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The effect of site factors on the growth of *Eucalyptus regnans* in Kinleith Forest.

Interim Report

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[1]Soils and Site Productivity Group
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Report 17 June 1993

Confidential to Participants of the Management of Eucalypts Cooperative

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INTRODUCTION.

New Zealand only has a small planted resource of eucalypts, the total area planted being approximately 15,000 hectares. Large scale plantings of eucalypts occur in other countries such as Brazil, South Africa and Australia, and these plantings are commonly of high production value. In New Zealand comparable uniformly high levels of productivity have not been achieved. Growth has been characterised by considerable variability, even within the same stand, and generally lower than expected productivity.

A number of eucalyptus species are planted in New Zealand, the most common being *E. regnans*, with approximately 8000 hectares established, with 80% of the resource concentrated in the Bay of Plenty region. Growth of regnans varies over the region, however of more concern is the large variation in growth within stands, where considerable fluctuation in basal area and height has been recorded over short distances. Such variation within stands poses problems for management of the stands as a production unit, and the variation at a scale of less than 100 hectares was addressed in this study. While variation in growth can be caused by a number of factors such as disease, genetic characteristics of the trees, or silvicultural history; it appears that in this instance it is the environment into which regnans has been planted that is the cause of much of the noticed variation in growth. One dominant factor appears to be aspect (R. van Rossen *pers. comm.* 1991), and another landform. The study is being conducted as part of the research program of the Eucalypt Management Co-operative.

Conditions for growth of *Eucalyptus regnans* both naturally and in plantations has been summarised by Turnbull and Pryor (1984). It occurs naturally in Victoria and Tasmania between latitudes 37 and 48°S, the altitudinal range is 120-1100m in Victoria and 30-610m in Tasmania. The range of natural climatic conditions is narrow. Cochrane (1969) summarised these conditions as a moist environment with mean annual rainfall of over 1200 mm, with a winter maximum, absence of long periods of water stress, shelter from strong winds and free air drainage to reduce the effects of frost. Best development occurs on deep fertile loamy soils which are moist and well drained, regnans does occur also on podsols, upland and mountain podsols and kraznozems. Where soil fertility and rainfall is lower stands may be confined to valleys and along water courses. It grows poorly on permanently saturated sub soils. Ellis (1968) showed regnans to be more sensitive to site conditions than *E. obliqua, E. sieberi*, or *E. radiata*.

Regnans has been planted in trials at high altitude in a number of tropical countries and also in South Africa, Brazil and Zimbabwe. However, despite the good performance of some trials other species with a wider tolerance of site conditions have been selected for commercial planting except in New Zealand (Lembke 1977). This suggests that the variation in growth noted in New Zealand plantations is not unexpected.

The climate of regnans' natural habitat is similar to New Zealand's (James 1988) and its New Zealand site range includes most of the North Island south of Auckland, and the Nelson, Westland, Canterbury and Otago regions in the South Island. Most important site characteristics appear to be a sloping site with adequate moisture all year, good soil drainage and protection from salt winds.

Poole (1979) reported on *E. regnans* established in Kinleith forest. Ideal sites would be north facing sheltered slopes with good air drainage, if possible the sites should have a history of grazing and a good sward of legumes. However he suggested that no such sites were available and so the company endeavoured to find the best compromise when establishing *E. regnans*.

It is clear that in the following years regnans was planted on the best available sites, but that based on assessment of growth even these sites appeared to be unacceptably variable. Reasons for this variability were sought by the members of the Eucalypt Management Co-operative and interim results of the ensuing research are reported here.

METHODS

• **Site Description and Stand Histories**. Sites were chosen in four blocks of Kinleith Forest located within 10 km north of Tokoroa (Figure 1). Topography was mainly rolling with short slopes of about 20 degrees. Altitude was approximately 850 ft.a.s.l. The Kinleith area has a mean annual rainfall of 1508 mm, uniformly distributed throughout the year. All areas accessible to a bulldozer had been v-bladed and mounded after clearfelling the previous crop. Stands were planted in 1980 with *E. regnans* seedlings of Franklin seed origin. Initial stocking ranged from 1152 to 1496 s.p.ha. It is likely that an initial 30g of Urea was applied per tree on the plant line and another 60 g between the lines. An aerial application of 250 kg Urea ha^{-1} was applied in the second growing season.. Stocking was reduced to between 650 and 712 s.p.ha. by thinning at age 3. The ranges in initial stocking and thinning intensity depended on stand.

