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

T.W. Payn and G.R. Oliver

NZFRI

Report No. 21 June 1994

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EXECUTIVE SUMMARY

Concern about the variability in growth pattern of *Eucalyptus regnans* at a stand level was raised by the members of the Management of Eucalypts Cooperative. Environmental factors were suggested as important determinants of the growth pattern and a study designed to investigate the effects of environmental and soil factors on *E. regnans* growth. Growth within the Kinleith region was found to be affected predominantly by aspect and landform with topsoil depth and pH also important. There was also a relationship between growth and soil nitrogen and phosphorus supply and a weak implication of calcium and possibly magnesium in the growth pattern. These variables are far less important than the aspect and landform however. Stocking over the study site had been affected by site, and although the reasons for this are unknown, micro climatic factors are likely to be important. Multiple regression models developed to predict growth contained easily measured soil and site variables and the models should be tested further in the Bay of Plenty. Future studies should concentrate on climate, soil pattern and the development of a productivity map for the region.

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

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ABSTRACT

Concern about the variability in growth of *Eucalyptus regnans* at a stand level was raised by the members of the Management of Eucalypts Cooperative. Environmental factors were suggested as important determinants of the growth pattern and a study designed to investigate the effects of environmental and soil factors on *E. regnans* growth was undertaken. Growth within the Kinleith region was found to be affected predominantly by aspect and landform with topsoil depth and pH also important. There was also a relationship between growth and soil nitrogen and phosphorus supply and a weak implication of calcium and possibly magnesium in the growth pattern. These variables are far less important than the aspect and landform however. Stocking over the study site had been affected by site, and although the reasons for this are unknown, micro climatic factors are likely to be important. Multiple regression models developed to predict growth contained easily measured soil and site variables and the models should be tested further in the Bay of Plenty. Future studies should concentrate on climate, soil pattern and the development of a productivity map for the region.

INTRODUCTION

New Zealand has only 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 *Eucalyptus regnans*, with approximately 8000 hectares established; 80% of the resource concentrated in the Bay of Plenty region. Growth of *E. 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 *E. 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 Management of Eucalypts Co-operative.

Conditions for growth of *E. 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^{o}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. *E. regnans* also occurs on podsols, upland and mountain podsols and kraznozems. Where soil fertility and rainfall are lower, stands may be confined to valleys and along water courses. It grows poorly on permanently saturated sub soils. Ellis (1968) shows *E. regnans* to be more sensitive to site conditions than *E. obliqua, E. sieberi*, or *E. radiata*.

E. 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 of these 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 the natural habit of *E. regnans* 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 at that time and so the company endeavoured to find the best compromise when establishing *E. regnans*.

It is clear that in the following years *E. regnans* was planted on the best available sites, but subsequent assessment of growth showed that even these sites appeared to be unacceptably variable. Reasons for this variability were sought by the members of the Management of Eucalypts Co-operative and results of the 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 260 m.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 clear felling of the previous crop. Stands were planted in 1980 with *E. regnans* seedlings of Franklin, Tasmania, seed origin. Initial stocking ranged from 1152 to 1496 stems ha^{-1}. 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 stems ha^{-1}. by thinning at age 3. The ranges in initial stocking and thinning intensity depended on stand the plots were located in.

• **Plot Selection**. Forty six circular plots (each 0.04ha) were established in 1992, when stands were 11 years old, to cover different aspects, slopes, altitude and crown health within the four blocks.

• **Plot description**. A description was made of the understorey, noting the proportion of cover by the main species. Landform (crest, top slope, mid slope, lower slope, 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). 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), Predominant Mean Height (PMH), Basal Area (BA), Volume (VOL) and within plot variance of DBH were computed for each plot using the PSP database system.

• **Foliar variables**. Samples of mature current year's foliage were taken from the upper crown of 10 trees in all plots in March 1994 and bulked by plot.

• **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 $105^{o}C$ until reaching constant weight. Samples for chemical and physical analysis were air-dried and passed through a 2 mm sieve. Soil samples were analysed for pH, Total N, organic carbon; Bray P, K, Ca, and Mg; and particle size fractions according to standard NZ FRI methods (Nicholson 1984). Foliage samples were oven dried at $70^{o}C$ and then ground in a Wiley mill to pass through a 1 mm sieve. Concentrations of N, P, K, Ca, Mg, B, Mn, Zn, and Cu in the foliage were determined using the methods of 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 Pearson correlation coefficients determined for various combinations of growth, foliar 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

• Tree Growth.

• Variability.

Growth data for the plots is summarised in Table 1. The range in growth across plots was large for all variables, with mean top height, for example, showing a difference of 13.9 metres between the worst and the best plots and mean top diameter showing a range of 16.0 cm. Stocking was also very variable, ranging from 375 to 850 stems ha^{-1}. The target of the thinning at age 3 was between 650 and 712 stems ha^{-1}, so whether this variation is due to silvicultural operations or site factors needs to be tested. The variation in stocking was reflected in both plot basal area and volume, which had large ranges and coefficients of variation of 26 and 33.5% respectively. Variables unaffected by stocking (such as mean top height and diameter) had much lower coefficients of variation; in the order of 10%. As a measure of within plot variation, the variance associated with DBH was calculated for each plot. The variance showed a large range with a high CV of 33.3% suggesting the within plot variance was strongly affected by either site or possibly stocking. Correlation of within plot variance with stocking however indicated a non significant coefficient of 0.24127 (p=0.1062) suggesting site factors were affecting the within plot diameter distributions.

Table 1. Summary of growth data from the 46 plots in the *E. regnans* site study.

Statistic	DBH (cm)	MTD (cm)	PMH (m)	MCRH (m)	MTH (m)	STOCK stems.ha^{-1}	BA ($m^2 ha^{-1}$)	VOL ($m^3 ha^{-1}$)	DBHVAR
Mean	22.5	32.2	26.3	15.8	26.4	600	26.8	250.4	58.4
Min	15.6	23.0	19.3	11.2	19.5	375	11.06	78.8	14.6
Max	30.7	39.0	32.5	21.4	33.4	850	41.2	422.9	96.6
S.Dev	2.71	3.44	2.76	1.81	2.66	109.6	6.99	84.01	19.5
C.V. (%)	12.0	10.7	10.5	11.4	10.1	18.3	26.0	33.5	33.3

• Intercorrelations.

Correlations between measured growth variables were generally significant. If the variation in stocking over the plots was due to silvicultural history, it would be necessary to pick a growth variable that was independent of stocking as the indicator of site. The literature suggested that Mean Top Diameter was likely to be independent of stocking, and in this data set this was confirmed with a correlation coefficient of 0.14762 (p=0.3276). If stocking was found to be purely an effect of variable management regime, this could then be minimised by using the MTD as the indicator of site productivity in the subsequent analysis. If site had affected stocking then the appropriate variables to use as indicators of site productivity would be Basal Area or Volume which include the effect of stocking. Correlations are shown in Table 2.

Table 2. Correlations between tree growth variables in the 46 *E. regnans* plots

Variable	DBHVAR	VOL	BA	STOCKING	MCRH	PMH	MTH	MTD
MTD	0.69623	0.83694	0.80374	0.14762	0.58952	0.81712	0.82344	1.0000
	0.0001	*0.0001*	*0.0001*	*0.3276*	*0.0001*	*0.0001*	*0.0001*	
MTH	0.55236	0.86056	0.76602	0.29265	0.82052	0.96079	1.0000	
	0.0001	*0.0001*	*0.0001*	*0.0484*	*0.0001*	*0.0001*		
PMH	0.61906	0.84734	0.75554	0.28139	0.81407	1.0000		
	0.0001	*0.0001*	*0.0001*	*0.0582*	*0.0001*			
MCRH	0.41938	0.63795	0.51583	0.16720	1.0000			
	0.0037	*0.0001*	*0.0002*	*0.2667*				
STOCKING	0.24127	0.48161	0.57793	1.0000				
	0.1062	*0.0007*	*0.0001*					
BA	0.50716	0.97789	1.0000					
	0.0003	*0.0001*						
VOL	0.51540	1.0000						
	0.0002							
DBHVAR	1.0000							

• **Foliar nutrition.**

Foliar nutrient analysis for the 46 plots is summarised in Table 3

Table 3. Summarised foliar nutrient concentrations for the 46 plots of the *E. regnans* site study.

