9/92

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RESOURCE CENTRE:	PLANTATION MANAGEMENT	EXPT NO.:	
CODE:	92 / 93 (Financial Year) 105 (Resource Centre No.)	WORK PLAN NO.:	
AUTHOR:	I.P. McINNES	DATE:	13/4/93
TITLE:	PREDICTING GREEN CROWN HEIGHT IN DOUGLAS-FIR		

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AUTHOR(S): I.P. McINNES **DATE:** 13.4.93

KEYWORDS: *PSEUDOTSUGA MENZIESII*, CROWN

ABSTRACT*

A function to predict the green crown height of Douglas-fir in New Zealand was developed for use in construction of an 'EARLY" type growth model for Douglas-fir.

This function was of the form:

$$\text{Crown Height} = \text{Mean Top Height} - (\beta 1 \times \text{Mean Top Height}^{\beta 2} \times \text{Stocking}^{\beta 3})$$

and had the following coefficients:

$\beta 1 = 14.284$
$\beta 2 = 0.238$
$\beta 3 = -0.14353$

All independent variables were significant at the 95 percent level of probability, and the R^2 value was 0.44.

The function was developed from a limited data set so obtaining more data in the near future is important for the validation and improvement of the function. In particular, some regions within New Zealand have very few crown height measurements and there are no measurements for stands less than 15 years of age.

OBJECTIVE

To fit a function which predicts the height of the green crown for Douglas-fir in New Zealand. This function would be dependent on variables such as stocking and height. The function will be an important step in the construction of a Douglas-fir "EARLY" type growth model.

INTRODUCTION

Crown height functions have not been produced in great abundance in New Zealand, either for radiata pine or for any other species. Two functions for radiata pine currently exist. One was developed by Beekhuis (1965) and the other by Garcia as part of PPM88. The two radiata functions were both of the form below.

$$\text{Crown Height} = \text{MTH} - (\beta 1 \times \text{MTH}^{\beta 2} \times \text{SPH}^{\beta 3})$$

There are no functions available for Douglas-fir in New Zealand. The form above was chosen as a starting point for the construction of the function for Douglas-fir.

The reason for developing a crown height function is for use in building a Douglas-fir "EARLY" type growth model. This requires a measure of green crown which is not available due to the infrequent measurement of green crown in Permanent Sample Plots (PSPs). A function will allow green crown to be predicted for those PSPs that do not already have it measured. A green crown function will also be useful in predicting branch senescence and the transition between live (growing) and dead branches.

METHOD

The Data set.

The first step was to obtain a data set from the PSP system that could be used to develop the function. It consisted of all Douglas-fir plots in New Zealand for which crown measurements had been taken. Crown height is not a particularly common measurement and only a small number of PSPs have had this variable measured. These also tended to be measured infrequently, rather than at the time of each remeasurement. Generally, plots will have been measured several times for crown height, (depending on their age), or not at all.

The initial data set contained 309 observations (ie an observation is a measurement of crown height in a plot). This set was examined closely and graphed to determine any abnormalities. Several observations were outside the general trend so these were excluded from the data set. One source of problems was the effect of thinning. When a stand has been thinned, the green crown will be at a level caused by the stocking before thinning, not the post-thinning stocking. To overcome this, the stocking before the thinning was used, rather than the remaining stocking. Measurements shortly after a thinning were excluded as the crown was not at the level expected of a stand of that stocking, ie it had not yet started to rise again.

This resulted in a reduced data set containing 266 observations. These are described by region and forest in Table 1.

Table 1. Location of Crown Height Observations.

Region	Forest	No. of Plots	No. of Observations
Rotorua	Kaingaroa	34	113
	Waimihia	4	12
	FRI Grounds	1	7
	Horohoro	1	7
Wellington	Karioi	3	15
	Gwavas	1	1
Nelson	Golden Downs	7	19
Canterbury	Hanmer	7	38
	Coalgate	3	15
Southland	Blue Mountains	10	39
		71	266

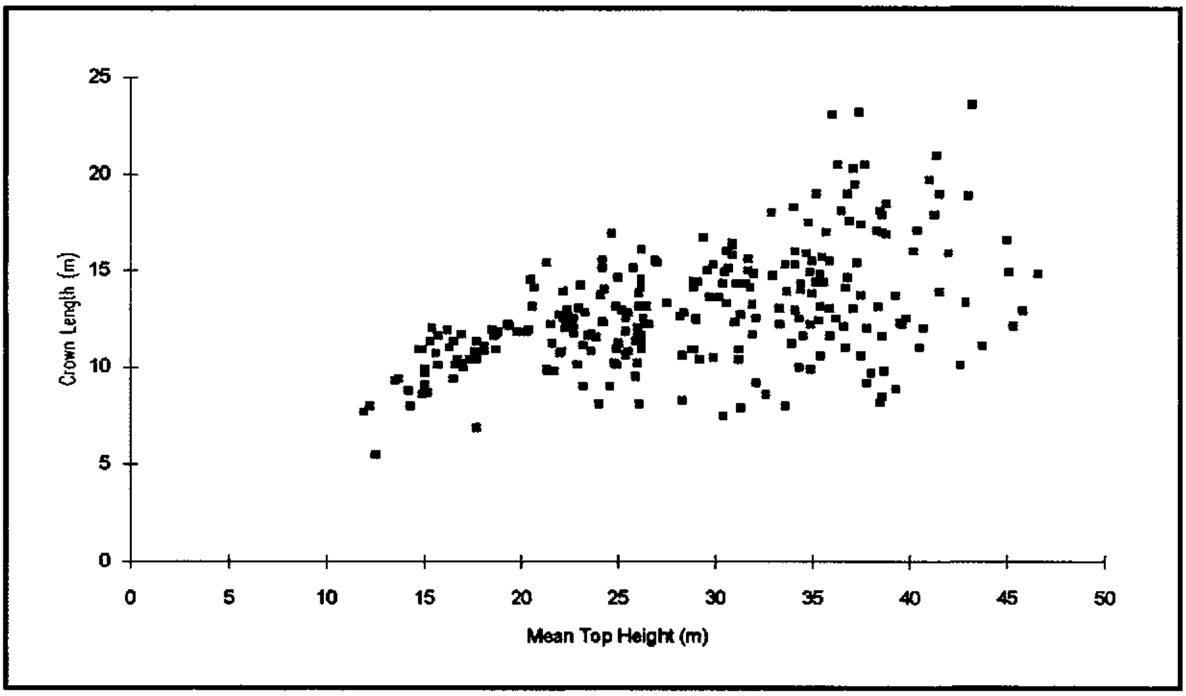
A brief summary of the data is contained in Table 2.

Table 2. Summary of Data .

	Mean	Minimum	Maximum
Age	36.0	16	65
Stocking	756	148	2530
Mean Top Height	28.6	11.9	46.6
Crown Height	15.7	3.4	33.2
Crown Length	12.9	5.5	23.6

Figure 1 shows the crown length data plotted against mean top height.

Figure 1. Crown Length



As the previous tables and figures show, this is only a small data set and the data is very limited in some respects. This in particular relates to region, ie Nelson and Wellington have very few observations. Also there is no data from coastal forests in Southland and Otago for example. There are no observations of crown heights for stands less than 15 years old. These are needed to indicate when the crown will start to rise from ground level.

The data set used included the following variables ;

Plot-ID : the plot identification number as used on the PSP system. Includes Region, Experiment number, Sub-experiment number, Plot number, and Sub-plot number.

Forest : Abbreviated code for the forest in which the plots are.

Age : age of trees at time of measurement (years).

SPH : live stems per hectare.

Crown Height : height of the green crown above ground level (m). The value is the average of those green crowns measured in each plot.

MTH : mean top height (m), as calculated by the PSP system.

DBH : mean diameter of trees in the plot (cm).

MTD : mean top diameter (cm).

Analysis Conducted.

The data was analysed using Microsoft Excel Version 4.0. The dependent variable used was Crown Length, ie the length of the green crown from the top of the tree. This was calculated by subtracting the mean crown height from the MTH. Crown length was used as it tends to remain the same once full canopy closure has been attained. Crown height will continue to rise as stand height increases so is less satisfactory (Beekhuis 1965).

The first function tested was of the same form as the radiata pine functions and involved height and stocking. The regression statistics and residual error was looked at to see if other variables might improve the precision of the predictions.

A second function tested also used mean diameter and mean top diameter. This was then compared to the first function.

The possibility of a relationship between diameter and green crown height was investigated as this may have some effect on the utility of the function when incorporated within packages such as STANDPAK.

The results of the analysis are in the next section.