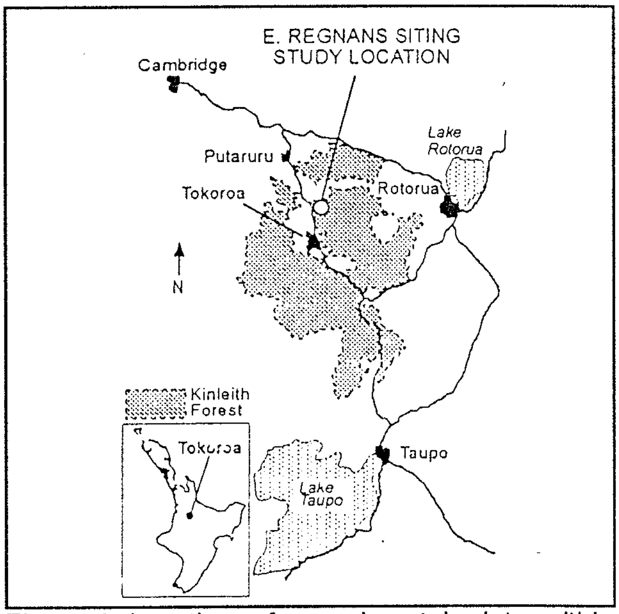

Figure 1 Location of experimental plots within Kinleith Forest.

• **Plot Selection**. Forty six circular plots (each 0.04ha) were established over a range of sites covering different aspects, slopes, altitude and crown health amongst the 4 blocks.

• **Plot description**. A description was made of the understorey, noting the proportion of cover by the main species. Landform (crest, topslope, midslope, lowerslope, terrace, basin), aspect, slope, topex (elevation angle to horizon), tree crown health (1-5, best to worst) and presence of v-bladed mounds was also recorded.

• **Growth Variables.** All trees were measured for diameter at 1.4m above ground (DBH) and mapped by compass bearing and distance from the plot centre according to the PSP system (Ellis and Dunlop 1991 unpubl. report). Twelve trees per plot were measured for total and crown height, including 4 trees for predominant mean height. The variables Mean Top Height (MTH), Mean Top Diameter (MTD), Mean Crown Height (MCRH), Plot Mean Height (PMH), Basal Area (BA), and Volume (VOL) were computed for each plot and output from the PSP database system.

• **Soil variables**. In each plot a centrally located soil pit was dug to 1.2m and the original undisturbed horizons described by depth, colour, presence of stones and roots, texture and drainage. The topsoil (A horizon) depth was measured and sampled for chemical and physical analysis with 25 random Hoffer cores bulked to form 1 composite sample per plot. Soil A horizons were sampled for bulk density with 4 random undisturbed ring cores per plot. Soil B and C horizons were sampled from the 4 sides of each pit.

• **Analytical Procedures**. Bulk density samples were oven-dried at 105 degrees C until reaching constant weight. Samples for chemical and physical analysis were air-dried and passed through a 2 mm sieve. A horizon samples were analyzed for pH, Total N, Bray P, K, Ca, and Mg according to standard NZFRI methods (Nicholson 1984).

• **Statistical methods.** Univariate statistics were computed for all variables to determine normality of distribution. A suitable transformation was applied where necessary and prior to further analysis. Summary statistics for each variable were computed and then Pearson correlation coefficients determined for various combinations of growth and site variables. Multiple regression models were constructed for the dependent growth variables using site variables as independent variables. Where variables were non continuous, such as aspect or landform, these were treated as class variables and Analysis of Variance procedures used in place of the correlation analysis. Class variables were included in the multiple regression models. The SAS (SAS Institute 1985) statistical package was used for the analysis.

RESULTS.

This report will not cover all results exhaustively, but will concentrate on highlighting various important findings to date.