Statistic	N	P	K	Ca	Mg	B	Mn	Zn	Cu
	$mg.g^{-1}$					$mg.kg^{-1}$			
Mean	19.41	1.12	8.56	4.94	2.25	14.8	704.5	15.8	6.1
Min	10.76	0.96	6.24	3.80	1.92	12.0	345.0	12.0	4.9
Max	22.47	1.36	10.79	5.95	2.61	20.0	1259.0	20.0	6.9
S.dev	1.76	0.11	0.87	0.53	0.16	1.7	167.0	1.7	0.5
C.V. (%)	9.06	9.82	10.16	10.72	7.11	11.48	23.70	10.75	8.19

There are no published data for *E. regnans* for foliar critical levels below which growth is restricted. There were no elements that appear to be unusually low or highly variable over the plots based on the mean values for the foliage samples; coefficients of variation range from 7.11 to 11.48% except for Mn which was 23.7%. However this element was in high concentration in the foliage and was unlikely to be either deficient or toxic based on literature relating to pines. However the concentrations of both N and P fall into what would be defined as deficient for *P. radiata* for some of the plots. This could indicate that these two elements were contributing to the growth variation among the plots. Minimum values for all other elements were above the critical concentration as related to *P. radiata*.

• **Site variables.**

• *Physiographic.*

Physiographic variables are summarised in Table 4. Aspect was a class variable (ie. split into N, NE etc) so was not tabulated. Plots were fairly evenly distributed over all the aspect classes. Landform was also a class variable so was not tabulated, although Topex , which is linked to landform, was. Slope ranged from near flat (1^{0}) to very steep (34^{0}) in the plots, and Topex (a measure of exposure) from 44 to 146^{0}, 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.

Table 4. Summary of some environmental variables measured for the 46 plots of the *E. regnans* site study.

Statistic	Slope (%)	Topex (^{0})	Depth A (cm)	Depth Taupo (cm)	Altitude (m)
Mean	12	83	5.4	61.5	293
Min	1	44	0.9	0	256
Max	34	146	13.8	>120	329
S.Dev	9.9	22	2.92	34.8	20.2
C.V. (%)	82	26	54	56	6.88

• *Soil descriptions.*

Soil profile descriptions are shown in Appendix 1.

• ***Soil chemistry.***

Soil samples were taken down the profile for each separate horizon in each plot. For analytical purposes the horizons were labelled from 1 to 6 depending on their position in the profile. Of the soil pits sampled there were a maximum of 6 horizons identified and sampled; the average was about four horizons per profile. Soil chemical and physical data are summarised by horizon in Table 5.

Table 5. Mean soil chemical and physical data for horizons sampled from the 46 *E. regnans* plots

Variable	Horizon					
	1	2	3	4	5	6
pH	5.21	5.92	5.96	5.97	6.01	5.88
Total N (%)	0.419	0.084	0.102	0.074	0.053	0.028
Carbon (%)	7.35	1.13	1.04	0.68	0.57	0.31
C:N	17.59	13.37	10.94	9.45	10.08	11.1
Bray P ($mg.kg^{-1}$)	12.27	5.29	3.02	1.89	1.25	0.83
Bray Ca ($cmol_c.kg^{-1}$)	3.08	0.56	0.60	0.71	0.63	0.26
Bray K ($cmol_c.kg^{-1}$)	0.30	0.32	0.25	0.09	0.22	0.04
Bray Mg ($cmol_c.kg^{-1}$)	1.08	0.24	0.32	0.39	0.52	0.07
Silt (%)	26.1	21.0	15.3	14.4	13.8	6.8
Clay (%)	4.9	2.2	2.2	2.4	2.9	0.2

The soils were moderately acid and showed an increase in pH down the profile to pH values of about 6.0. All nutrient concentrations declined with increasing horizon number, and the most fertile horizon was the A in terms of concentrations of nutrients. However the thickness of this horizon would affect the nutrient budget available to the tree. The soils would be characterised as moderately fertile. The organic component will be dominant with regards nutrient supply as the percentage clay was very low. Cation data were not normally distributed so log transformations were used in statistical analysis.

• Principal components analysis.

• Site variables

Principal components analysis is a means of distilling a number of variables into a number of composite ones and then relating these variables to dependant variables such as basal area or mean top diameter. All continuous site and soil variables were used in the analysis. Only chemical data from the upper two horizons was used as the analysis cannot handle missing values easily. The first seven components accounted for 76% of the variation and so later ones were discarded. Interpreting the components was difficult; only the important variables in components 1, 2 and 3 seemed to make logical sense. Principal component 1 seems to be a measure of exposure and nutrients while component 2 seems related to nutrients and the differences between horizon 1 and 2. Component 3 is a measure of altitude, A horizon thickness and a fertility component. The other components were discarded at this stage.

The principal components were then correlated with the growth variables. Significant correlations are shown in Table 6.

Table 6. Correlation of principal components 1 and 2 with tree growth variables, *E. regnans* study.

Component	MTD	PMH	MCRH	MTH	VARDBH	MTD/MTH
1	-0.28921		-0.29161		-0.44059	
p>F	*0.0512*		*0.0493*		*0.0022*	
2		0.30846	0.37671	0.26442		0.39007
p>F		*0.0370*	*0.0099*	*0.0758*		*0.0074*
3					-0.29849	
p>F					*0.0436*	

Correlations were negative for component 1, suggesting that increased exposure leads to not only poorer growth but also less variance in within plot DBH. Component 2 variables indicated that improved nutrient supply and lower altitude gave better height growth. Variables within component 3 suggested that increased altitude and thicker A horizon leads to decreased variance in DBH within the plot. One related point that emerged from the analysis was that as a number of variables were contained within each component and contributed to that component. This means the variables are intercorrelated and it may be difficult to disentangle effects of these variables on growth.

• Correlation analysis.

The PCA did not yield very useful results overall so further investigation of the relationship between site, soil, tree growth and foliar variables was made using correlation analysis.

Growth and site

Correlation analysis showed a number of site variables to be correlated with tree growth (Table 7). As some of the correlations were significant at close to the 5% level the significance level was extended to 10% to show those variables. There was a negative correlation between Topex, the degree of exposure, and Mean Top Diameter, Volume and DBH variance. This indicates that the more exposed sites have greater productivity and stand uniformity as smaller values of Topex indicate a greater degree of exposure. Altitude had a significant negative effect on growth, higher altitudes showed poorer growth. This is notable given the relatively small range in altitude of all the plots, from 256 m.a.s.l to 329 m.a.s.l. Thickness of horizon 1 was negatively correlated with growth for all growth variables suggesting that plots with less topsoil had better 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. Increased thickness of Taupo pumice appears to be related to better height growth.

The results of the ANOVA to test the effect of aspect on tree growth showed that it was a significant factor affecting tree growth. Graphs 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. The fact that site had an effect on stocking is important as this shows that the variation in stocking is not an artefact of past stand management. There was an interaction between aspect, landform and stocking.

The effect of aspect and depth of Taupo on growth were investigated together in an ANOVA; there were significant interactions ($p<0.05$) of aspect and depth of Taupo on mean top diameter, mean crown height, basal area and volume.

Table 7. Correlation of growth and site variables for *E. regnans* site study significant at $p<0.1$.

Variable	MTD	PMH	MCRH	MTH	BA	VOL	DBHVAR	MTD/MTH
Slope								0.30175
p>F								*0.0415*
Topex	-0.38104					-0.36781	-0.32753	0.33934
p>F	*0.0009*					*0.0119*	*0.0263*	*0.0210*
Altitude	-0.28121	-0.40113	-0.33913	-0.33451			-0.47617	
p>F	*0.0583*	*0.0057*	*0.0211*	*0.0231*			*0.0008*	
Thickness (1)	-0.33382	-0.29898		-0.28455	-0.41470	-0.3470	-0.28899	
p>F	*0.0234*	*0.0435*		*0.0553*	*0.0042*	*0.0066*	*0.0514*	
Thickness (2)							0.29822	
p>F							*0.0441*	
Taupo		0.30199	0.36514	0.27815				
p>F		*0.0414*	*0.0216*	*0.0612*				

• *Growth and soil chemistry*

There were reasonably good correlations between soil chemical variables and tree growth variables (Table 8). Increased Bray P concentration in the top three horizons had a positive effect on mean crown height and mean top height. Increase in pH was also related to improved growth. Other variables were negatively correlated with growth. Calcium, potassium and magnesium concentrations may affect tree shape, with a negative effect on height growth and positive on basal area in a number of cases. This is only a hypothesis at this stage however. High carbon and C:N ratios in horizons 2 and 3 also seem to be associated with poorer height growth.

Table 8. Correlations between soil chemical variables and *E. regnans* growth, significant at $p<0.05$.