RESULTS

The first regression was of the form below :

$$\text{Crown Length} = \beta 1 \times MTH^{\beta 2} \times SPH^{\beta 3} \quad (1)$$

$$\Rightarrow \text{Crown Height} = MTH - (\beta 1 \times MTH^{\beta 2} \times SPH^{\beta 3})$$

The regression gave the following coefficients :

$\beta 1 = 14.284$

$\beta 2 = 0.238$

$\beta 3 = -0.14353$

The regression was done on Microsoft Excel so log transformations were used for the regression and then converted back to give the coefficients above. The statistical analysis is included in Appendix One. The coefficients for MTH and SPH were significant at the 95 percent probability level. The R^2 value was 0.44. The plots of the residuals (actual crown length minus predicted) are shown as Figures 2 and 3.

Figure 2. SPH Residual Plot.

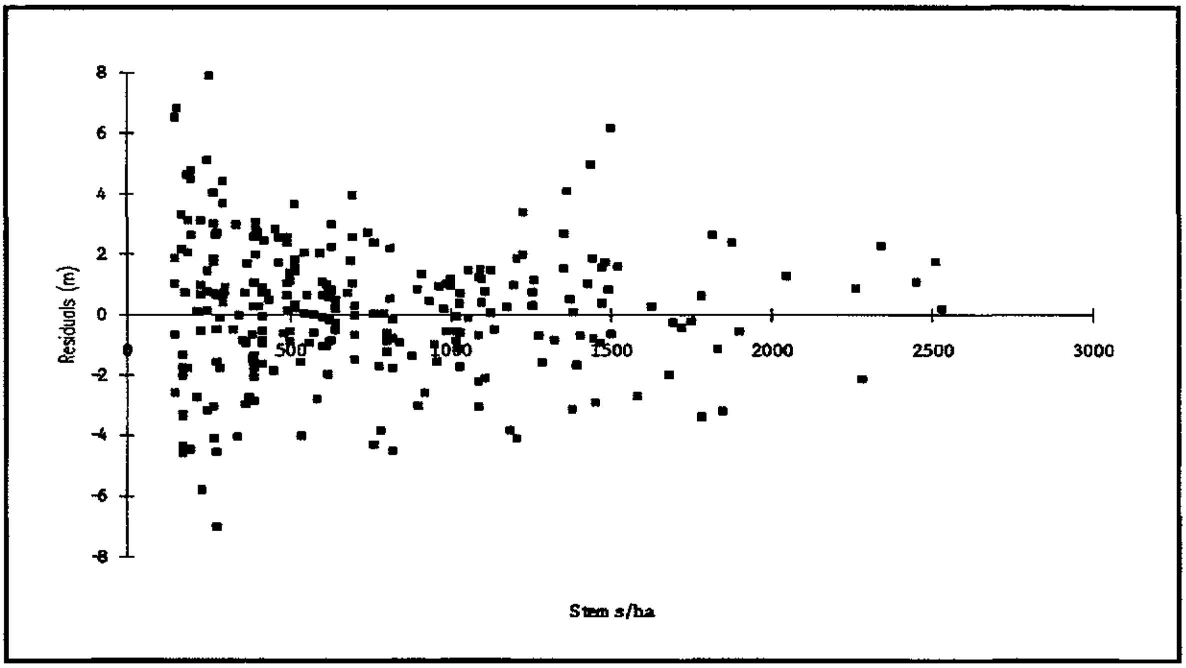
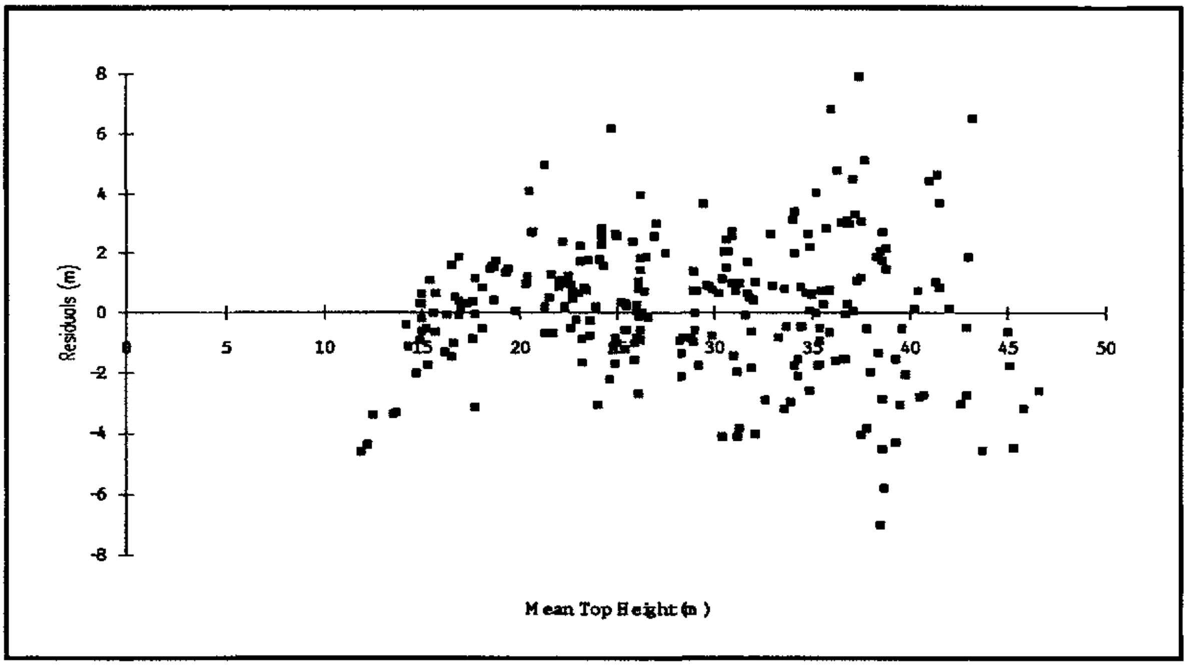


Figure 3. MTH Residual Plot



The residuals were plotted against a number of other variables such as DBH and MTD to see if a pattern emerged. These graphs have been included in Appendix One. No trends were apparent.

The effect of thinning may be quite important so the residuals were plotted against the time since thinning. After a thinning, the crowns will be above their normal height and will take some time to return to equilibrium. This only applied to some plots as many were unthinned. The residuals were classified into three thinning levels, Heavy (18-39.9 % stems remaining), Medium (40-59.9 % stems remaining), Light (60-80 % stems remaining). These are included below as Figures 4.1, 4.2, and 4.3. The graphs indicate that the data used in this analysis is free of any apparent effects of thinning in "lagging" the green crown length.

Figure 4.1 Heavy Thinning (18-39 % stems remaining).

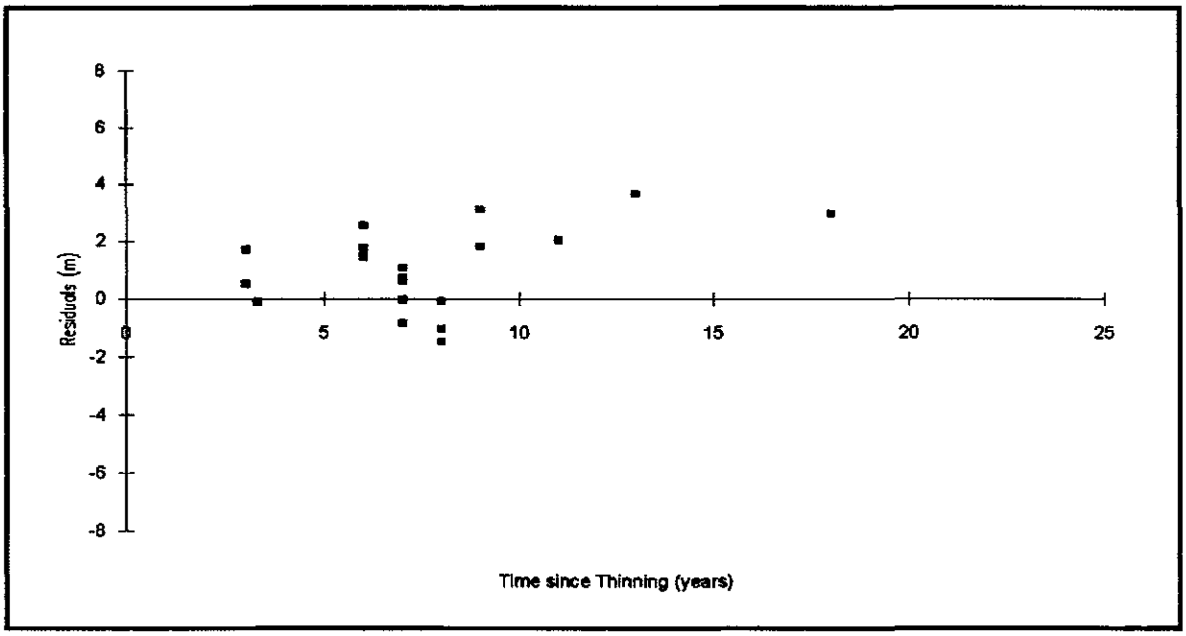


Figure 4.2 Medium Thinning (40-59 % stems remaining).