Table 1 Summary of growth data *E. regnans* site study

Statistic	MTD (cm)	PMH (m)	MCRH (m)	MTH (m)	STOCK (s.p.ha)	BA (m^2ha^{-1})	VOL (m^3ha^{-1})
Mean	32.2	26.3	15.8	26.4	600	26.8	250.4
Min	23.0	19.3	11.2	19.5	375	11.6	78.8
Max	39.0	32.5	21.4	33.4	850	41.2	422.9
S.Dev	3.44	2.76	1.81	2.66	109.6	6.99	84.01
C.V. (%)	10.7	10.5	11.4	10.1	18.3	26.0	33.5

Tree Growth. Growth data for the plots is summarised in Table 1. The range of growth across plots is large for all variables, with mean top height for example showing a difference of 13.9 metres between the worst and the best plots. Stocking is also very variable, ranging from 375 to 850 stems per hectare. This variation is reflected in both plot basal area and volume, which have a large range and coefficients of variation of 26 and 33.5% respectively. Variables unaffected by the variable stocking (height and diameter) have much lower coefficients of variation in the order of 10%.

Site Variables. Physiographic variables are summarised in Table 2. Aspect was a class variable (i.e. split into N, NE etc) so is not tabulated. Neither is landform though Topex

Table 2 Summary of some environmental variables measured in *E. regnans* site study.

Variable	Mean	Min	Max	S.D	C.V(%)
Slope (°)	12	1	34	9.9	82
Topex (°)	83	44	146	22	26
Depth A (cm)	5.4	0.9	13.8	2.92	54
Depth Tp (cm)	61.5	0	>120	34.8	56

which is linked to landform is. Slope ranged from flat to very steep in the plots, and Topex (a measure of exposure) from 44 to 146°, the lower number indicating a greater degree of exposure. A horizon depths ranged from practically zero (due often to past disturbance) to a maximum of about 14 cm and were very variable between plots (CV=54%). The depth of Taupo indicates the thickness of Taupo pumice overlying the older more weathered holocene ash (Vucetich and Wells 1978) and ranged from zero to greater than 120 cm. Soil chemical data from the A horizon (Table 3) indicated moderately acid soils with N levels ranging from 0.29 to 0.60%. Phosphorus levels were adequate for tree growth on average but ranged from 4.6 to 33.3 $mgkg^{-1}$. Cation concentrations were as expected for these soil types. Non normal distribution of cation data required the use of log transformed data in subsequent analysis.

Table 3 A horizon soil chemical data *E. regnans* site study

Variable	Mean	Min	Max	S.D.	C.V.(%)
pH	5.21	4.80	5.61	0.17	3.3
N (%)	0.41	0.29	0.60	0.06	14.6
Bray P($mgkg^{-1}$)	12.6	4.6	33.3	5.51	43.7
K ($meq100g^{-1}$)	0.30	0.09	0.85	0.15	50.0
Ca($meq100g^{-1}$)	3.08	1.36	7.26	1.23	39.9
Mg($meq100g^{-1}$)	1.01	0.40	2.68	0.44	43.5

Correlation analysis.

A correlation matrix was constructed for all continuous variables. Significant correlations between site and growth variables are shown in Table 4. Soil pH is positively correlated with both height and diameter growth. Increasing thickness of Taupo pumice also linked to better height growth. Other correlations are negative, apparently decreasing A horizon depth results in better tree growth. This may possibly indicate the importance of site cultivation, those sites with a history of the most intensive site preparation may have the least identifiable remaining topsoil. Decreasing both altitude and Topex result in better growth. The correlation of potassium with growth was unexpected, it appears as a negative correlation.

Table 4 Correlation coefficients significant at $P<0.05$ for *E. regnans* site study.

Variable	MTD	MTH	PMH	BA	VOL
	(cm)	(m)	(m)	(m^2ha^{-1})	(m^3ha^{-1})
pH	0.3327	0.37832	0.3861		
log K	-0.3182		-0.3182	0.3445	-0.2947
Topex	-0.3810			-0.3961	-0.3678
Depth A	-0.3200			-0.3857	-0.3671
Altitude		-0.3345	-0.4011		
Depth Tp		0.3019	0.3019		

The results of the ANOVA done to test the effect of aspect on tree growth showed that variable to be a significant factor affecting tree growth. Plots of the growth variables including stocking against aspect are shown in Figures 2 to 7. Bars with common letters were not significantly different at $P=0.05$ as determined by Duncan's multiple range test. There were no significant differences in growth variables across landform classes.