Soil variable[1]	Growth	r	$p>F$
Bray P (1)	Mean crown height	0.38639	0.0080
Bray P (2)	Mean crown height	0.43030	0.0028
Bray P (2)	Mean top height	0.31158	0.0350
Bray P (3)	Mean crown height	0.40956	0.0087
Bray Ca (1)	DBH variance	-0.37307	0.0107
Bray Ca (1)	Mean top height/MTD	-0.39592	0.0065
Bray Ca (2)	DBH variance	-0.47206	0.0009
Bray Ca (2)	Mean Crown Height	-0.38910	0.0075
Bray Ca (2)	Plot mean height	-0.38423	0.0054
Bray Ca (3)	Basal area	0.35051	0.0266
Bray Ca (5)	Basal area	0.89349	0.0411
Bray K (1)	Mean top diameter	-0.36265	0.0133
Bray K (1)	Basal area	-0.39397	0.0067
Bray K (1)	Volume	-0.35830	0.0145
Bray K(1)	Mean top height/MTD	0.31055	0.0357
Bray Mg(1)	Mean top height/MTD	0.33952	0.0210
Bray Mg(2)	DBH variance	-0.40488	0.0053
pH (1)	Mean top diameter	0.33278	0.0238
pH (1)	Plot mean height	0.38615	0.0080
pH (1)	Mean top height	0.37835	0.0095
pH (1)	DBH variance	0.31108	0.0353
pH (1)	Basal area	0.31502	0.0330
pH (1)	Volume	0.33835	0.0215
Nitrogen (2)	DBH variance	-0.36250	0.0133
Carbon (2)	Plot mean height	-0.32155	0.0293
Carbon (2)	DBH variance	-0.39939	0.0060
Carbon (2)	Mean crown height	-0.29519	0.0464
Carbon (3)	Mean top height	-0.31931	0.0046
C:N (2)	Mean top height	-0.31008	0.0360
C:N (2)	Plot mean height	-0.34054	0.0206

[1] Values in parentheses are horizon number.
[2] Cation correlations are for (1+ log cation concentrations)

• *Growth and Foliar nutrients*

Calcium, magnesium, manganese and copper were significantly correlated with growth. Neither nitrogen or phosphorus were related as we hypothesised when evaluating the foliar nutrient concentrations. Copper was very highly significantly related but to only one growth variable so the result may be chance. Calcium was negatively correlated with growth; this suggested that Ca is accumulating in the foliage of the slower growing trees and that it was not affecting growth as such. A similar conclusion may be drawn for Mn. Magnesium was positively correlated with height growth. That both soil and foliar Ca and Mg appear related to tree growth is interesting and could be taken further.

Table 9. Correlations between foliar nutrients and *E. regnans* growth, significant at $p<0.05$.

Foliar nutrient	Growth	r	p>F
Ca	Mean top diameter	-0.43879	0.0023
Ca	Plot mean height	-0.40882	0.0048
Ca	Mean top height	-0.41023	0.0046
Ca	Basal area	-0.50422	0.0004
Ca	Volume	-0.48273	0.0007
Mg	Plot mean height	0.37668	0.0098
Mg	Mean crown height	0.37198	0.0109
Mg	Mean top height	0.38881	0.0076
Mn	Plot mean height	-0.42477	0.033
Mn	Mean top height	-0.37735	0.0097
Cu	Mean crown height	0.92737	0.0044

• *Foliar nutrients and soil chemistry*

No relationships between corresponding elements in the soil and foliage were found apart from N in horizon 2 and this was a negative correlation. All other relationships were indirect.

Table 10. Correlations between foliar nutrients and soil chemical variables, significant at $p<0.05$.

Soil variable[1]	Foliar nutrient	r	p>F
Nitrogen (2)	Nitrogen	-0.50986	0.003
Nitrogen (1)	Magnesium	0.44163	0.0021
Bray P (3)	Phosphorus	0.38328	0.0146
Bray Ca (2)	Magnesium	-0.29552	0.0462
Bray Ca (4)	Phosphorus	0.51938	0.0132
Carbon (1)	Magnesium	0.45500	0.0015
Carbon (2)	Magnesium	-0.36487	0.0127
Carbon (2)	Zinc	-0.29277	0.0483
Carbon (2)	Nitrogen	-0.46206	0.0012
Carbon (5)	Potassium	-0.90391	0.0351
C:N (1)	Nitrogen	0.39508	0.0066
C:N (4)	Boron	-0.65019	0.0011

[1] Values in parentheses are horizon number.

• **Growth and Soil type.**

Soils were classified into soil types based predominantly on depth of Taupo pumice. This yielded two soil types the Taupo loamy sand and the Ngakuru silty loam. An ANOVA of growth by soil type showed some significant differences with PMH, MCRH, and DBHVAR higher on the Taupo soil. Other growth variables were not significantly affected. This analysis will be expanded in collaboration with Wim Rijkse as the results of his Kinleith survey are finalised. We may end up with a few more soil types once further discussions have been had.

Model building.

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 0.7523 (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.

It was heartening to be able to describe such a large proportion of the variation in the multiple regression models. To explain why aspect in particular 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. 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 nor 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 top slopes and to accumulate on lower slopes and basins (Figure 7). There was a significant interaction of aspect and landform on tree growth as previously mentioned. No additional chemical variables from the subsoil improved the models built in the previous section.

DISCUSSION.

A wide range of data was collected and used in the modelling process. However the resultant models were fairly straightforward and included easily measured variables. This is good from a management perspective as data collection is relatively easy with only one soil chemical variable (pH) included, and that is from the topsoil. The models should therefore be readily applicable in practise and by people with only a limited knowledge of soil science. The variables included in the model are not strongly intercorrelated and this implies the models should be reasonably robust.

The most intriguing variable in the model is A horizon depth. This was negatively correlated with growth and we initially thought to be an indirect measure of the beneficial effect of cultivation on growth. However this was not the case and we now suggest that this was due to an interaction with aspect; deeper topsoils had built up on the poorer sites due to slower organic matter cycling. This is essentially a microclimatic effect. It has not been possible to test this rigorously on existing data, and remains to be proved.

From the study it appears that site factors are affecting tree growth more strongly than soil chemical factors though the latter are related to growth in some instances. No one nutrient was controlling growth, the suggested N and P limitations shown in the foliage chemistry were not supported by good relations with soil chemistry or growth, although there were correlations between soil and foliar chemistry and a relationship between soil P and growth. We suggest that these elements are likely to be important if there is a need to stimulate tree growth by fertiliser application. Bathgate *et al.* (1993) suggested P may be limiting to *E. regnans* growth on these soils and found responses to P fertiliser application with seedlings in a pot experiment (Bathgate unpublished data). The role of calcium and possibly magnesium in *E. regnans* growth is interesting. Calcium may affect tree shape with an alteration of height to diameter ratio and the within plot diameter variance. We had hypothesised that the symptoms of Barron Rd syndrome (tip and leaf die back) were similar to boron deficiency. However foliar B concentrations were consistently well above critical levels for *P. radiata* and we have concluded that this element is unlikely to be implicated in any growth variation in this study.

One of the most difficult aspects of this study has been the description and sampling of the soils and subsequent analysis of the data. We attempted to sample horizons rather than depths and to construct nutrient budgets for each site based on that. However soil disturbance from logging and site preparation made this very difficult. The upper two horizons were often mixed and hard to describe. Using horizon thickness and nutrient concentration in combination did not improve the models produced. There are factors in favour of both approaches to soil sampling. It is easier to sample depths in the upper horizons but it is valuable to have the full soil description and to sample by horizons, especially in this region where horizons are often different pumice types with quite different mineralogy. This information is very valuable but statistical analysis is far harder due to variation in presence of the different horizon types at the different sites.

Climatic variables have not been included in the study so far, but this aspect is under study by Keith Ashby at Auckland University. Although he will be predicting climatic data for the sample plots, rather than measuring the data, the analysis should aid in explaining the variation in growth due to aspect and other site factors such as landform. At a later stage it would be interesting to follow up the climatic work with some micro climate measurements on the plots, although these will be affected by the presence of the current crop. Generally the east and south aspects had poorer growth than the north and west and this is possibly because they are cooler and wetter.

The variation in stocking in the plots has been shown to be an effect of site rather than thinning effects on the different sites. What is not clear is when the mortality that must have occurred on some of the sites actually took place. It must have been post thinning (no mention was made of mortality problems in the stand records) and probably fairly shortly after as there is little or no evidence of recent mortality in the plots. Whether the mortality was due to climatic factors, such as frost, or disease such as Barron Rd syndrome is unknown, but it may be that investigation of this would allow improvement of management practises to minimise the effect. If stocking variation is removed from the equation, variation in tree growth over the sites is not huge (see CVs, Table 1). Investigation of stocking * aspect effects in other age classes of *E. regnans* would determine whether such variation in stocking was constant and therefore possibly management induced or due to a unique climatic or disease event in this age class of *E. regnans*.

As previously noted, these models are reasonably user friendly and we believe could be applied within the Bay of Plenty region over similar conditions as occur in the study area. The next stage for this work would be to test the model outside the limits of the study area by collecting relevant data from existing PSPs in *E. regnans*. A plot data sheet is included in Appendix 2. Collection of more variables than those actually occurring in the models are suggested. It is likely that the model's fit will be poorer for plots which are located outside the limits of the initial study, for instance altitude may become more important in the models. The additional data is easy to collect and will allow revision of the models where appropriate. The only variable required by the models that is not immediately available is topsoil pH, which can be analysed for at the NZ FRI within two weeks of sample receipt. The PSP plots will be of varied age so where possible plot data collected at age 11 years will be used in the analysis. Extrapolation of data from measurements taken near age 11 years could be used. If no data is available the *E. regnans* growth model could be used to estimate age 11 data.

