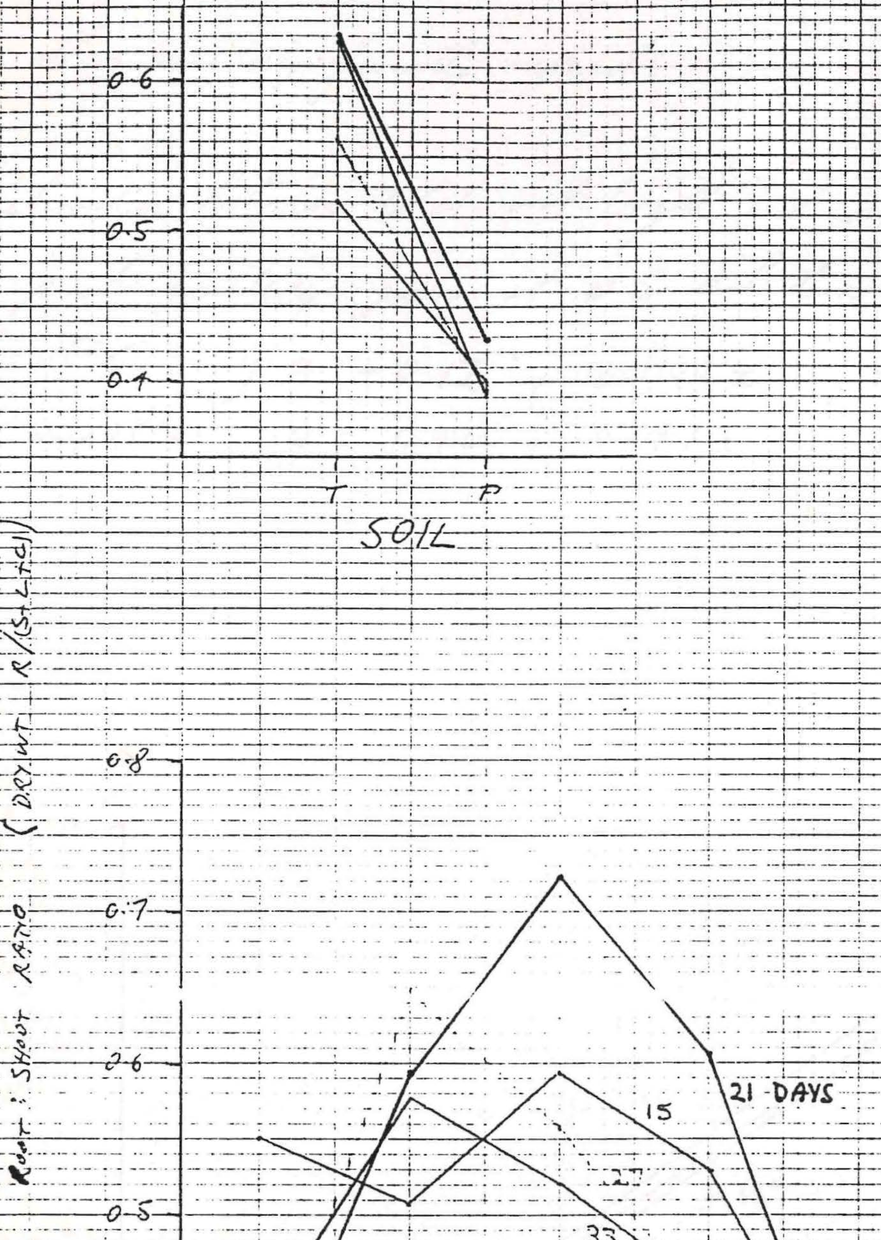

220
H4
180
PLANT DRY WT. (MG)
140
H3
100
H2
60
H1
20
15
20
25
30
35
TEMPERATURE

7



Are these curves different if not simply put whole shoot / or plant.

Fig 8


0.6
0.5
0.4
T
P
SOIL
ROOT : SHOOT RATIO (DRY WT R/(S+L+C))
0.8
0.7
0.6
0.5
0.4
0.3
21 DAYS
15
27
33
15
20
25
30
35
TEMPERATURE

9

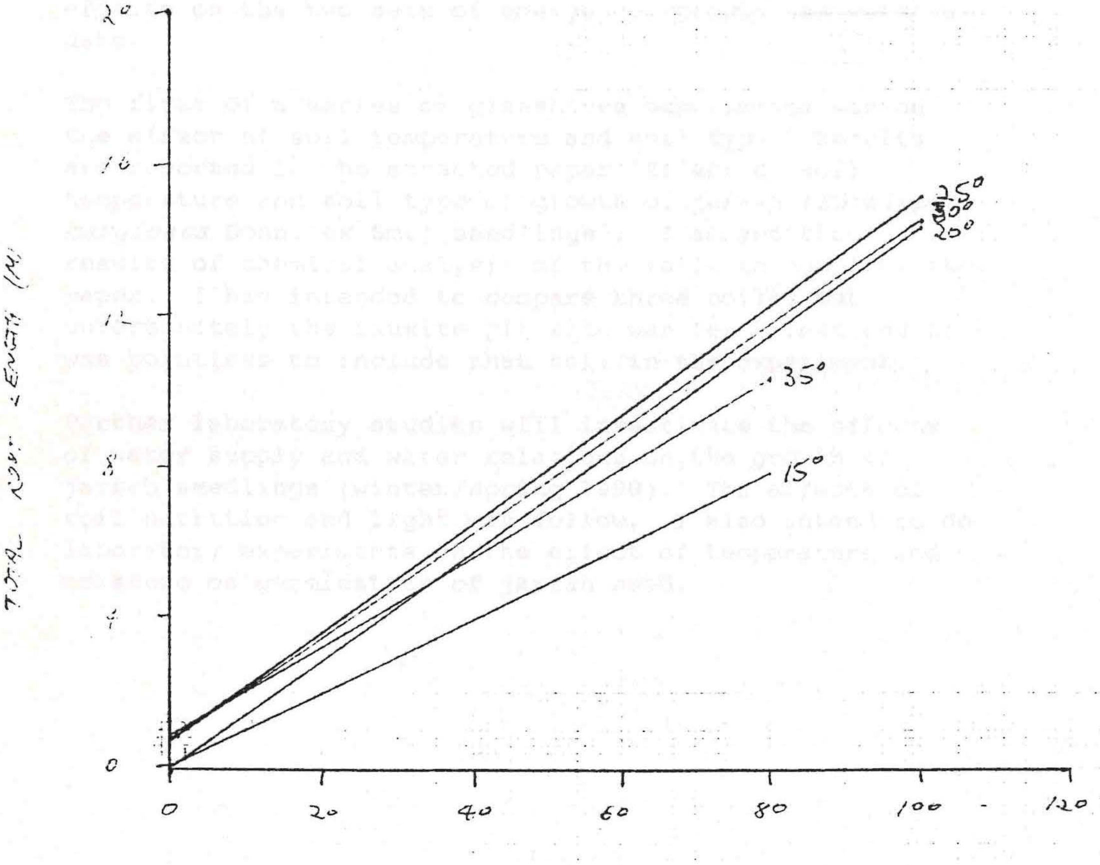
Slope of 15° regression is significantly different to rest of data ($p = 0.048$)

No others are significantly different.

Fig 10: Relationships between total root length (cm) and root dry wt (g) for jarrah seedlings grown at 5 soil temperatures.

For 15°C $y = -0.12 + 0.099x$ $r^2 = 0.90$

For 20-35°C $y = 0.46 + 0.141x$ $r^2 = 0.88$



? give equations in text & delete the Fig