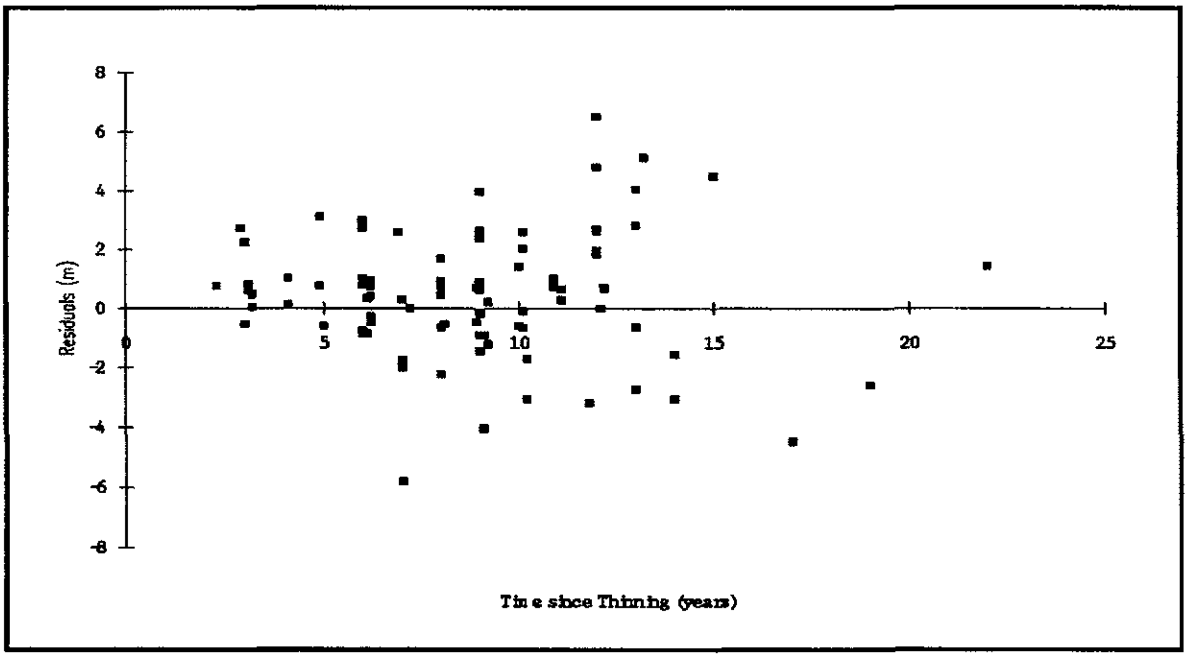
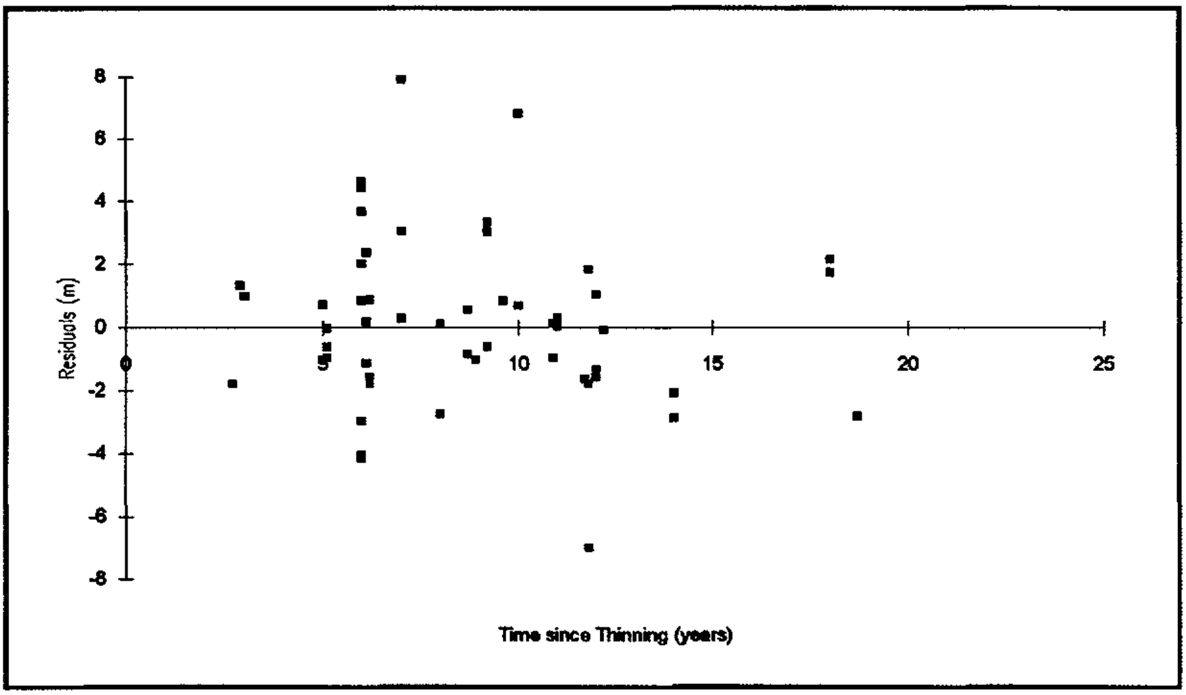


Figure 4.3 Light Thinning (60-80 % stems remaining)



A second regression was undertaken using a slightly different form that incorporated DBH and MTD. Trees with larger diameters tend to be taller than trees with smaller diameters and this may possibly apply to crown height as well. That is, trees with a larger DBH will have a higher green crown height. The regression below would show if this would have any significant effect on the function.

$$\text{Crown Length} = \beta1 \times MTH^{\beta2} \times SPH^{\beta3} \times (DBH/MTD)^{\beta4} \qquad (2)$$

This gave the following coefficients :

$\beta1 = 14.963784$

$\beta2 = 0.235868$

$\beta3 = -0.15165$

$\beta4 = -0.05642$

The statistics for this analysis and the plots of the residuals have been included in Appendix Two. It was shown that the coefficient β4 was insignificant at the 95 percent probability level and made a minimal improvement on the predictive ability of the model. The initial function is better as it involves fewer variables but explains almost the same amount of variation.

Another aspect that was investigated is the relationship between tree diameter and crown height. The Petterson height curve is used to show the relationship between diameter and tree height so it is possible that there maybe a similar relationship between tree diameter and crown height. Individual tree data from several PSPs was plotted to see if there was such a trend. Some examples are included in Appendix Three. Crown height tends to remain at a constant level throughout the stand with diameter having no effect even though the tree heights will vary. This indicates that there is a relationship between tree height and crown length, rather than crown height.

CONCLUSIONS

Of the functions tested, the following is deemed to be the best predictor of crown height for Douglas-fir in New Zealand.

$$\text{Crown Height} = \text{MTH} - (14.284 \times \text{MTH}^{0.238} \times \text{SPH}^{-0.14353})$$

Although only two forms of function have been looked at in any detail in the preceding pages, others were investigated. A linear function is obviously not going to be suitable due to the nature of the data, as can be seen in Figure 1 earlier. There is a definite trend existing that will not be modelled at all well by a linear function.

Plots of the residual errors showed no patterns so the inclusion of other variables would not improve the model. A function which included DBH and MTD was tested but this made very little difference to the precision of prediction.

The chosen function (1) does have it's limitations. These are mainly with regard to the data set. A large amount of the data came from the Rotorua region, with very small amounts from Nelson and Wellington. This means that any predictions would be likely to be better for Rotorua than for other regions. The plots of the residual values by region are included in Appendix One (Figures A4.1 to A4.5). The data did not include any very young data to show when the green crown began to rise above ground level. This has been partly rectified by the installation of a large trial in a 10 year old stand in Kaingaroa for which crown heights have been measured.

RECOMMENDATIONS

The major recommendation for the future is to increase the database of crown heights for Douglas-fir in New Zealand. A larger set will allow better models to be developed. One aspect is to get more information in regions for which there is currently little data. Rotorua region has a large amount of data relative to the other regions which all have very little. Within certain regions, the data is not very representative of the forests present, for example, there is no data from the coastal forests of Canterbury and Otago.

This could partly be overcome by including crown height as a measurement to be taken from most PSPs at the next measurement. Plots that have only recently been thinned should be excluded but otherwise a wide coverage should result.