The body of knowledge on the effects of environmental factors on *E. regnans* growth is now much larger than it was three years ago and there are a number of opportunities for further work either within the Management of Eucalypts Co-operative or as part of the PGSF or University research programmes. In summary, the work of Guo Lanbin funded by the MEC, MERT and the University of Waikato is now complete and written up (Guo 1993, Bathgate *et al* 1993). The data sets are stable and the GIS models developed are available for further detailed analysis if the need arises. The Dept of Geography at the University of Waikato is interested in investigating some of the more spatial aspects of the GIS based data. The MEC siting study data sets are now complete, stable and well analysed (this study). Keith Ashby of the Dept of Environmental Sciences at Auckland University has access to this data to augment his complementary study of climatic variables affecting *E. regnans* growth. He is working with BIOCLIM on both national and local scales. John Bathgate of the Dept Biological Sciences at the University of Waikato has done a number of nutritional pot studies based on the soils occurring in Guo Lanbin's micro plots. The models have been roughly applied to Omatoroa forest by Neil Gheerkens of P.F. Olsens to delineate sites with varying productivity expectations. Within the Bay of Plenty there has been increased interest in soil mapping and Wim Rijkse of Landcare Research is involved in various forest soil surveys. This information will contribute to the understanding of *E. regnans* growth patterns and opens up further opportunities for testing the site/growth models based around soil/landscape models for the region. The development of an *E. regnans* productivity map for the Bay of Plenty should be well within reach if we are able to combine the developed models, climatic information and expand the models to PSPs within the region.

CONCLUSIONS

Eucalyptus regnans growth within the Kinleith region is affected predominantly by aspect and landform with topsoil depth and pH also important. There is also a relationship between growth and soil nitrogen and phosphorus supply and a weak implication of calcium and possibly magnesium in the growth pattern. These variables are far less important than the aspect and landform however. Stocking over the study sites had been affected by site, and although the reasons for this are unknown, micro climatic factors are likely to be important. Multiple regression models developed to predict growth use easily measured soil and site variables and the models should be tested further in the Bay of Plenty. Future studies should concentrate on climate, soil pattern and the development of a productivity map for the region.

ACKNOWLEDGEMENTS

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LITERATURE CITED

Bathgate J.L., Guo, L.B., Allbrook R.B., Payn T.W., 1993. Microsite effect on *Eucalyptus regnans* growth. New Zealand Journal of Forestry Science. 23(2):154-162.

Cochrane G.R, 1969. Ecological Valence of Mountain Ash (Eucalyptus regnans F.Muell) as a Key to its Distribution. Vict.Nat. 86:6-10.

Ellis J.C., Dunlop J.D., 1991. Minimum standards for collection of growth data from permanent sample plots. Stand Growth Modelling Co-operative Report No 4. FRI Project record No. 2092.

Ellis R.C, 1968. Some Factors Effecting the Differentiation of Forest Sites in Southern Victoria. Unpublished Ph.D thesis, University of Melbourne.

Guo. L.B. 1993. Microsite effects on *Eucalyptus regnans* growth. M.Phil thesis. Unviversity of Waikato.

James R.N., 1988. Eucalyptus Regnans for Agroforestry. Forest Research Institute, Rotorua. Bulletin 139.

Lembke C.A., 1977. N.Z. Forest Products Ltd turns to eucalypts. Australian Forest Industries Journal. 43(7):26-31.

Nicholson G., 1984. Methods of soil water and plant analysis. N.Z. Forest Service, Forest Research Institute, Rotorua. F.R.I. Bulletin 70.

Poole B.R., 1979. Eucalypts at N.Z. Forest Products Limited. *In* Workshop on Special Purpose Timbers. N.Z. Forest Service, unpublished.

SAS Institute., 1985. SAS Users Guide, Version 5. Box 8000, Cary, N. Carolina.

Turnbull J.W., Pryor L.D., 1984. Choice of species and seed sources. *In* Eucalypts for wood production (Eds Hills W.E., Brown A.G.) pp6-65. CSIRO/Academic Press, Melbourne.

Vucetich C.G., Wells N., 1978. Soils, Agriculture, and Forestry of the Waiotapu region, Central North Island, New Zealand. N.Z. Soil Bureau 31. 100pp.

Figure 1. Location of study site.

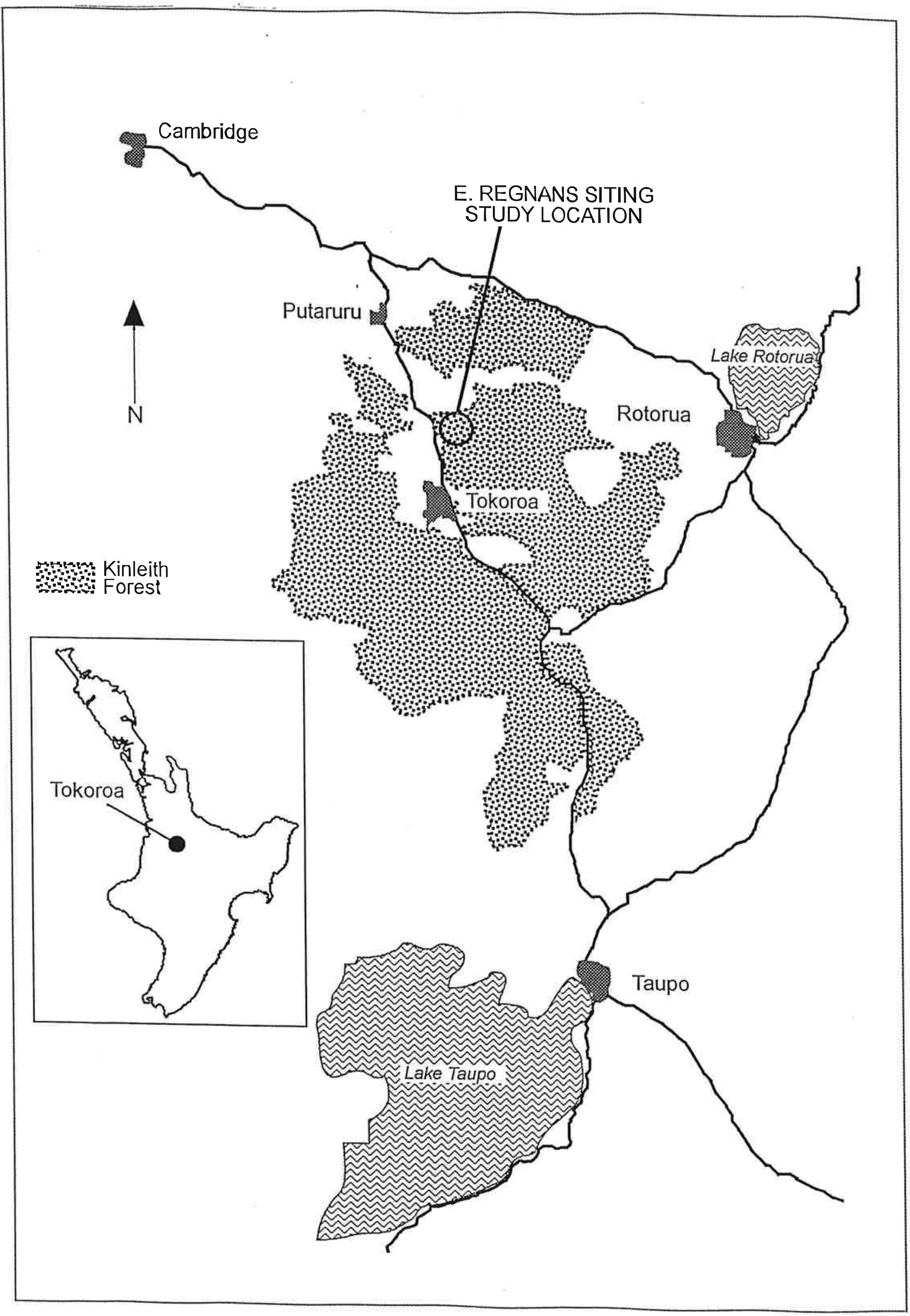
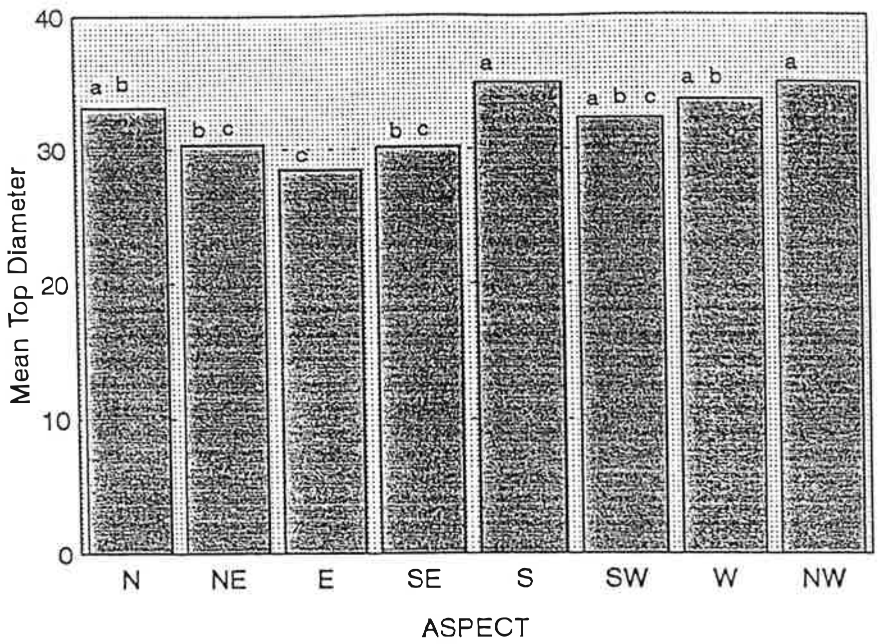