Multiple regression models.

After determining which variables were affecting growth singly multiple regression models were constructed to determine how much of the growth variation could be explained by a multivariate model. The GLM procedure in SAS was used to allow inclusion of class variables such as aspect and landform with other continuous variables. The cultivation effect inferred from the negative correlation of A horizon depth with growth was tested by including another variable covering the presence or absence of V blading on the site. The best model produced was for basal area, variables included were aspect, landform, pH and depth of the A horizon. The V blade variable did not contribute to the model and was dropped. The r^2 value of the model was 0.7324 ($P>F = 0.0001$). The full model is not reproduced here as there are a large number of coefficients related to each of the aspect and landform classes. The poorest model was for Mean Crown Height, with a r^2 of 0.4319, values for other models were between this and the basal area model. The modelling done was not exhaustive, and further work will be done.

It was heartening to be able to describe such a large proportion of the variation in the multiple regression models. But to explain why aspect particularly was having such an effect on tree growth was the next stage of the investigation. There were two hypotheses to be tested at this stage, first that the chemistry of the A horizon varied due to different weathering rates for example, and second that the soil type varied due to patterns of deposition of the most recent airfall tephra originating from the Taupo vicinity 1800 years BP. Thicker layers on the south and east aspects might be expected, and less on the northern sheltered aspects. Subsoil chemical analysis was not yet complete so no testing of the effect of subsoil chemistry was possible. An ANOVA of aspect with depth of the Taupo pumice and also the measured chemical variables showed no significant effects of aspect on these properties indicating that neither topsoil fertility or thickness of Taupo pumice varied with aspect. Pumice thickness did however vary with position in the landscape though the model was only weak. This variation may have masked the effect of aspect on thickness. Pumice layers tended to be thinner on ridge crests and topslopes and to accumulate on lower slopes and basins (Figure 7). Further analysis of effect of aspect on soil chemistry by landform unit may help.

Other hypotheses to be tested at a later date will be the importance of subsoil chemistry effects on tree growth. If none of these show up as important then this may point towards varying moisture conditions on the different sites.

CONCLUSIONS.

At this stage of the study it has been shown that the growth of *E. regnans* is affected by a number of environmental variables including aspect, altitude, landform, depth of the A horizon and thickness of Taupo pumice. Soil pH and exchangeable K concentrations in the A horizon are the only chemical variables related to growth. While multiple regression models could describe between 46 and 73% of the growth variation the reasons for the effect of the variables on tree growth are as yet undetermined. Plots on different aspects do not have significantly different A horizon chemistry or soil profile characteristics. Subsoil chemistry remains to be investigated.