The other large deficit is regarding the age classes for which the data is available. There is no data for the very young stands, ie less than 15 years. This is important so as to determine when the green crown will start to rise above ground level. A large trial recently installed in a 10 year old stand of Douglas-fir in Kaingaroa will help to some extent but more data will be needed in the future. This problem could be overcome by putting in some temporary plots in young stands specifically for the purpose of obtaining crown data.

The collection of this data would enable a validation of the function in the near future, and if necessary, for the improvement of the model. The current function with it's limited data base should be used with care.

The crown height to diameter relationship was only looked at briefly and there is more work that could be done on this in the future. This will be quite important for the development of single tree growth models.

REFERENCES

Beekhuis, J., 1965. Crown Depth of Radiata Pine in Relation to Stand Density and Height. *New Zealand Journal of Forestry* 10 (1) : 43-61.

APPENDIX ONE.

Crown Height Function One - Statistics and Residuals.

This Appendix contains the statistics on the crown height function and the residual plots by several variables.

Regression Statistics	
Multiple R	0.66149216
R Square	0.43757188
Adj R Square	0.43329486
Standard Error	0.17297665
Observations	266

Analysis of Variance

	df	*Sum of Sq*	*Mean Sq*	*F*	*Sig F*
Regression	2	6.12227884	3.06113942	102.307655	1.3609E-33
Residual	263	7.86920261	0.02992092		
Total	265	13.9914814			

	Coefficients	*Std Error*	*t Statistic*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.65914101	0.20154227	13.193962	6.7815E-31	2.26229941	3.05598261
lnMTH	0.2379999	0.03822811	6.22578335	1.8672E-09	0.16272784	0.31327197
lnSPH	-0.1435338	0.01694416	-8.4709902	1.6995E-15	-0.1768973	-0.1101704

Figure A1. Residual Error against Diameter.

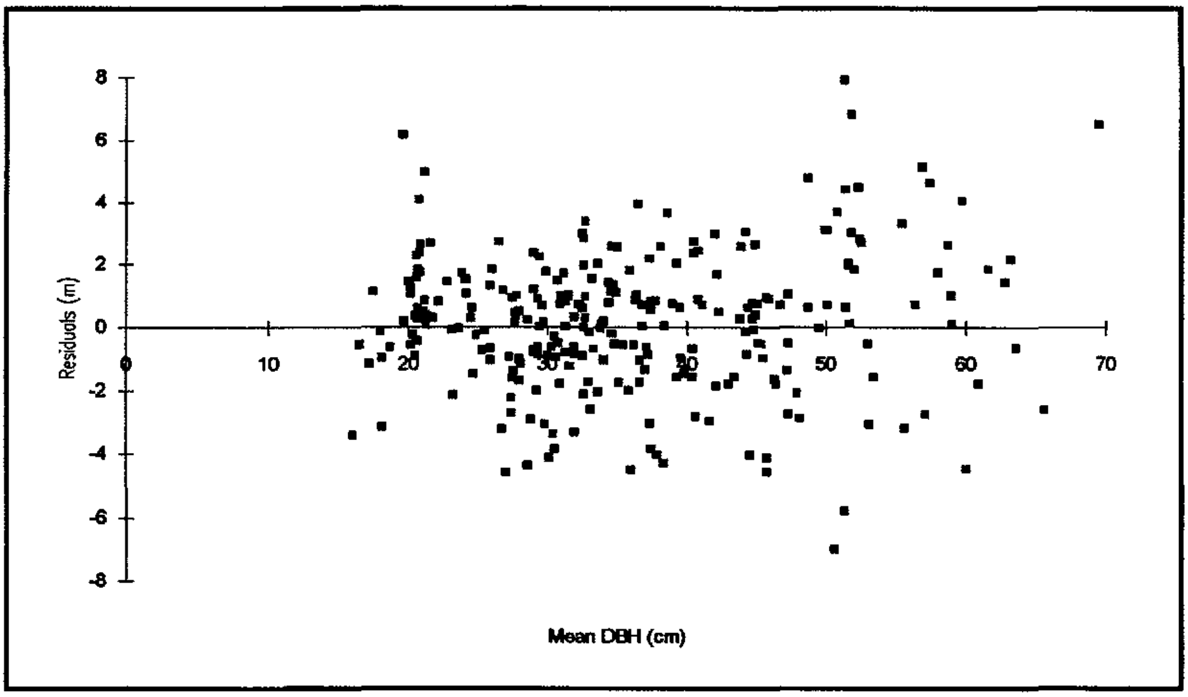


Figure A2. Residual Error against Mean Top Diameter.

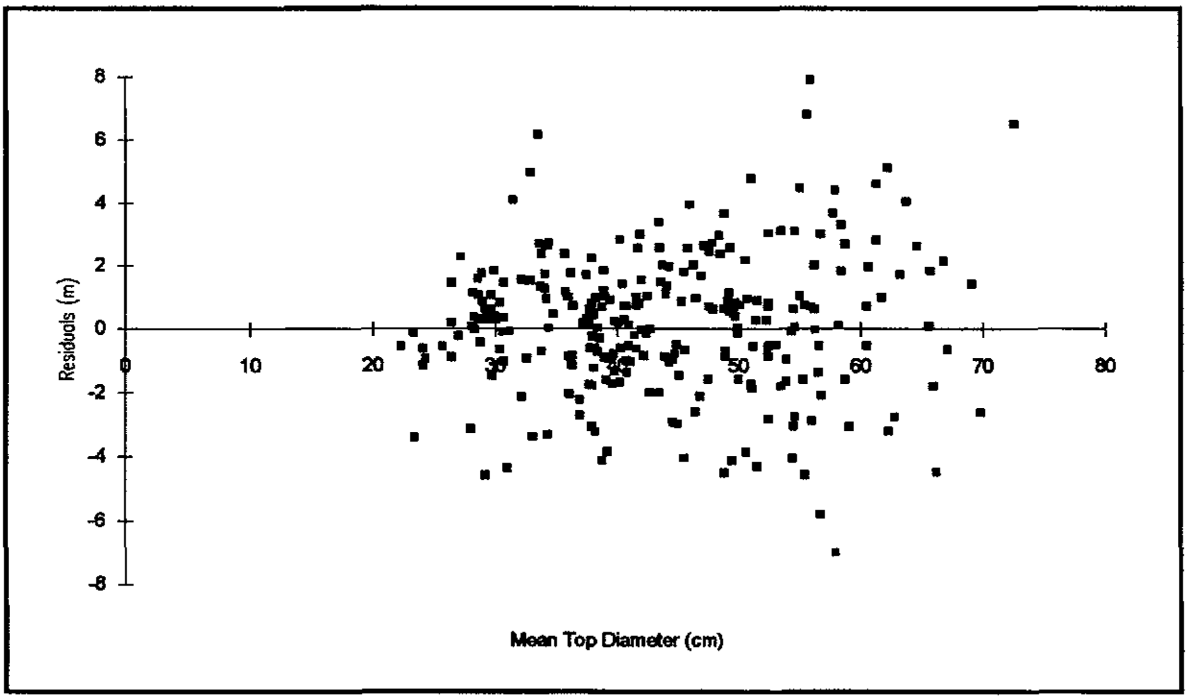
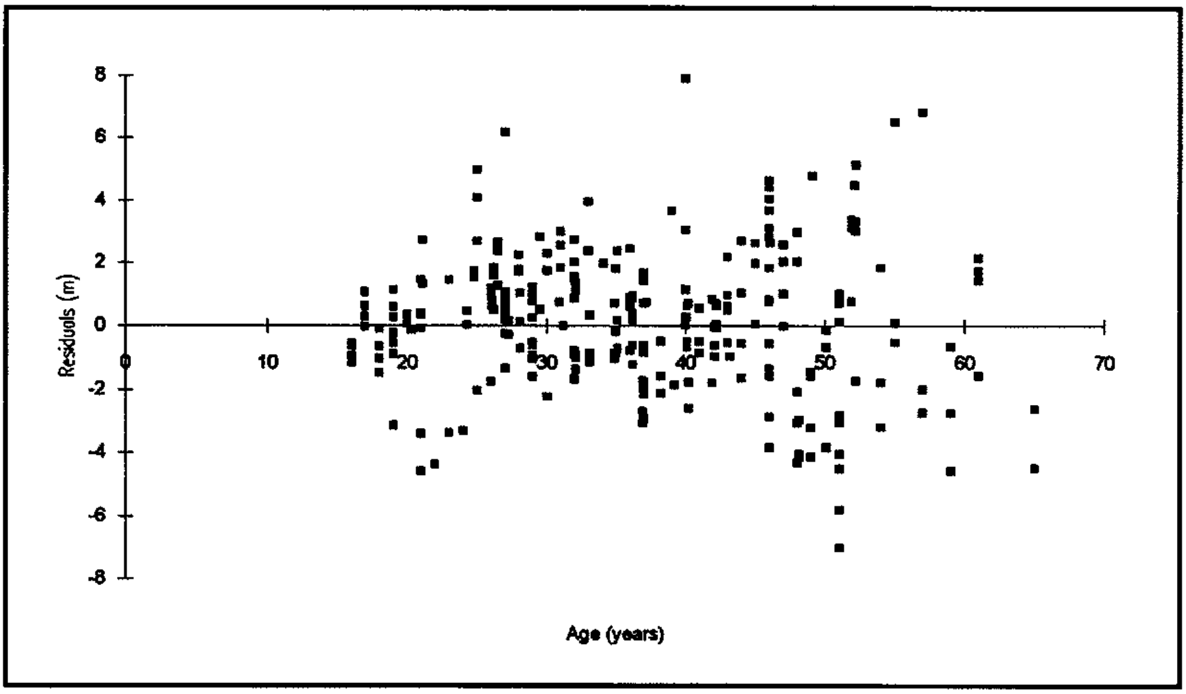


Figure A3. Residual Error against Age.