Figure 2



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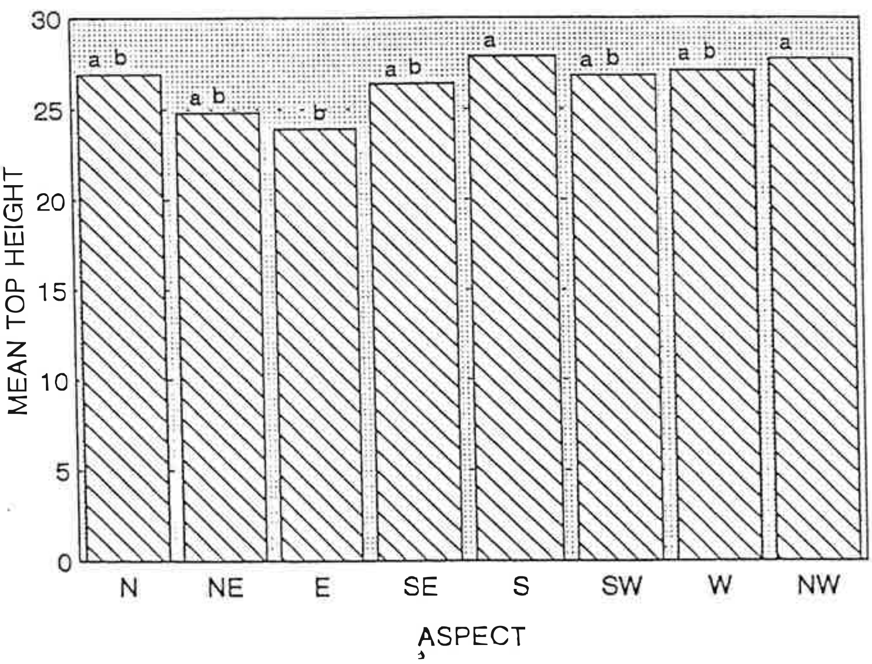

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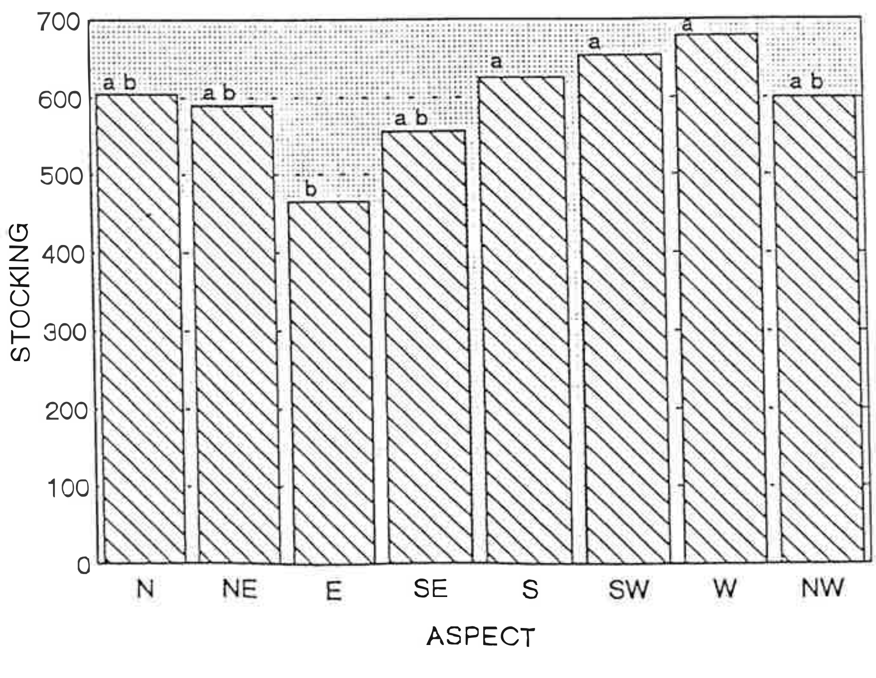

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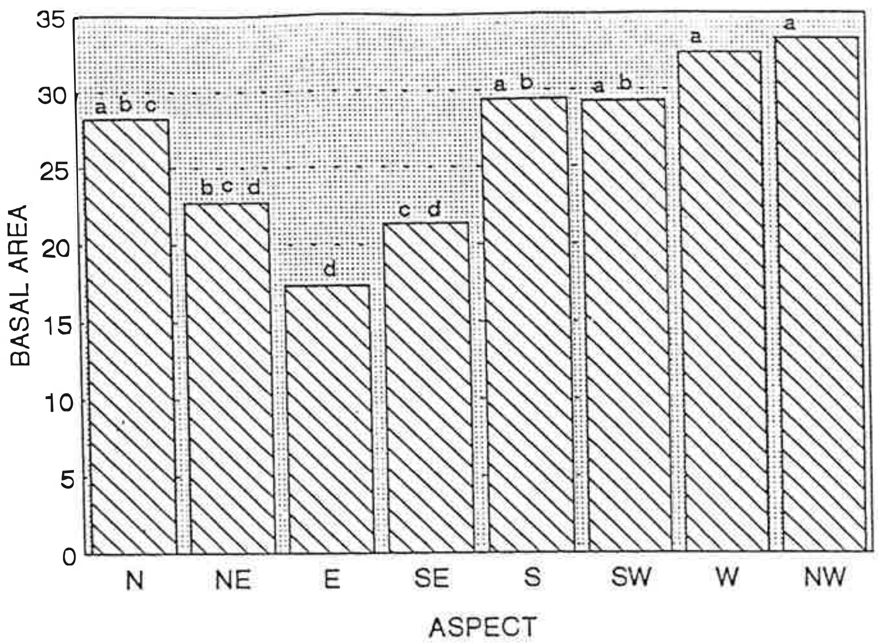