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Figure 2

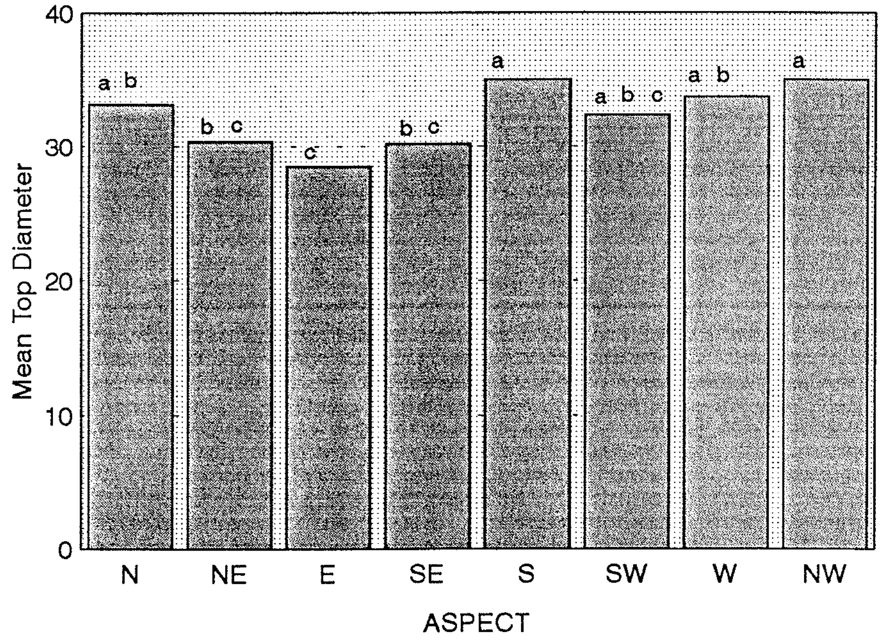

Figure 3

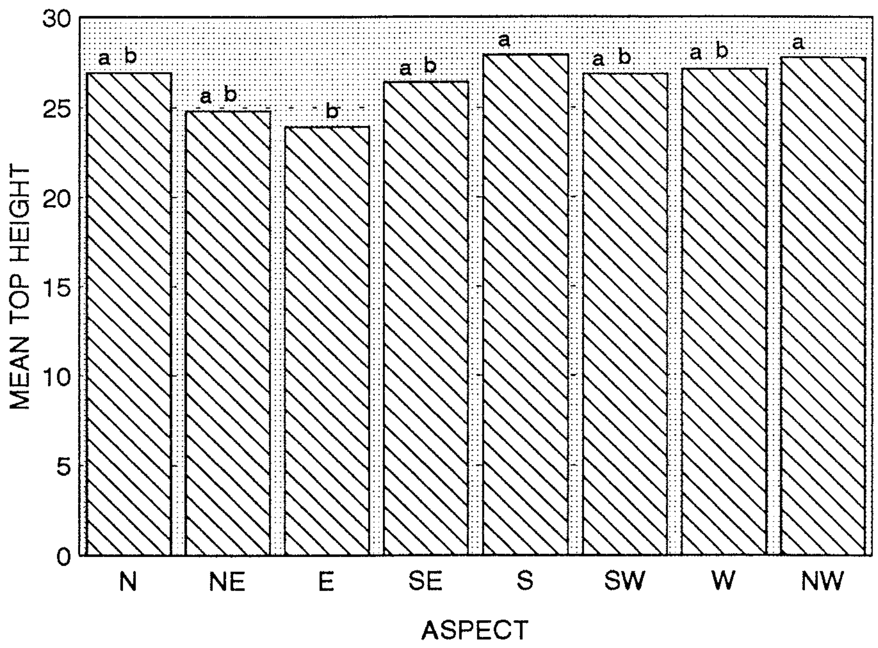

Figure 4