Residual Errors graphed by Region.

Figure A4.1 Rotorua Region.

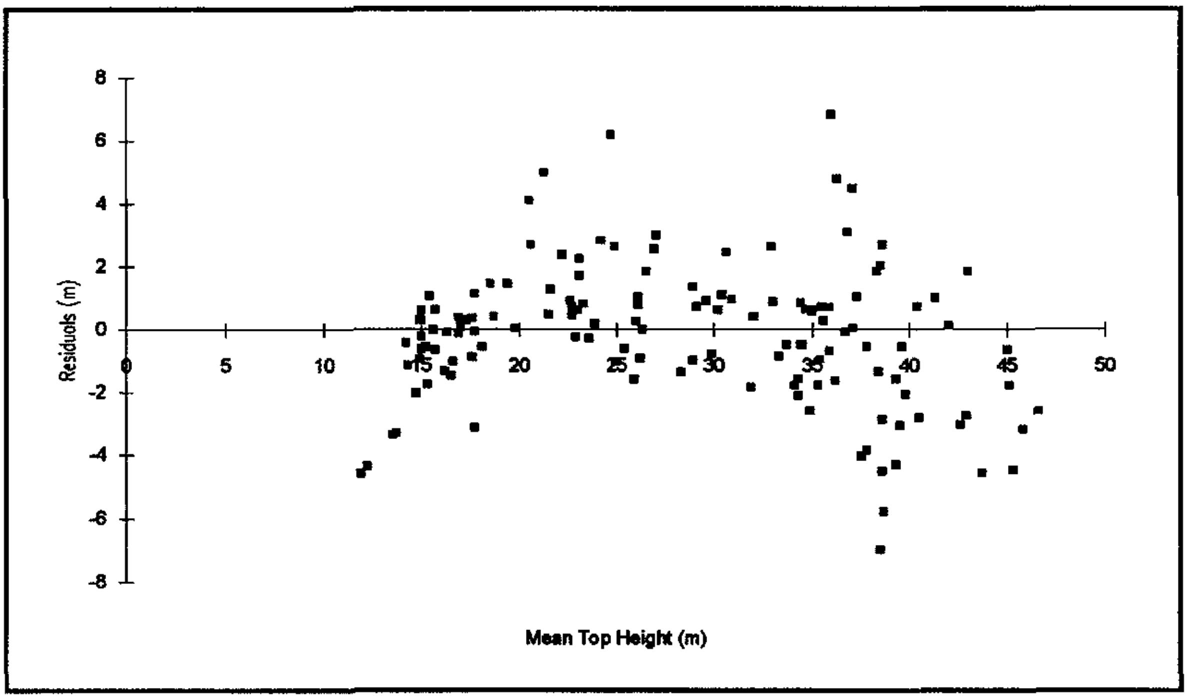


Figure A4.2 Wellington Region.

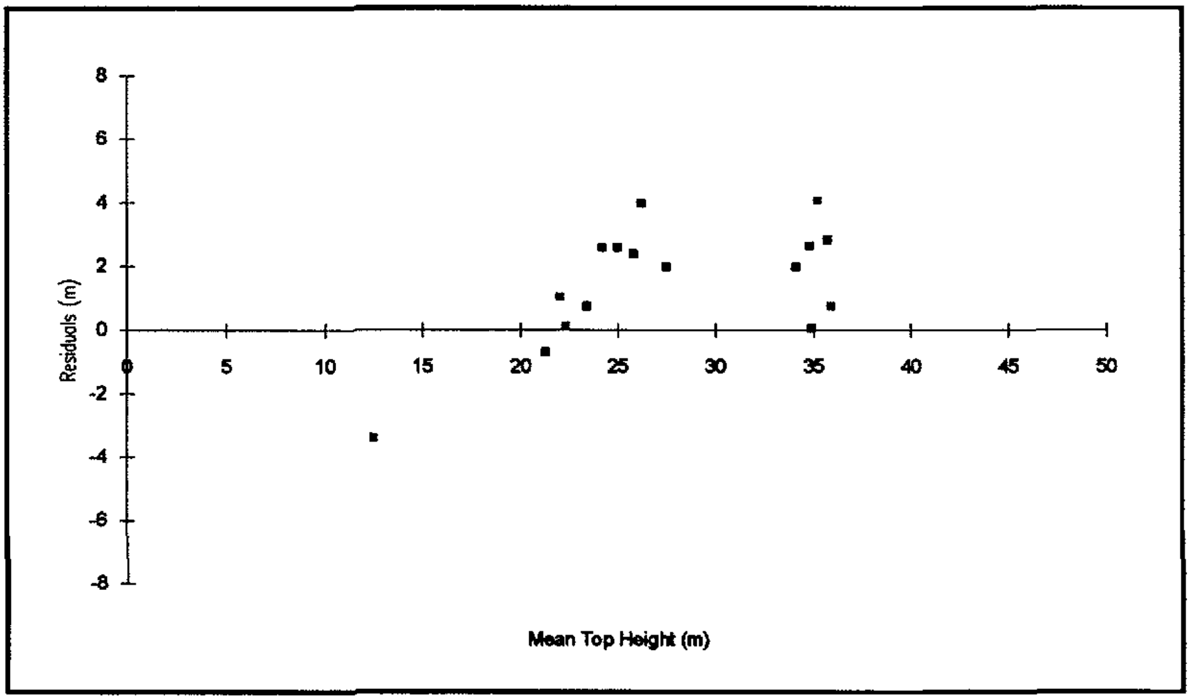


Figure A4.3 Nelson Region.

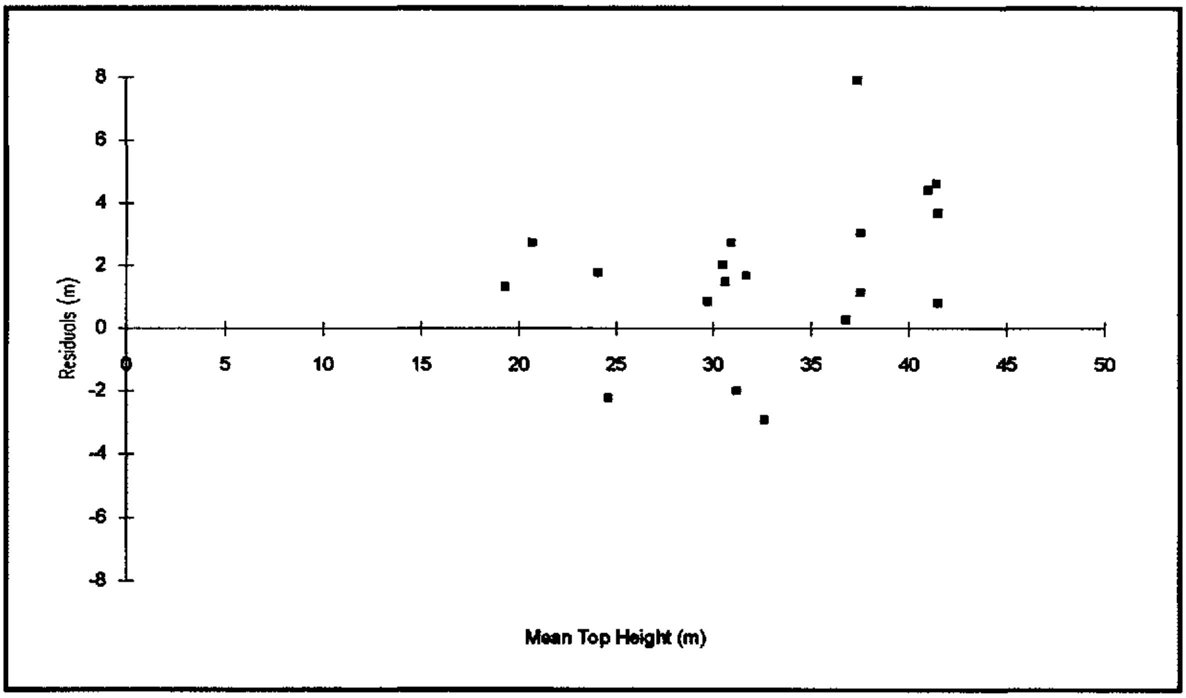


Figure A4.4 Canterbury Region.