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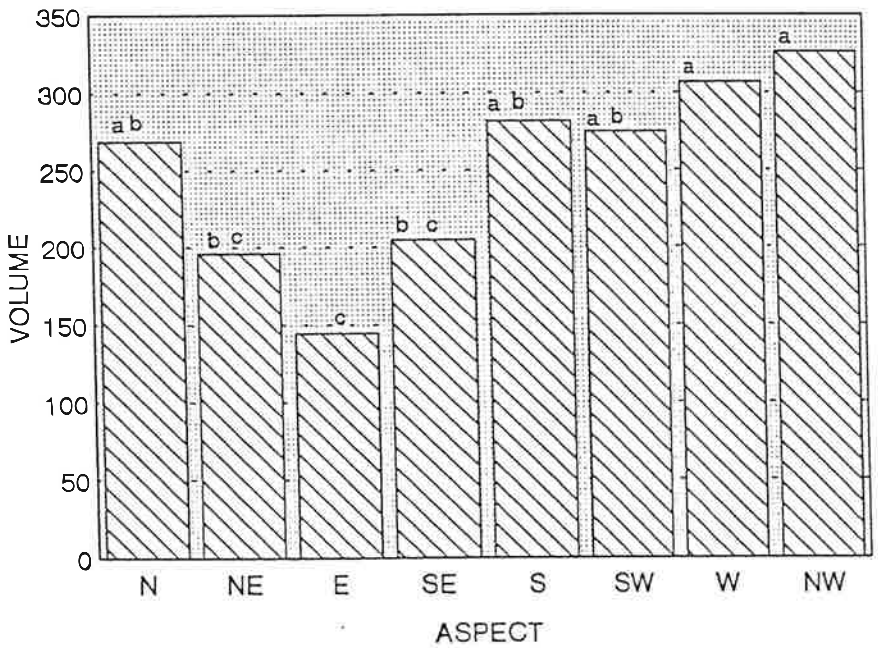
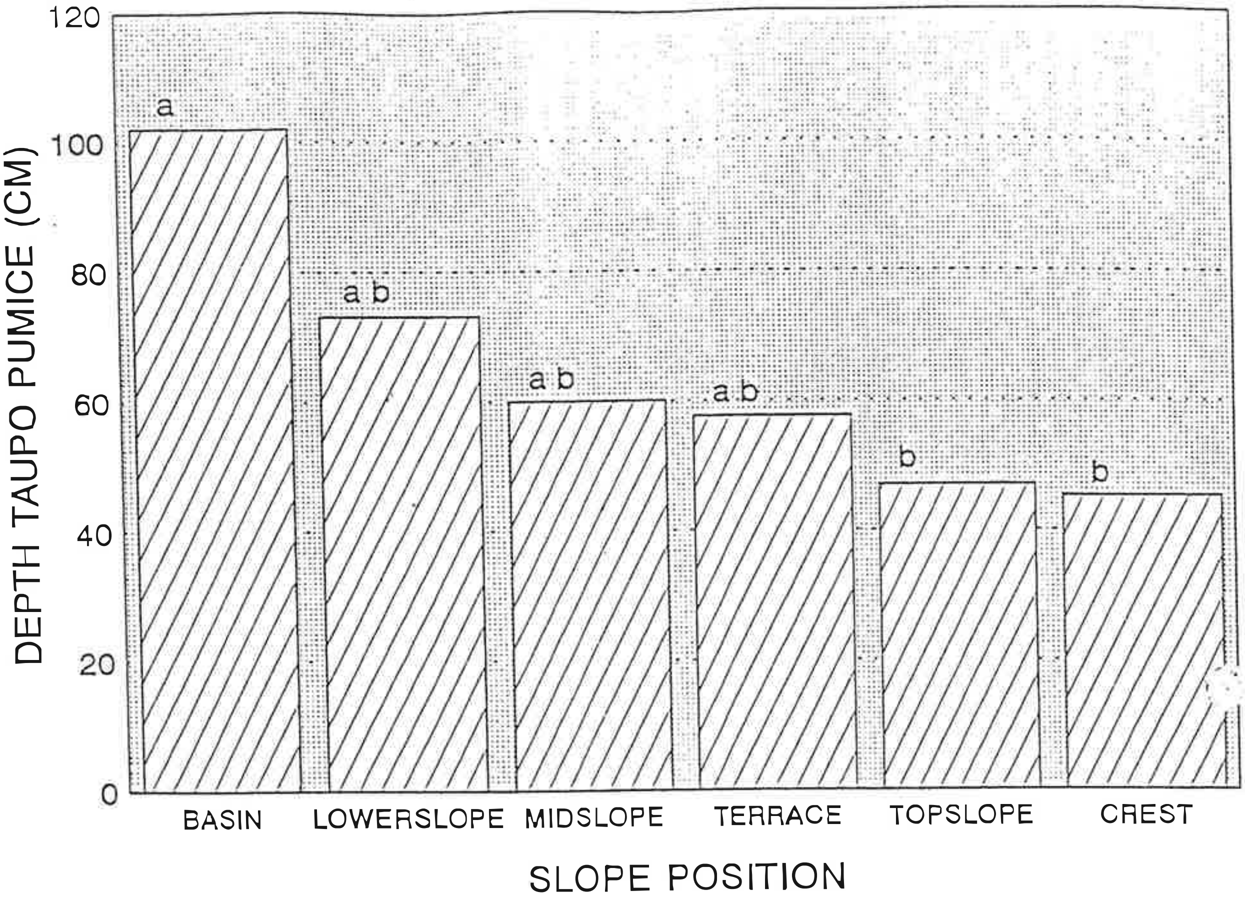


Figure 7. Depth of Taupo pumice in landscape



APPENDIX 1. **Soil profile information for sample plots.**

Kinleith Forest

Plot No.:	1
Compartment:	Jeff Rd

Effective rooting depth (m):	>1.2
Rooting barrier:	none
Water table (m):	>1.2
Parent material:	Taupo pumice
Moisture condition:	barely moist
Drainage:	good
Site preparation:	V bladed, 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 8	Very dark brown (10YR 2/2) to black (2.5Y 2/0), friable, roots abundant.
B	8 - 23	Yellowish brown (10YR 5/4) to dark reddish brown (5YR 3/4), firm, pumice lapilli common (Taupo pumice), some mixing with above, roots common.
C	23 - 49	Pale yellow (2.5Y 7/4), firm, pumice lapilli common (Taupo pumice), charcol fragments, roots rare.
B2	49 - 108	Yellowish brown (10YR 5/8), firm, roots rare.
B3	108 - >120	Yellowish brown (10YR 5/6), firm, roots absent.

Plot No.:	2
Compartment:	Jeff Rd

Effective rooting depth (m):	>1.2
Rooting barrier:	none
Water table (m):	>1.2
Parent material:	
Moisture condition:	moist
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
A	0 - 12	Black (10YR 2/1), very friable, roots abundant.
AB	12 - 23	Very dark brown (10YR 2/2), friable, roots abundant.
B	23 - 70	Yellowish brown (10YR 5/6), friable, roots abundant to common.
B2	70 - 120	Yellowish brown (10YR 5/4), friable to firm, roots rare.

Plot No.: 3
Compartment: Jeff Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed, 12 years since logging

Horizon	Depth (cm)	Description
A	0 - 9	Black (2.5YR 2/0), friable, roots abundnt.
B	9 - 27	Dark yellowish brown (10Yr 3/4), friable to firm, pumice lapilli common (Taupo pumice), roots common.
B2	27 - 92	Yellowish brown (10YR 5/6), firm, roots common to rare.
B2	92 - >120	Light olive brown (2.5Y 5/4), firm to very firm, roots rare.

Plot No.: 4
Compartment:

Effective rooting depth: >1.3
Rooting barrier: none
Water table: >1.3
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladd, 12 years since logging

Horizon	Depth (cm)	Description
A	0 - 6	Black (5YR 2/1), friable, roots abundant.
B	6 - 24	Yellowish brown (10YR 5/6), pumice laoilli (Taupo pumice), roots common.
C	24 - 71	Light yellowish brown (2.5Y 6/4), friable to firm, pumice lapilli common (Taupo pumice), roots rare.
B2	71 - 120	Yellowish brown (10YR 5/6), firm, roots rare.

Plot No.: 5
Compartment:

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed, 12 years since logging, mound height 42 cm

Horizon	Depth (cm)	Description
A	0 - 5	Dark reddish brown (5YR 3/2), friable, roots abundant.
B	5 - 32	Brownish yellow (10YR 6/6), firm, roots rare.
B2	32 - 120	Yellowish brown (10YR 5/6), firm, roots rare.

Plot No.: 6
Compartment: Puriri Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed, mounds

Horizon	Depth (cm)	Description
A	0 - 12	Very dark brown (10YR 2/2), friable, roots abundant.
B	12 - 36	Light olive brown (2.5Y 5/5), friable, pumice lapilli common (Taupo pumice), roots common.
B2	36 - 110	Dark yellowish brown (10YR 4/4), friable, roots common.
B3	110 - >120	Yellowish brown (10YR 5/8), friable, roots common to rare.

Plot No.:	7
Compartment:	Jeff Rd

Effective rooting depth:	110
Rooting barrier:	welded ignimbrite
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
A	0 - 10	Black (10YR 2/1), friable, roots abundant.
B	10 - 40	Yellowish brown (10YR 5/6), friable, pumice lapilli rare (Taupo pumice), roots common.
B2	40 - 110	Yellowish brown (10YR 5/4), friable to firm, angular ignimbrite fragments, roots rare.
C3	110 - >120	Olive brown (2.5Y 4/4), very firm, ignimbrite, roots absent.

Plot No.:	8
Compartment:	Jeff Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	
Drainage:	good
Site preparation:	some V bladed mounds, 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 8	Black (10YR 2/1), very friable, roots abundant.
A2	8 - 19	Very dark brown (10YR 2/2), friable, pumice lapilli common (Taupo pumice), roots abundant.
B2	19 - 41	Dark yellowish brown (10YR 4/4), friable, pumice lapilli common (Taupo pumice), roots abundant.
B3	41 - 76	Yellowish brown (10YR 5/6), friable, weathered and rounded ignimbrite fragments, roots abundant.
B4	76 - 120	Dark yellowish brown (10YR 4/4), friable to firm, weathered and rounded ignimbrite fragments, roots rare.

Plot No.: 9
Compartment:

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: some V bladed mounds, 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 7	Black (7.5YR 2/0), friable, roots abundant.
B	7 - 62	Yellowish brown (10YR 5/8), Taupo pumice, roots abundant.
B2	62 - 120	Yellowish brown (10YR 5/6), roots rare.