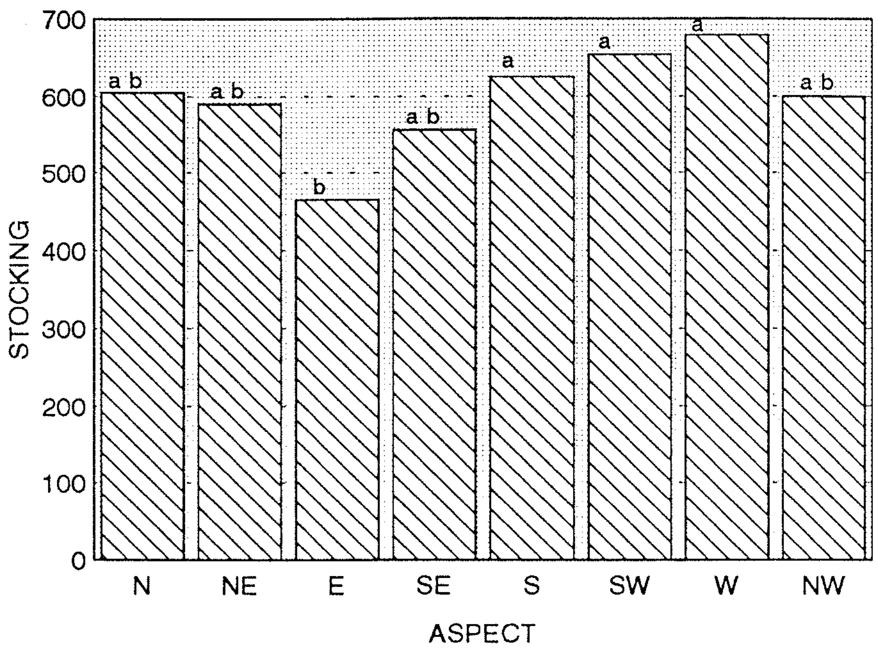

Figure 5

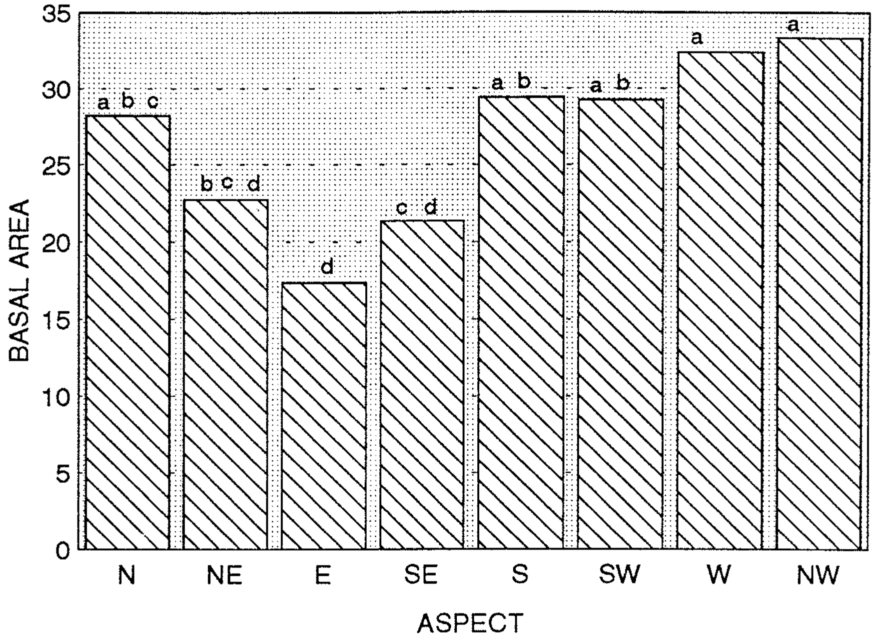

Figure 6

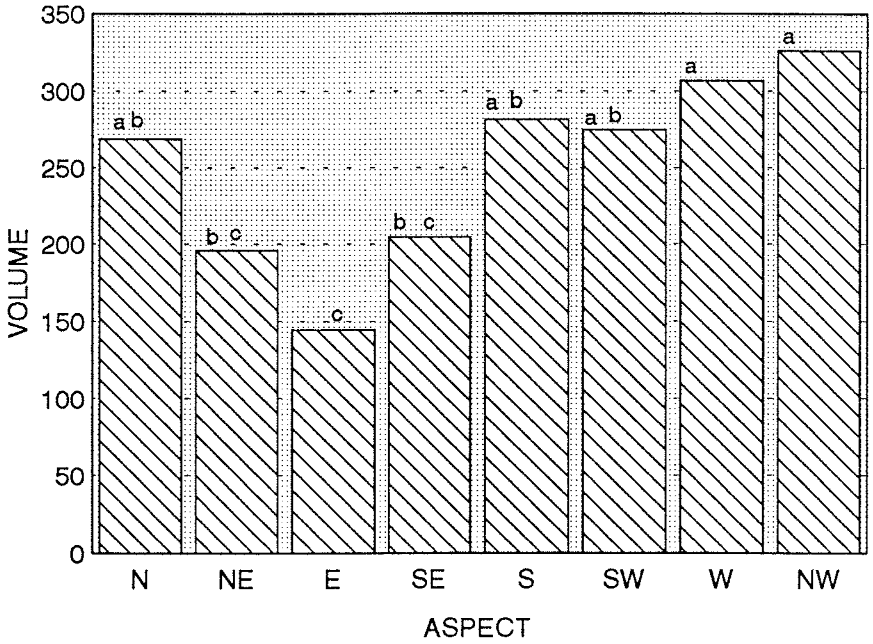

Figure 7. Depth of Taupo pumice in landscape