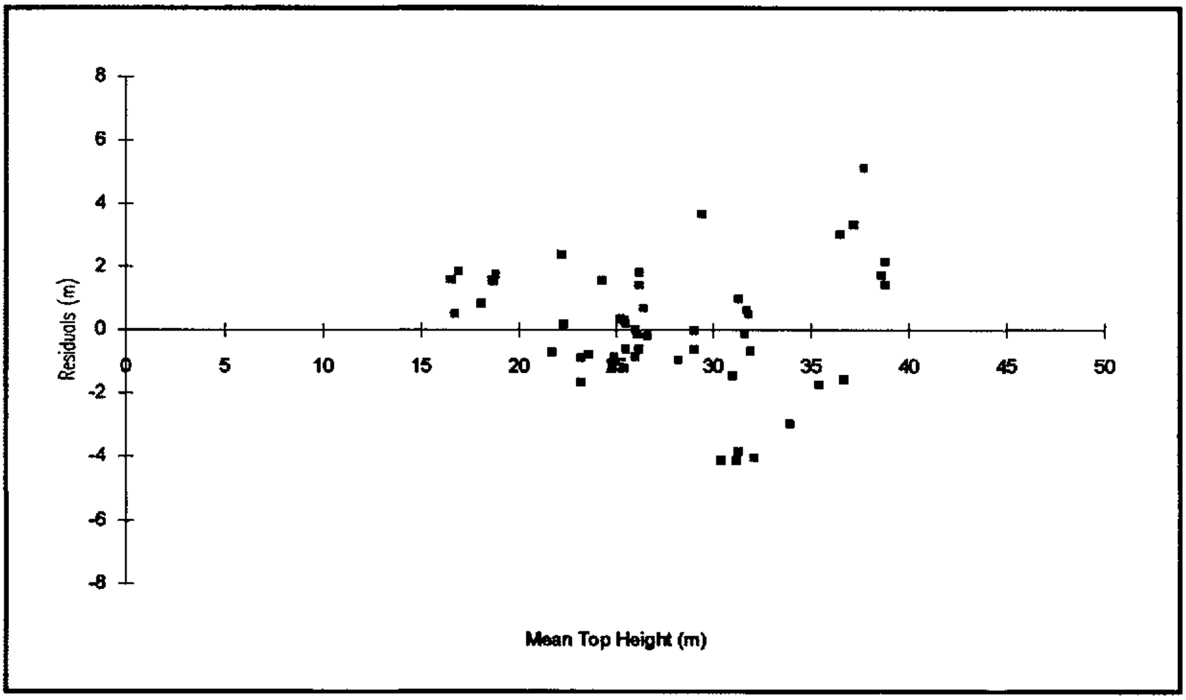
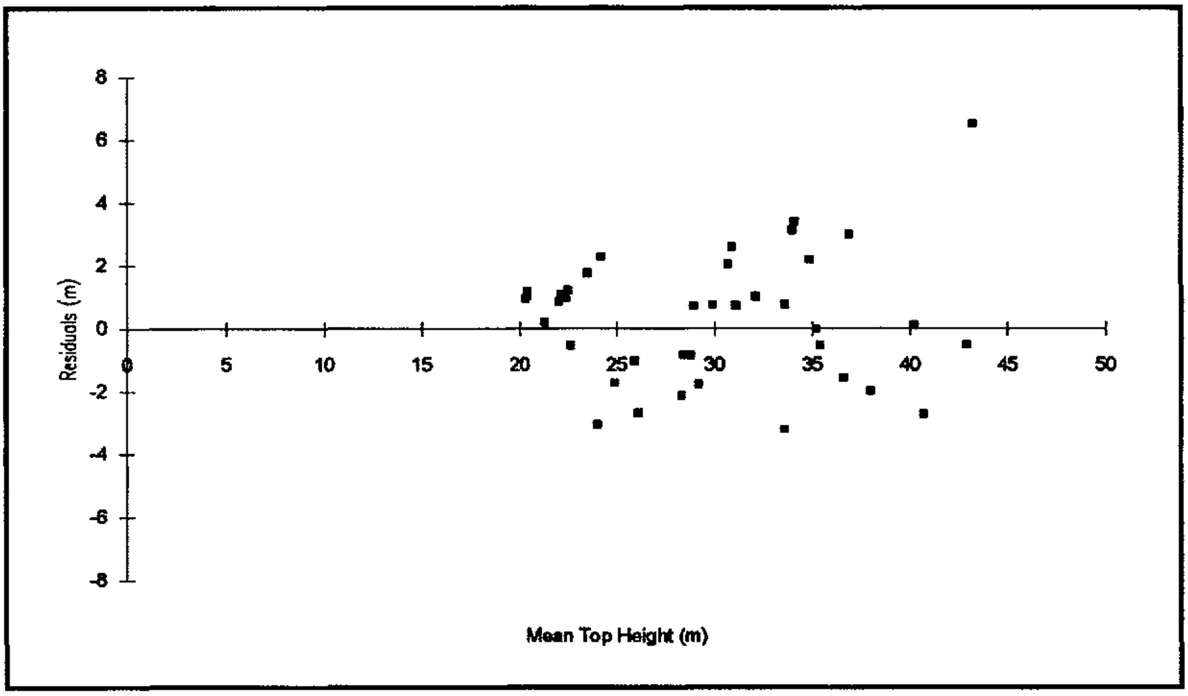


Figure A4.5 Southland Region.



APPENDIX TWO

Regression Two - Statistics and Residual Errors.

Regression Statistics	
Multiple R	0.66159
R Square	0.437701
Adj R Square	0.431263
Std Error	0.173286
Observations	266

Analysis of Variance

	df	*Sum of Sq*	*Mean Sq*	*F*	*Sig F*
Regression	3	6.124092	2.041364	67.98155	1.52E-32
Residual	262	7.867389	0.030028		
Total	265	13.99148			

	Coeff	*Std Error*	*t Statistic*	*P-value*	*Lower95%*	*Upper95%*
Intercept	2.705633	0.276698	9.778292	1.76E-19	2.160798	3.250468
lnMTH	0.235868	0.039267	6.006725	6.22E-09	0.158548	0.313187
lnSPH	-0.151648	0.037128	-4.084457	5.86E-05	-0.224755	-0.078541
lnDBH/MTD	-0.056423	0.229618	-0.245728	0.806083	-0.508555	0.395708

Figure A5. SPH Residual Plot.

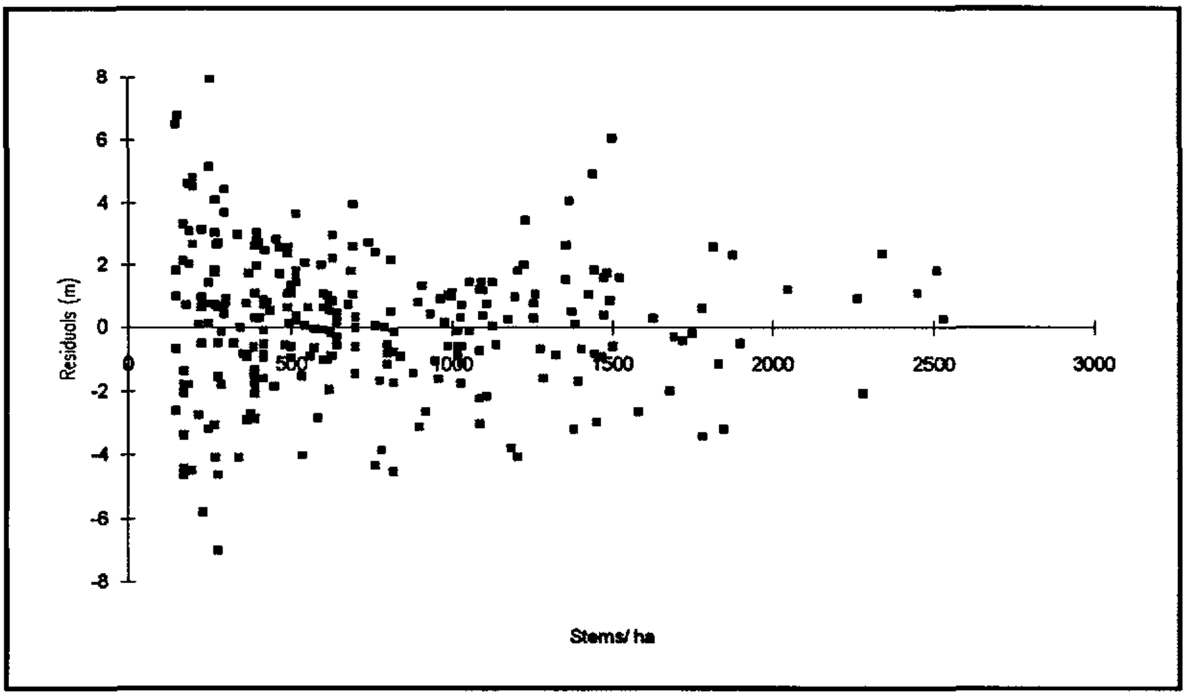


Figure A6. MTH Residual Plot.

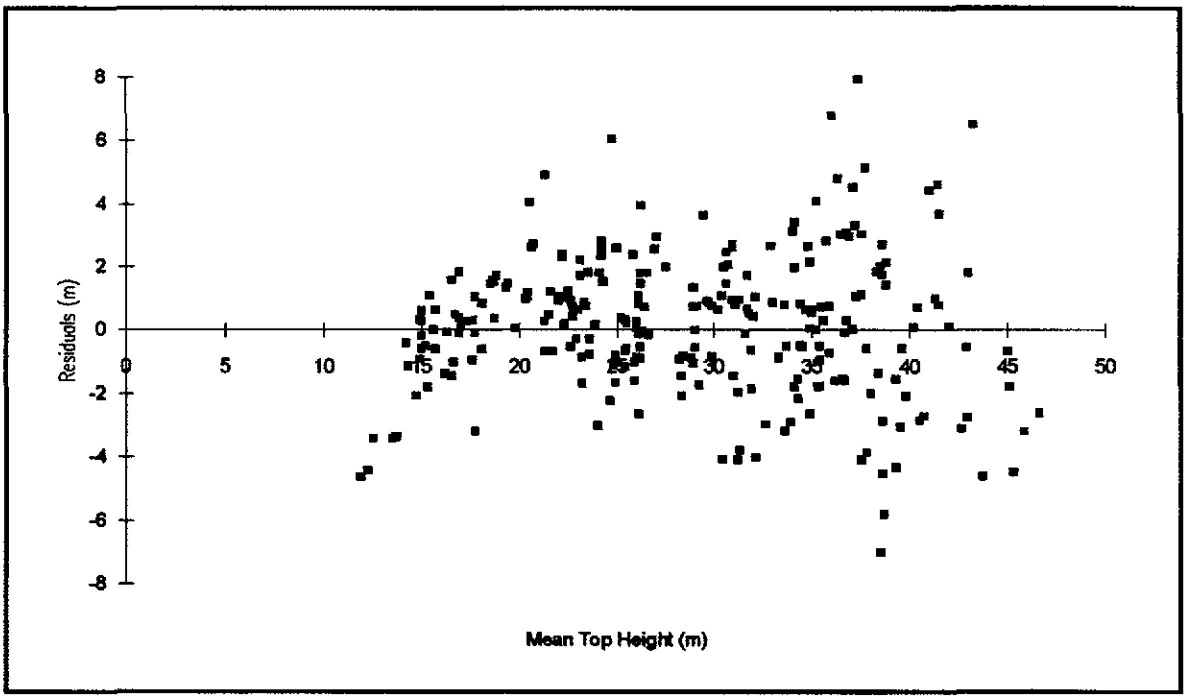
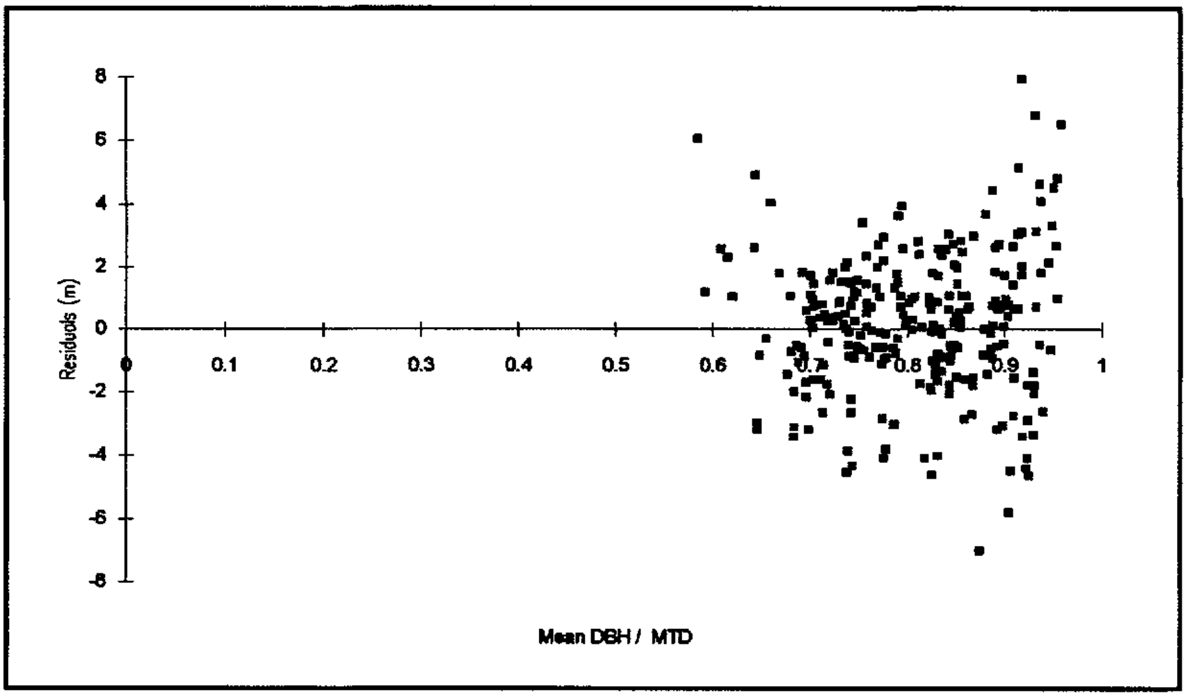


Figure A7. DBH/MTD Residual Plot.



APPENDIX THREE

Graphs of Individual Diameters against Crown Height for Selected Permanent Sample Plots.

Figure A8. RO 2080/0/3/0 Age 27, 173 Stems/ha.

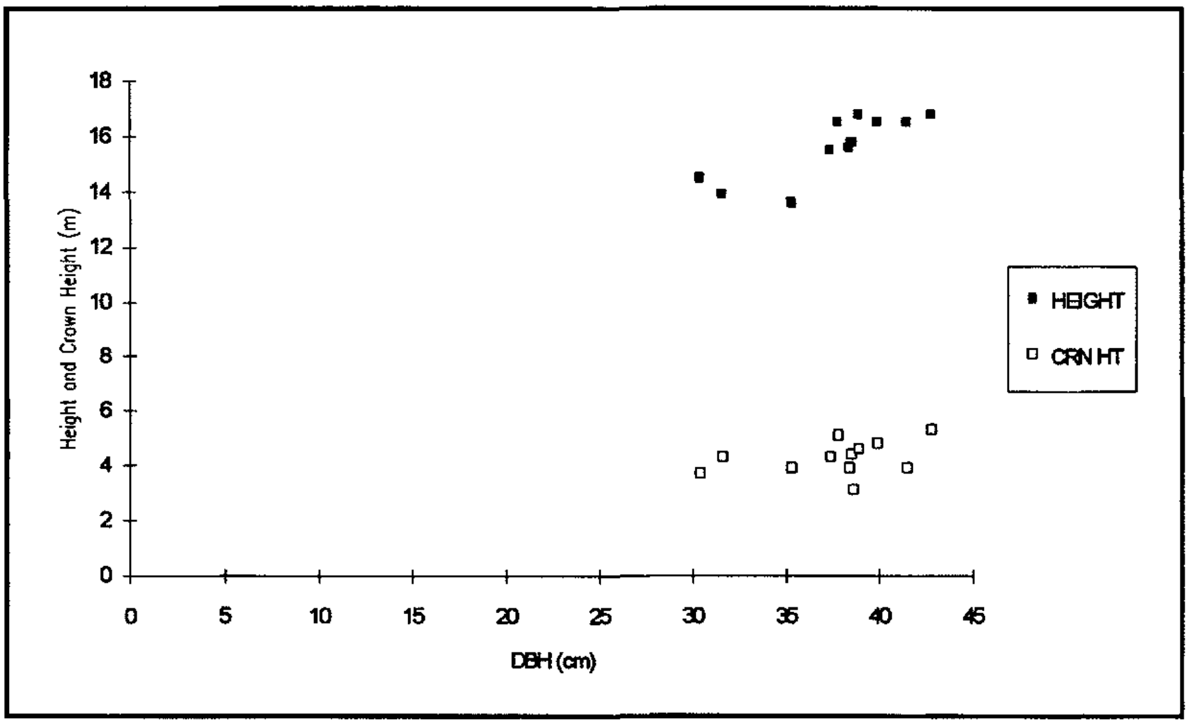


Figure A9. CY 112/0/1/0 Age 35, 622 Stems/ha.

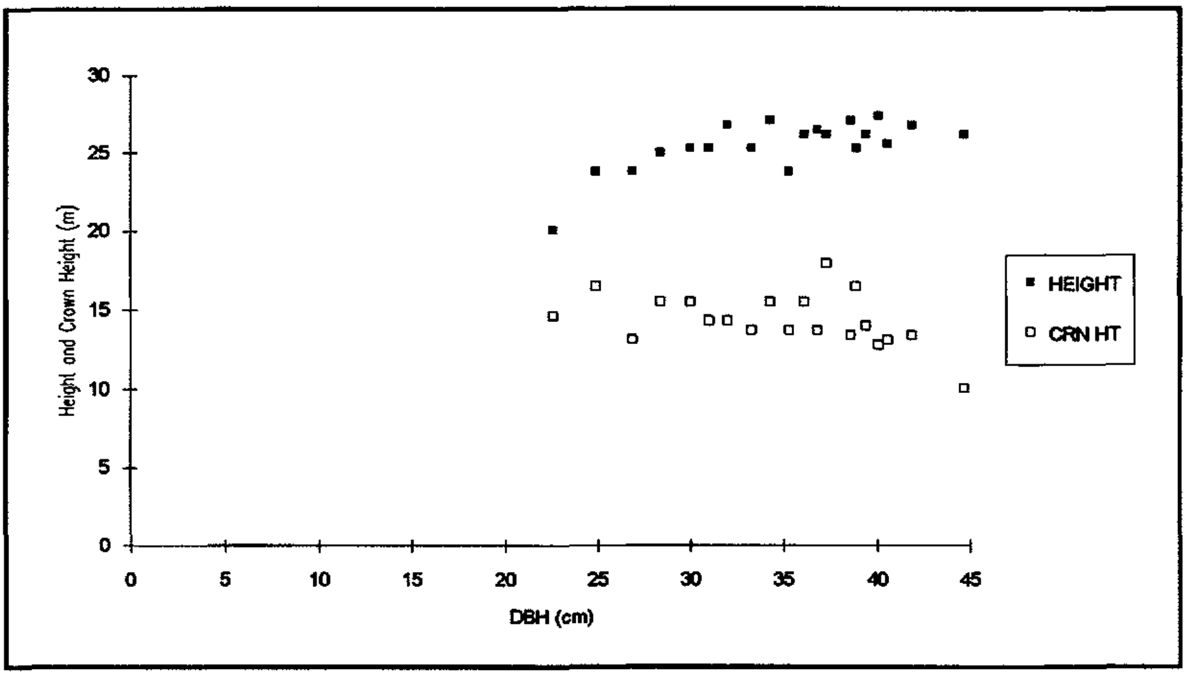


Figure A10. CY 112/0/1/0 Age 61, 168 Stems/ha.

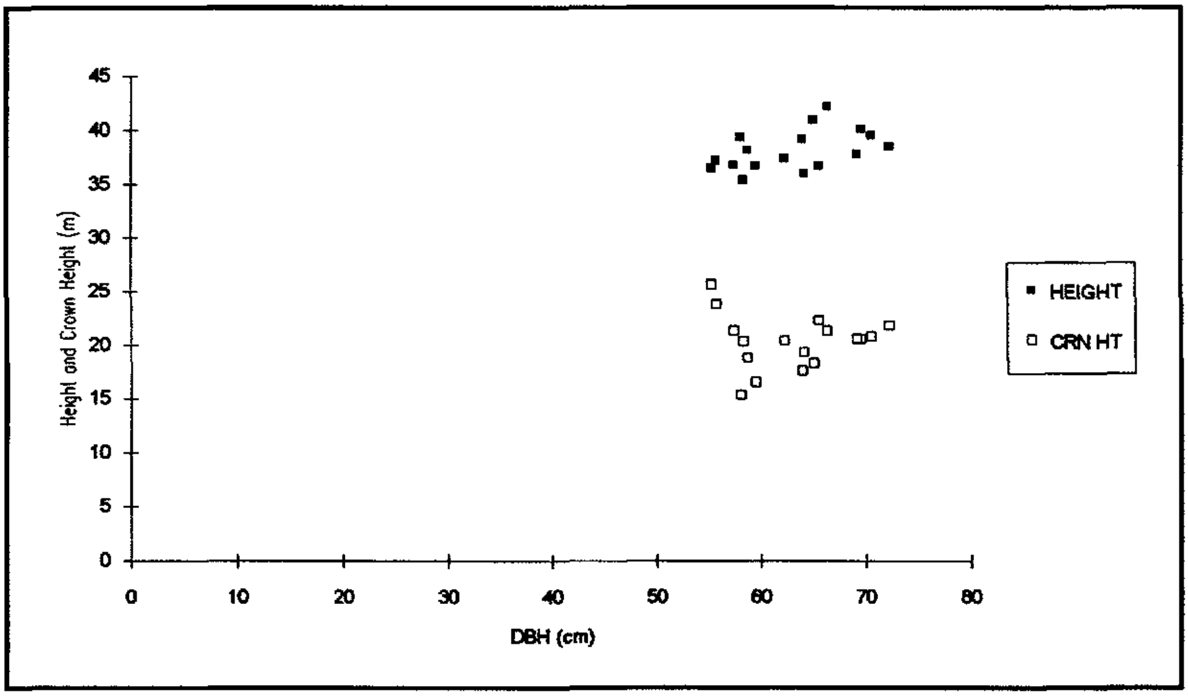


Figure A11. RO 906/0/3/0 Age 16, 1833 Stems/ha.

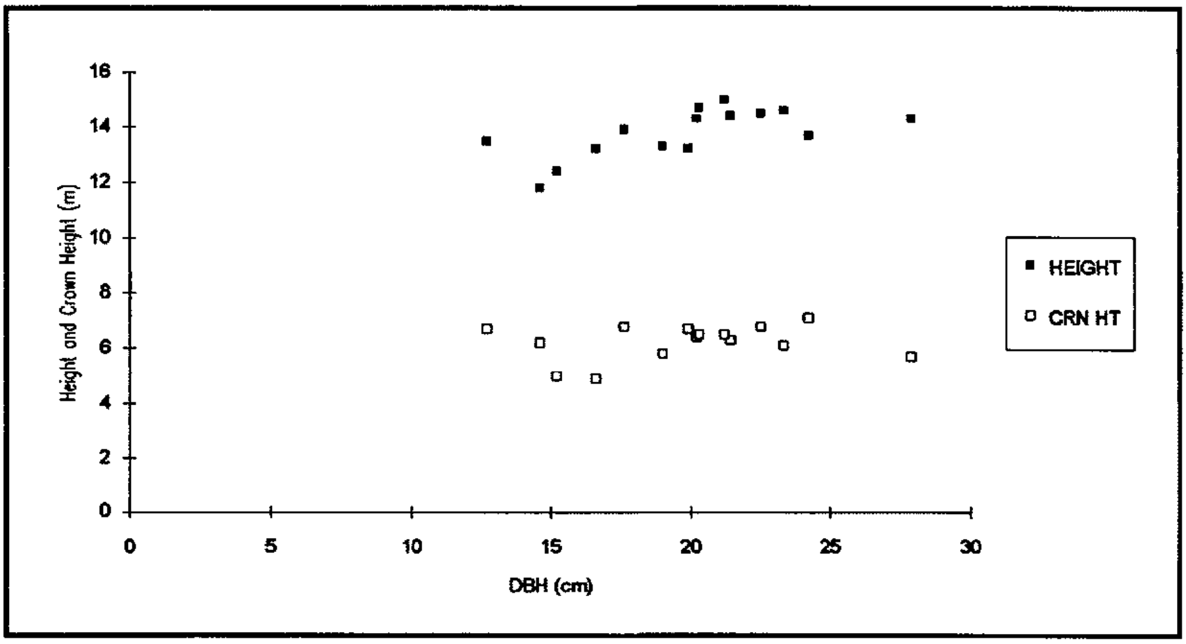


Figure A12. RO 20/0/3/0 Age 41, 1136 Stems/ha.