Plot No.: 10
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 9	Dark brown (7.5YR 3/2), friable, roots abundant.
B	9 - 70	Dark yellowish brown (10YR 4/4) to light olive brown (2.5Y 5/4), friable to firm, pumice lapilli rare (Taupo pumice), roots abundant.
B2	70 - 97	Dark yellowish brown (10YR 4/4), friable to firm, roots common.
B3	97 - >120	Yellowish brown (10YR 5/8), friable to firm, roots common to rare.

Plot No.: 11
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height 20 - 47 cm.

Horizon	Depth (cm)	Description
A	0 - 7	Black (7.5YR 2/0), friable, roots abundant.
B	7 - >120	Pale brown (10YR 6/3), friable to firm, pumice lapilli common to rare (Taupo pumice), roots rare.

Plot No.: 12
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
A	0 - 9	Black (2.5YR 2/0), friable, roots abundant.
B	9 - 21	Very dark grey brown (2.5Y 3/2), friable to firm, pumice lapilli rare (Taupo pumice), roots common.
B2	21 - 70	Brown (10YR 5/3), friable, pumice lapilli common (Taupo pumice), roots common to rare.
B3	70 - >120	Yellowish brown (10YR 5/8), friable to firm, some paleosol develoment, roots common.

Plot No.:	13
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
A	0 - 8	Black (2.5YR 2/0), friable, roots abundant.
B	8 - 43	Yellowish brown (10YR 5/8) to very pale brown (10YR 7/3), friable, pumice lapilli rare (Taupo pumice), roots common.
B2	43 - >120	Yellowish brown (10YR 5/8), friable to firm, roots common.

Plot No.:	14
Compartment:	Jeff Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height 21 cm

Horizon	Depth (cm)	Description
B	0 - 43	Brown (10YR 5/3), firm, pumice lapilli common (Taupo pumice), roots rare.
B2	43 - 108	Dark yellowish brown (10YR 4/4), friable to firm, roots common to rare.
B3	108 - >120	Dark yellowish brown (10YR 4/4), firm, roots rare.

Plot No.: 15
Compartment: Jeff Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed mounds

Horizon	Depth (cm)	Description
Bp	0 - 18	Light yellowish brown (2.5Y 6/4), friable, pumice lapilli common (Taupo pumice), roots common.
B2	18 - 89	Yellowish brown (10YR 5/8), friable, roots common.
B3	89 - >120	Yellowish brown (10YR 5/6), friable to firm, roots common.

Plot No.: 16
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: dry to moist
Drainage: good
Site preparation: 13 years since logging, animal cultivation

Horizon	Depth (cm)	Description
A	0 - 8	Black (2.5Y 2/0), friable, roots abundant.
B	8 - 72	Yellowish brown (10YR 5/8), firm, pumice lapilli rare (Tauo pumice), roots common.
B2	72 ->120	Yellowish brown (19YR 5/6), firm, roots rare.

Plot No.:	17
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 12 years since logging

Horizon	Depth (cm)	Description
A	0 - 11	Black (10YR 2/1), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	11 - >120	Pale brown (10YR 6/3), firm, pumice lapilli common (Taupo pumice), charcol fragments, roots common to rare.

Plot No.:	18
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	
Moisture condition:	moist
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
B	0 - 45	Yellowish brown (10YR 5/8), friable to firm, roots common.
B2	45 - >120	Yellowish brown (10YR 5/6), friable to firm, roots common to rare.

Plot No.: 19
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed mounds, 13 years since logging, mound height 28 - 35 cm

Horizon	Depth (cm)	Description
A	0 - 12	Very dark brown (10YR 2/2), friable, roots abundant.
B	12 - 37	Yellowish brown (10YR 5/6), firm, pumice lapilli rare (Taupo pumice), roots abundant to common.
B	37 - >120	Pale brown (10YR 6/3), firm, pumice lapilli rare (Taupo pumice), roots rare.

Plot No.: 20
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed mounds, 13 years since logging, mound height 30 - 35 cm

Horizon	Depth (cm)	Description
A	0 - 9	Very dark brown (10YR 2/2), friable, roots abundant.
B	9 - 56	Light olive brown (2.5Y 5/4), friable to firm, pumice lapilli common to rare (Taupo pumice), roots common to rare.
B2	56 - >120	Dark yellowish brown (19YR 4/4) to yellowish brown (10YR 5/6), friable to firm, some paleosol development, roots common to rare.

Plot No.:	21
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height upto 40 cm

Horizon	Depth (cm)	Description
B	0 - 46	Light olive brown (2.5Y 5/4), friable, pumice lapilli common to rare (Taupo pumice), roots common to rare.
B2	46 - 114	Yellowish brown (10YR 5/6), friable to firm, roots common to rare.
B3	114 - >120	Olive brown (2.5y 4/4), friable, roots rare.

Plot No.:	22
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height 35 cm.

Horizon	Depth (cm)	Description
A	0 - 8	Dark brown (7.5YR 3/2), friable, roots abundant.
B	8 - 58	Light olive brown (2.5Y 5/4), firm, pumice lapilli common (Taupo pumice), roots rare.
B2	58 - >120	Yellowish brown (10YR 5/4), friable to firm, roots common.

Plot No.:	23
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mound remnants, 13 years since logging, mound height 8 - 20 cm.

Horizon	Depth (cm)	Description
A	0 - 8	Dark brown (10YR 3/3), friable, roots abundant.
B	8 - >120	Light olive brown (2.5Y 5/4), firm, pumice lapilli common (Taupo pumice), roots rare.

Plot No.:	24
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height 9 - 17 cm.

Horizon	Depth (cm)	Description
A	0 - 9	Black (2.5Y 2/0), friable to firm, roots abundant.
B	9 - 57	Pale yellow (2.5Y 7/4), firm, pumice lapilli common (Taupo pumice), roots rare.
B2	57 - >120	Yellowish brown (10YR 5/8), firm, pumice lapilli rare (Taupo pumice), roots rare to common.

Plot No.: 25
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 8	Very dark brown (10YR 2/2), friable, roots abundant.
B	8 - 52	Dark yellowish brown (10YR 3/4) to light yellowish brown (2.5Y 6/4), friable, pumice lapilli common (Taupo pumice), roots common.
B2	52 - >120	Yellowish brown (10YR 5/8), friable, pumice lapilli common (Taupo pumice), roots common.

Plot No.: 26
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed mounds, 13 years since logging, mound height 16 - 26 cm

Horizon	Depth (cm)	Description
A	0 - 15	Dark reddish brown (5YR 2/2), friable, roots abundant.
B	15 - 52	Yellowish brown (10YR 5/6) to light olive brown (2.5Y 5/4), firm, pumice lapilli common (Taupo pumice), roots abundant to common.
B2	52 - >120	Dark yellowish brown (10YR 4/4), friable to firm, roots abundant to common.

Plot No: 27
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 8	Very dark brown (10YR 2/2), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	8 - 64	Light olive brown (2.5Y 5/46), friable to firm, pumice lapilli rare (Taupo pumice), roots rare.
B2	64 - >120	Yellowish brown (10YR 5/6), friable to firm, roots common to rare.

Plot No: 28
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height 13 - 23 cm.

Horizon	Depth (cm)	Description
A	0 - 25	Black (2.5Y 2/0), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	25 - 115	Dark yellowish brown (10YR 4/4) to pale brown (10YR 6/3), friable, pumice lapilli common (Taupo pumice), roots rare to common.
B2	115 - >120	Dark yellowish brown (10YR 4/4), friable to firm, roots common to rare.

Plot No: 29
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed mounds, 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 8	Very dark brown (10YR 2/2), friable, roots abundant.
B	8 - 49	Light olive brown (2.5Y 5/4), firm, pumice lapilli common (Taupo pumice), roots common.
B2	49 - >120	Dark yellowish brown (10YR 4/4), firm, roots common.

Plot No: 30
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material:
Moisture condition: moist
Drainage: good
Site preparation: 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 7	Very dark brown (10YR 2/2), friable, roots abundant.
B	7 - 26	Dark yellowish brown (10YR 4/4), friable to firm, roots abundant to common.
A2	26 - 41	Olive brown (2.5Y 4/4), friable, pumice lapilli common (Taupo pumice), roots common.
B2	41 - >120	Yellowish brown (10YR 5/4), friable to firm, roots common.

Plot No: 31
Compartment:

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
A	0 - 12	Very dark brown (10Yr 2/2), friable, roots abundant.
B	12 - 55	Light olive brown (2.5Y 5/4), friable to firm, pumice lapilli common (Taupo pumice), roots common.
A2	55 - 84	Dark yellowish brown (10YR 4/4), friable to firm, roots common.
B2	84 - >120	Yellowish brown (10YR 5/6), firm to friable, roots rare.

Plot No: 32
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
AB	0 - 16	Dark brown (7.5YR 3/2) to very dark brown (10YR 3/2), friable to firm, roots abundant to common.
B	16 - 89	Brownish yellow (10YR 6/8), friable to firm, pumice lapilli common (Taupo pumice), roots rare.
C	89 - >120	Light brown grey (2.5Y 6/2), firm, roots rare.

Plot No: 33
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: 13 years since logging

Horizon	Depth (cm)	Description
AB	0 - 18	Very dark brown (10YR 2/2), friable, roots abundant.
A2	18 - 38	Brownish yellow (10YR 6/6), friable to firm, pumice lapilli rare (Taupo pumice), roots adundant.
B2	38 - 77	Light olive brown (2.5Y 5/4), firm, pumice lapilli rare (Taupo pumice), roots rare.
B3	77 - >120	Brownish yellow (10YR 6/8), firm, roots common to rare.

Plot No: 34
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 22	Black (2.5Y 2/0), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	22 - 37	Very dark grey (10YR 3/1) to very dark grey brown (10YR 3/2), friable to firm, pumice lapilli rare (Taupo pumice), roots abundant to common.
BC	37 - 52	Light yellowish brown (2.5Y 6/4), firm, pumice lapilli common (Taupo pumice), roots common.
B2	52 - >120	Yellowish brown (10YR 5/8), firm, roots common.

Plot No: 35
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	
Moisture condition:	moist
Drainage:	good
Site preparation:	13 years since logging

Horizon	Depth (cm)	Description
A	0 - 7	Very dark brown (10YR 2/2), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B2	7 - >120	Yellowish brown (10YR 5/6), firm to friable, roots common.

Plot No: 36
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 20	Black (10YR 2/1), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	20 - 62	Light olive brown (2.5Y 5/4), firm to very firm, pumice lapilli common (Taupo pumice), roots rare.
B2	62 - >120	Yellowish brown (10YR 5/8), friable to firm, roots common to rare in upper 20 cm to rare below.

Plot No:	37
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height 11 cm

Horizon	Depth (cm)	Description
B	0 - 66	Yellowish brown (10Yr 5/6) to light olive brown (2.5Y 5/4), friable, pumice lapilli rare (Taupo pumice), roots common to rare.
B2	66 - 97	Dark yellowish brown (19YR 4/4), firm, roots common.
B3	97 - >120	Yellowish brown (10YR 5/8), firm, roots rare.

Plot No:	38
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging, mound height 10 - 25 cm.

Horizon	Depth (cm)	Description
A	0 - 18	Black (2.5Y 2/0), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	18 - 103	Yellowish brown (10YR 5/6) to brownish yelow (10YR 6/6), friable, pumice lapilli common (Taupo pumice), roots common.
B2	103 - >120	Light yellowish brown (10YR 6/3), firm, roots common to rare.

Plot No: 39
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed mounds, 13 years since logging, mound height 15 cm.

Horizon	Depth (cm)	Description
A	0 - 6	Very dark gry brown (10YR 3/3), friable to firm, pumice lapilli rare (Taupo pumice), roots abundant.
B	6 - 40	Light olive brown (2.5Y 5/4), firm, pumice lapilli common (Taupo pumice), roots common to rare.
B2	40 - >120	Yellowish brown (10YR 5/6), firm, roots common.

Plot No: 40
Compartment: Moorhouse Rd

Effective rooting depth: >1.2
Rooting barrier: none
Water table: >1.2
Parent material: Taupo pumice
Moisture condition: moist
Drainage: good
Site preparation: V bladed mounds, 13 years since logging

Horizon	Depth (cm)	Description
A	0 - 7	Very dark brown (10YR 2/2), friable, roots absent.
B	7 - 25	Dark yellowish brown (10YR 3/4), firm, roots common.
A2	25 - 39	Very dark brown (10YR 2/2), firm, pumice lapilli rare (Taupo pumice), roots common.
B2	39 - 57	Light olive brown (2.5Y 5/6), firm, pumice lapilli common (Taupo pumice), roots common.
B3	57 - 99	Yellowish brown (10YR 5/6), firm, roots common.
B4	99 - >120	Yellowish brown (10YR 5/8), firm, roots common to rare.

Plot No:	41
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging.

Horizon	Depth (cm)	Description
A	0 - 11	Very dark brown (10YR 2/2), friable, roots abundant.
A2	11 - 36	Dark yellowish brown (10YR 3/4), friable to firm, pumice lapilli rare (Taupo pumice), roots common.
B2	36 - 95	Olive brown (2.5Y 4/4), firm, pumice lapilli common (Taupo pumice), roots rare.
B3	95 - >120	Dark yellowish brown (10YR 4/4), firm to very firm, roots rare.

Plot No:	43
Compartment:	Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging.

Horizon	Depth (cm)	Description
A	0 - 8	Dark brown (7.5YR 3/2), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	8 - 24	Brownish yellow (10YR 6/6), friable to firm, pumice lapilli common (Taupo pumice), roots abundant to common.
A2	24 - 45	Dark brown (7.5YR 3/2), friable to firm, roots common.
B2	45 - 83	Yellowish brown (10YR 5/8), friable to firm, roots common.
B3	83 - >120	Yellowish brown (10YR 5/6), friable to firm, roots rare.

Plot No: 44
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging.

Horizon	Depth (cm)	Description
A	0 - 4	Dark brown (7.5YR 3/2), friable, roots abundant.
B	4 - 43	Yellowish brown (10YR 5/6), friable, pumice lapilli common to rare (Taupo pumice), roots common.
B2	43 - 76	Yellowish brown (10YR 5/4), friable, roots common to rare.
B3	76 - 96	Pale brown (10YR 6/3), firm, roots common to rare.
B4	96 - >120	Yellowish brown (10YR 5/4), firm, roots rare.

Plot No: 45
Compartment: Moorhouse Rd

Effective rooting depth:	
Rooting barrier:	
Water table:	0.35 m in pit
Parent material:	Taupo pumice
Moisture condition:	saturated
Drainage:	poor
Site preparation:	V bladed mounds, 13 years since logging.

Horizon	Depth (cm)	Description
A	0 - 10	
B	10 - >35	

NOTE:

Discontinous paleosols within pit wall and slope geomorphology suggest that slumping is typical at this site.

Plot No: 46
Compartment:

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging.

Horizon	Depth (cm)	Description
A	0 - 15	Dark brown (7.5YR 3/2), friable, pumice lapilli rare (Taupo pumice) roots abundant.
B	15 - 56	Light olive brown (2.5Y 5/4), firm, pumice lapilli common (Taupo pumice), roots common to rare.
B2	56 - >120	Yellowish brown (10YR 5/6), firm, roots common to rare.

Plot No: 47
Compartment: Moorhouse Rd

Effective rooting depth:	>1.2
Rooting barrier:	none
Water table:	>1.2
Parent material:	Taupo pumice
Moisture condition:	moist
Drainage:	good
Site preparation:	V bladed mounds, 13 years since logging.

Horizon	Depth (cm)	Description
A	0 - 9	Very dark brown (10YR 2/2), friable, pumice lapilli rare (Taupo pumice), roots abundant.
B	9 - 40	Light yellowish brown (10YR6/4), firm, pumice lapilli common (Taupo pumice), roots common.
A2	40 - 63	Dark yellowish brown (10YR 3/4), firm, roots common.
B2	63 - >120	Yellowish brown (10YR 5/8), firm, roots common to rare.

APPENDIX 2. Plot sheet for gathering information from PSP plots for model testing.

Management of Eucalypts Cooperative

EUCALYPT SITE SURVEY

Forest:

Compartment:

Plot Number:

(Use PSP Number if appropriate)

Species:

Age:

Date:

Person collecting data:

Longitude _____° _____'

Altitude: _________m

Slope: Uphill ° Opposite____°

Average_____°

Latitude _____° _____'

Aspect downhill_____° Compass pt_________

Landform

Topex:	
Cardinal Points (°)	Elevation angle (°)
0°	
45°	
90°	
135°	
180°	
225°	
270°	
315°	
Sum	

A Horizon Depths:	(mm)
1:	14:
2:	15:
3:	16:
4:	17:
5:	18:
6:	19:
7:	20:
8:	21:
9:	22:
10:	23:
11:	24:
12:	25:
13:	
Mean	

Map attached to show plot locations? ☐

Date soil samples sent to NZFRI for pH: ..../......../.......

Notes:

Aspect: Assessed within boundaries of plot. Use compass then convert to compass point (N, NE, E, SE, S, SW, W, NW)

Slope: Average of the angle taken from plot centre to highest point on plot perimeter and the angle to the plot perimeter directly opposite. Ignore negatives in calculating average slope.

Topex: Using hypsometer take angle to horizon or lowest point of sky if land obscured by trees etc.

A Horizon: Randomly locate 25 sample points. Remove litter layer to mineral soil. Make spade cut. Measure depth of black or dark brown soil in millimetres.

pH: Take a small subsample of soil (½cup approx) from each A horizon point and add to a plastic bag in which all 25 samples are bulked. Label bag clearly with plot number (as on this sheet), date, forest, company.

Landform: