PO Box 1127
Rotorua 3040
Ph: + 64 7 921 1883
Fax: + 64 7 921 1020
Email: info@ffr.co.nz
Web: www.ffr.co.nz

Theme: Radiata Management

Task No: 1.5
Milestone Number: 1.5.2

Report No. FFR- RO28

Effects of Pruning Intensity: Analysis of the Second Log Pruning Trial Series

Authors:
P Silcock, M Kimberley, A Callahan

Research Provider:
Scion

Date: May 2009

TABLE OF CONTENTS

EXECUTIVE SUMMARY

As a carry-over from the previous Scion/Industry research cooperatives (e.g., Plantation Management, Stand Growth Modelling, and Site Management), FFR is now responsible for experimental trials across New Zealand. Trials are expensive to install, maintain, and re-measure, and the benefit of these trials needs to be realised through the data being used, for example as stand-alone trial analysis of treatment effects, and collectively with other trials in the development of growth and quality models.

As part of the Radiata Management Theme 2008/09 work programme in IFS (Intensive Forest Systems) Objective 1 (Forest Growth and Quality in Forest Stand), the analyses of a selection of trial series was included. Along with the analysis of the 2nd Log Pruning Trial reported herein, the other two trial series that were analysed and reported separately include the 1975 Final Crop Stocking Trial, and the Special Purpose Breeds Trials.

The aim of this analysis was to:

- Assess whether the data from these trials are sufficient to provide for analyses on the economic efficacy of carrying out second-log pruning.
- Provide quantitative information on the effect of pruning above 6 metres.
- Compare results with current model predictions.

Four second log pruning trials were installed across a range of site qualities within New Zealand to monitor the effect on tree growth and log quality of pruning radiata pine above 6.0 metres. The trial series has now had all treatments applied and the subsequent growth response measured. Re-measurement frequency has been extended to a four-year schedule with wood quality assessment identified as a possibility closer to harvest.

The trials were designed to model the effects of dependant factors; final crop stocking; pruned height and pruning severity on the response variable, basal area. Three-factor regression found stocking and mean prune height to be significant determinants of basal area, with green crown remaining being a contributor in only one case. Two-factor regression found stocking and mean prune height to be significant determinants of basal area, with green crown remaining being a contributor in two cases. The low site quality trial displayed a strong relationship between site index and basal area, and was therefore poorly modelled until site index was accounted for. Using unpruned plots as the control, 'growth years lost due to pruning' was modelled with diameter at breast height as the dependant variable. 'Growth years lost due to pruning' increased with more intense pruning across all trial sites and stockings. A model was developed for 'growth years lost' using pruned height and green crown remaining as dependant variables.

Comparison of the actual data of all trials with predictions using the 300 Index growth model found the current 300 Index model to generally under-predict reduction in DBH due to high pruning. The inclusion of this dataset with future refitting of the 300 Index will improve growth predictions and allow future analysis on the economic efficacy of second log pruning.

Growth response to the different treatments is still evident in the latest measurements (especially in the ultra high prune height treatments), so further re-measurement is recommended to ensure this is captured and included in future growth models. Although current market conditions may not be a driver towards clearwood production, the data from this trial provide the extreme treatments needed in all biological growth models and are of sufficient quality to provide for any further analysis.

INTRODUCTION

The second log pruning trial series was initiated in 1993, when price premiums were consistently being received for high quality pruned logs, providing opportunities to increase returns by growing a greater volume of quality pruned logs. Some forest companies had already moved away from the accepted industry standard of pruning to approximately 6 metres by either pruning to 5.5 metres or higher to around 8.5 metres. This change in strategy was aimed at achieving multiples of peeler bolt lengths rather than sawlogs. Little was known of the effect on tree growth and the resulting diameter over stubs (DOS) of pruning the second log (i.e. above 6 metres). Regime evaluations using STANDPAK showed that under many scenarios second-log pruning could be a profitable management option. Lack of data from plots pruned above 6 metres meant that the predictions were never adequately validated. Consequently these trials were established to provide data on ultra high pruning and give confidence that model predictions were accurate in terms of clearwood production and tree growth.

The aim of this analysis is to:

- Assess whether the data from these trials are sufficient to provide for analyses on the economic efficacy of second log pruning.
- Provide quantitative information on the effect of pruning above 6 metres.
- Compare results with current model predictions.

Four second-log pruning trials were installed across New Zealand to monitor the effect on tree growth and log quality of pruning radiata pine above 6.0 metres. A three-dimensional response surface trial design was used incorporating 25 plots at each site. Table 1 describes the site level detail of each site.

Table 1. Site level detail of second log pruning trial series

Forest	Location	Forest Owner	Experiment No.	Site Index	Date Planted
Ngaumu	Wairarapa	JNL	FR 201	30	1985
Aupouri	Northland	JNL	FR 241	22	1987
Waiotahi	Eastern BOP	PRU Timber	FR 243	36	1988
Otago Coast	Otago	Wenita	FR 247	27	1986

These trials have been installed over a range of site qualities located at: Ngaumu (medium fertility, medium site index), Waiotahi (high site index, high fertility), Otago Coast (medium site index medium fertility) and Aupouri (low site index, low fertility). See Figure 1.

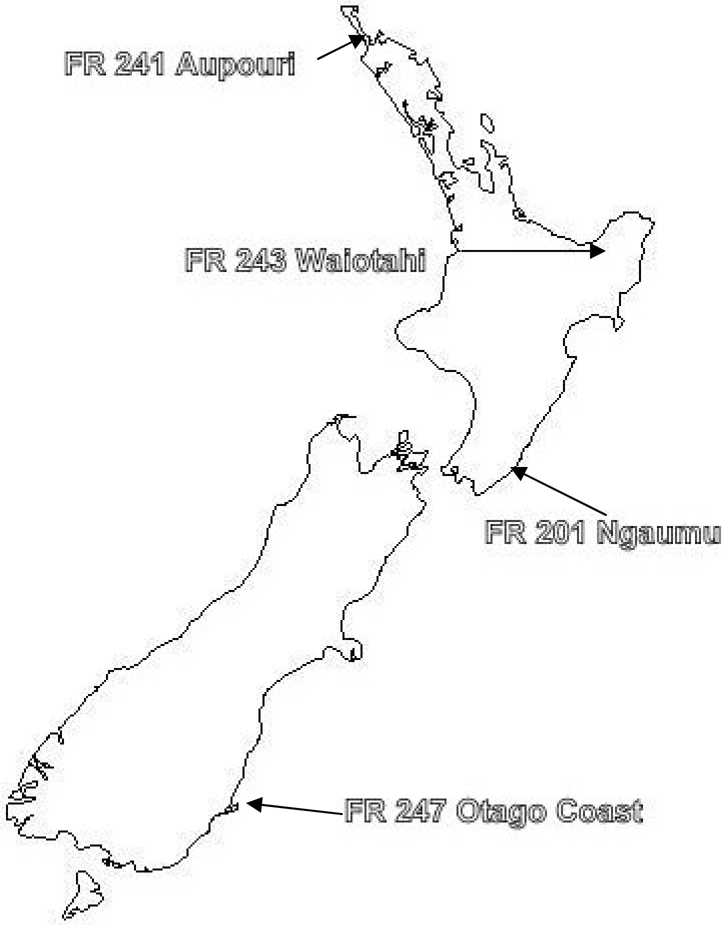

Figure 1. Trial locations across New Zealand.

The trial series was initiated by the Plantation Management Cooperative; further detail on the installation can be found in the installation report (Dean 1995). Interim analysis of the data set was carried out in 2002 by Dean and Kimberley (unpub). Individual plot data were compared with predictions from the EARLY growth model. Large errors were found in basal area increment predictions when pruning treatments were used above 6 meters. A model fitted to the response surface data available at the time found:

- Pruning above 6 metres disproportionately slows basal area growth rate when compared with conventional pruned heights.
- More intensive pruning (less green crown remaining) results in smaller diameter over stubs (DOS) measurements.
- DOS remains relatively constant up the stem for any given pruning intensity for trees pruned above 6 metres.

Since then:

- The final pruning treatment was carried out in FR 241 in the winter of 2005. Any response to this has been captured in the last 3 years' measurement, allowing a full analysis of the trial series to be carried out.
- A tree growth function to predict response of pruned height and intensity was incorporated into the 300 Index Model.

METHODS

Treatments

The treatments contained in these trials include: pruned heights ranging from 4.0 to 13.6 m, crown length remaining at each pruning lift ranging from 3.0 to 8.9 m, and final crop stockings ranging from 150 to 400 stems/ha. For each factor, a step length was selected and the treatment levels determined by multiplying step lengths by an interval, the product of which was added to or subtracted from the mean. Table 2 gives the treatment levels used. The mean treatment for this trial design was 8.8 m pruned height, 6.4 m crown length and 275 final crop stocking.

Table 2.
Summary of treatment levels.

		Intervals				
Factor	**Step length**	-1.68	-1	0	1	1.68
Pruned height	3.0m	4.0	5.8	8.8	11.8	13.6
Crown length	1.5m	3.9	4.9	6.4	7.9	8.9
Final crop stocking	75 stems/ha	150	200	275	350	400

The combinations of variables and number of plots for each site are given in Table 3. Note the control plots at 200 and 350 stems/ha.

Table 3.
Number of plots and pruned height. Filled cells give pruned height and number of plots for combinations of final stocking and crown length remaining.

		Final crop stocking (stems/ha)				
		150	200	275	350	400
Crown length remaining (m)	3.9			8.8* x1		
	4.9		5.8, 11.8 x2		5.8 x1, 11.8 x1	
	6.4	8.8 x2		4.0 x1, 8.8 x6, 13.6 x1		8.8 x1
	7.9		5.8 x1, 11.8 x2		5.8 x1, 11.8 x1	
	8.9			8.8 x1		
	Unpruned		0.0 x1		0.0 x1	

* pruned height (m)
Total number of plots = 25

Plot Layout

The trials were installed into stands with stockings of at least 400 acceptable stems per hectare. Trial installation was timed to be immediately prior to the high pruning to be carried out (i.e.<11.0m MTH). Each trial occupies 7.8 hectares of uniform land. There are 25 plots at each site. Each treatment plot consists of a 0.309 ha square (55.6 * 55.6 meters) plot within which a 0.1 hectare circular plot contains trees to be measured. The plot radius is 17.8 metres plus slope correction where required. This plot layout provides a minimum buffer of 10 metres.

Analysis

This trial was designed to assess the effects of dependent factors; final crop stocking (FCS); pruned height and pruning severity (green crown remaining) on basal area (BA). A trial design suited to regression analysis techniques was chosen in preference to designs allowing for comparison by analysis of variance. The data have been recorded as a time series up to 20 years, the latest common age for which PSP measurements are available for all trials.

Individual site analysis of BA

Three dimensional (three factor) surface regression (as graphed in Appendix 2) was used to show the overall trend between BA and the dependant factors. Two-factor general linear modelling (GLM) was run for each factor to show significance. Three-dimentional surface regression models with a variable not adequately fitting the model were updated excluding that variable. All models of the response surface design had very influential linear trends underlying the components. Quadratic components within the response surface regression which were not found to be significant were excluded.

Combined site analysis of Diameter growth

Site and stocking influence between treatments was removed from the analysis by using DBH as the dependant variable. The best expression of each treatment's effect on DBH was 'years lost in growth due to pruning'. To examine the different responses between trial sites, the control plots were used as a calibration. The time taken to reach a given diameter was compared to the control treatments. A model for BA as a function of pruned height and green crown remaining was developed which could perform well regardless of site and stocking

The data were then used to compare predictions from the 300 Index growth model to the actual data from each site. Table 4 shows the average site level data from all trial sites used to build an 'average site' to run through the 300 Index model. The mean BA and Mean Top Height (MTH) over all sites gave a 300 Index of 25 and mean Site Index (SI) of 28. Predicted BA for the 'average site' at age 20 with mean site parameters (275 sph, 6.4 GCR and 8.8 m prune height) was then compared to the same age data for each site, allowing the actual and predicted BA to be compared for all treatments.

Table 4.
Site detail used to run 300 Index model to compare actual growth response with predicted.

Trial	Latitude (°)	Altitude (m)	Initial stocking (sph)	FCS (sph)	MTH (m)	BA (m^2)
FR 201	40	260	1100	275	30.3	43.4
FR 241	34	50	1200	275	24.3	24.6
FR 247	45	120	1000	275	27.2	40.6
FR 243	38	90	645	275	34.4	45.1
Average	39	130	1100	275	29.1	38.3

RESULTS

Analysis of Basal Area response at each site

The initial analysis of the trends among all sites showed the behaviour of the dependent variables to the response variable, BA, to vary greatly between trial areas. Following this result, separate models were created for each trial to more effectively fit trends within each data set. The results from the full or reduced response surface regression or general linear model for of each of the trials are shown in Table 5.

Table 5.
Results from the response surface regression.

	Response surface regression		General linear model	
Trial	**Response R^2**	**Significant variables (p<0.05)**	**Response R^2**	**Significant variables (p<0.05)**
FR 247	0.95*	Stocking Prune Height Green Crown Remaining	0.88*	Stocking Prune Height Green Crown Remaining
FR 243	0.86	Stocking Prune Height	0.85	Stocking Prune Height
FR 241	0.27	Stocking Prune Height	0.20	Stocking Prune Height
FR 201	0.80	Stocking Prune Height	0.82*	Stocking Prune Height Green Crown Remaining

* = Full response surface regression or general linear model, otherwise results are from a reduced response surface regression or GLM

Response Surface Regression

Each surface regression (Appendix 1) shows the variation in basal area explained by each model (R^2) and those variables found to have a significant effect on basal area for each trial at age 20. The relationships between these variables for each trial are described by the response surface graphs (Appendix 2).

The surface regression for FR 247 (Appendix 1.1.1) showed that the trends within the regression variables, stocking, mean prune height and green crown all contributed to the final BA. The F-test for lack of fit showed the fitted response surface form was not significantly different from the true surface. The R^2 of 0.9484 indicates 95% of the variation in basal area is explained by this model and it should therefore be suitable for making predictions.

The surface regression for FR 243, FR 241 and FR 201 showed that prescribed green crown remaining was not a significant factor. Updated regressions were made analysing the data without prescribed green crown remaining. These new models (Appendix 1.2.1, 1.2.2 and 1.2.3) showed both mean prune height and stocking to individually contribute towards the model. The F-test for lack of fit showed the fitted response surface was not significantly different from the true surface. The R^2 for the response surface regressions are given in Table 5. The R^2 value of 0.2737 for FR 241 shows it to be a very poor model for making predictions. The R^2 for FR 243 and FR 201 show that sufficient variation in BA is explained and should therefore be reasonable models for prediction.

General Linear Models

Like the surface regressions, a GLM was run for each trial consisting of the dependent variables nominal green crown remaining, mean prune height and stocking and the response variable, BA. New models were then made for each trial based on the results from the overall GLM to try and create the best fitting equation for each model.

The GLM run for FR 247 and FR 201 (Appendix 3.1.1 and 3.1.2) showed the three dependant variables to have a significant effect on BA. The R^2 values (Table 5) suggest the variation in BA was sufficiently well explained by the components in the models. The residuals (Figure 3.1.1 and 3.1.2) were scattered with no apparent pattern. Quadratic terms were then added to the models, with no improvement, making the initial overall GLM the best to model the data.

A GLM was fitted to the data of trial 241 and 243. In both cases the variable prescribed green crown remaining was not found to be significant. As a result, prescribed green crown remaining was dropped from the analysis and new models were set up. These new models analysed BA by the factors stocking and mean prune height. An interaction term between stocking and mean prune height was added to the equations as it helped model the trend more effectively. These new models (Appendix 3.2.1 and 3.2.2) showed mean prune height, stocking and the interaction term to be significant. The R^2 value for FR 243 (Table 5) suggests the variation in BA is sufficiently well explained by the components in the model. The R^2 value for FR 241 (Table 5) suggests the variation in BA is not sufficiently well explained. Quadratic and exponential terms were then added with little success. The updated model is deemed the best fitting model for FR 243.

FR 241 showed that there was a trend or a component within the data that had not been modelled as the R^2 value did not go beyond 27% for any of the modelling attempts. Further investigation was carried out to see how this trial differed from the other trials. Scatter plots of site index against basal area were made for each trial which show the relationship between these variables. Figure 2 shows the scatter plot of FR 241 where there is a noticeable trend that shows basal area sharply increasing with site index. This trend is not evident in the data for the three other trials. As part of further investigation of this apparent relationship with basal area, site index was added into a full response surface analysis of trial 241 with other response variables green crown remaining, mean pruned height and stocking. The inclusion of site index in the response surface design meant that the R^2 value increased significantly to 0.94, and site index was thus an extremely strong contributor to basal area prediction.

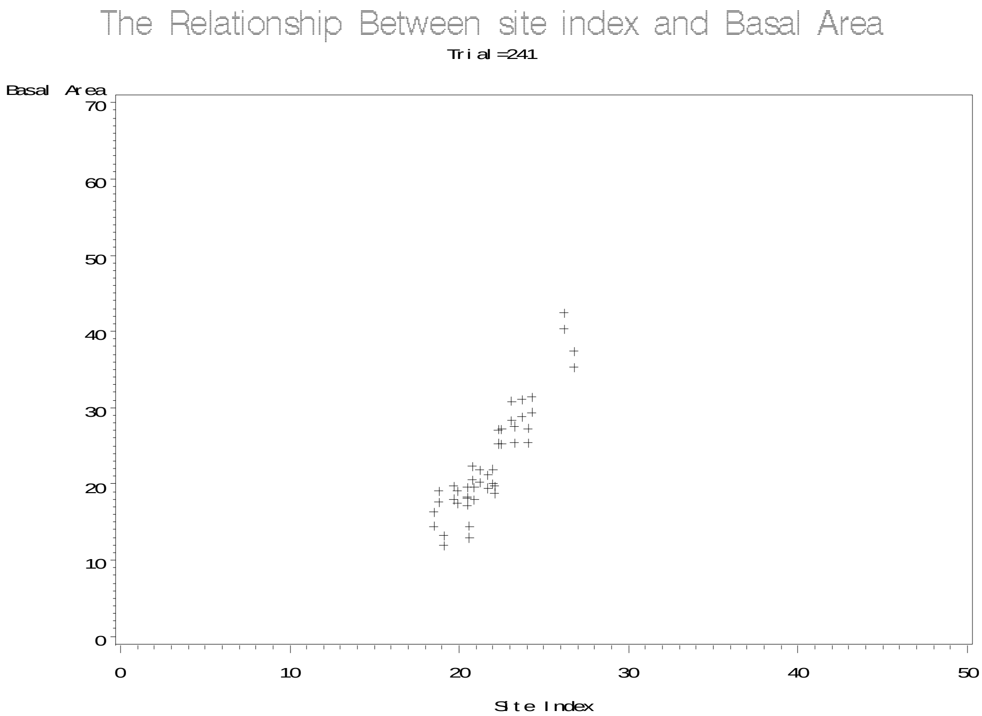

Figure 2. The relationship between site index and BA for FR 241.

Combined site analysis of Growth Years Lost due to pruning

In order to examine different responses between treatments, the control plots were used as a calibration, and the time taken to reach a given diameter was compared to the treatment plots. Figure 3 demonstrates the effect of pruning for each treatment mean averaged across all four sites expressed as growth years lost against the unpruned treatment.

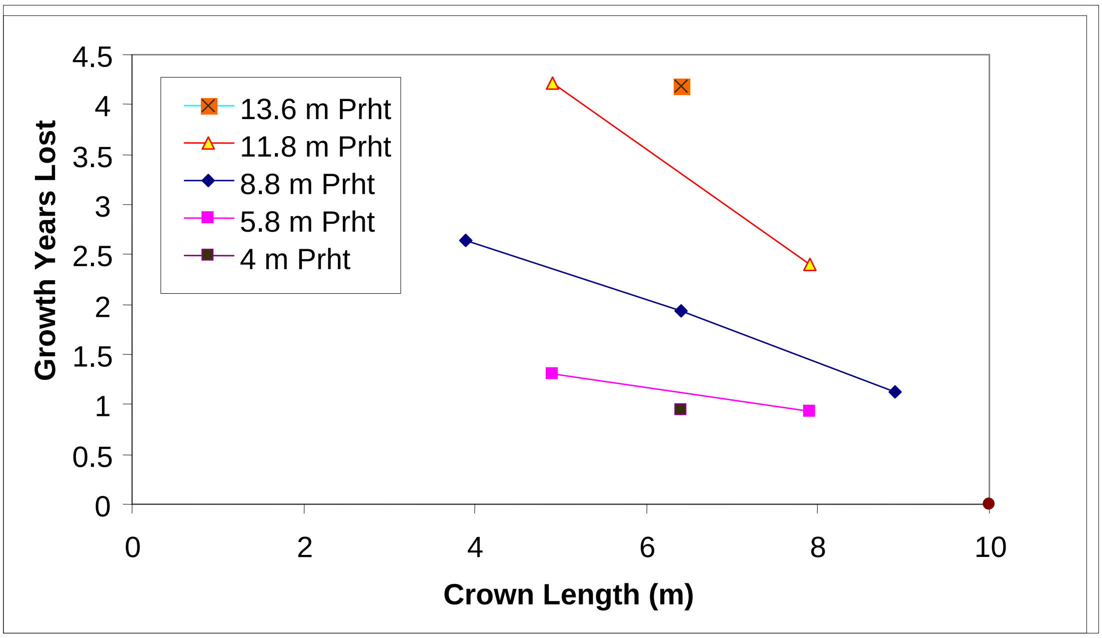

Figure 3. Treatment means averaged across all four trials showing growth years lost versus crown length.

The effect of prune height was largest where the 13.6 m pruned height results in approximately 4 years of diameter growth lost, while pruning to 4 m slows growth by around one year. Green crown remaining had less effect on growth lost than did prune height. Growth years lost increased with more intense pruning, and this effect increased with pruning height. Pruning to 5.8 m prune height with a 5 m green crown remaining resulted in only marginally more growth loss than the 8 m green crown remaining, while the growth loss was nearly doubled in the 11.8 m prune height treatment.

The growth years lost due to pruning was able to be analysed across all trial sites when no significant differences between site or stocking were found. Because of the absence of any site and stocking by pruning treatment interaction, it was possible to fit a model as a function of pruned height and green crown remaining which performed well regardless of site and stocking:

$$\text{Years lost} = 0.0220 * \text{PrHt}^{2.41} (1 - 0.0962*\text{GrCR})$$

where PrnHt is the pruned height (m)
GrCR is the green crown remaining (m)

Figure 4 demonstrates the influence pruning height and intensity have on diameter growth loss where an increase in pruned height and/or more severe pruning treatment results in more growth years lost as predicted by this model.

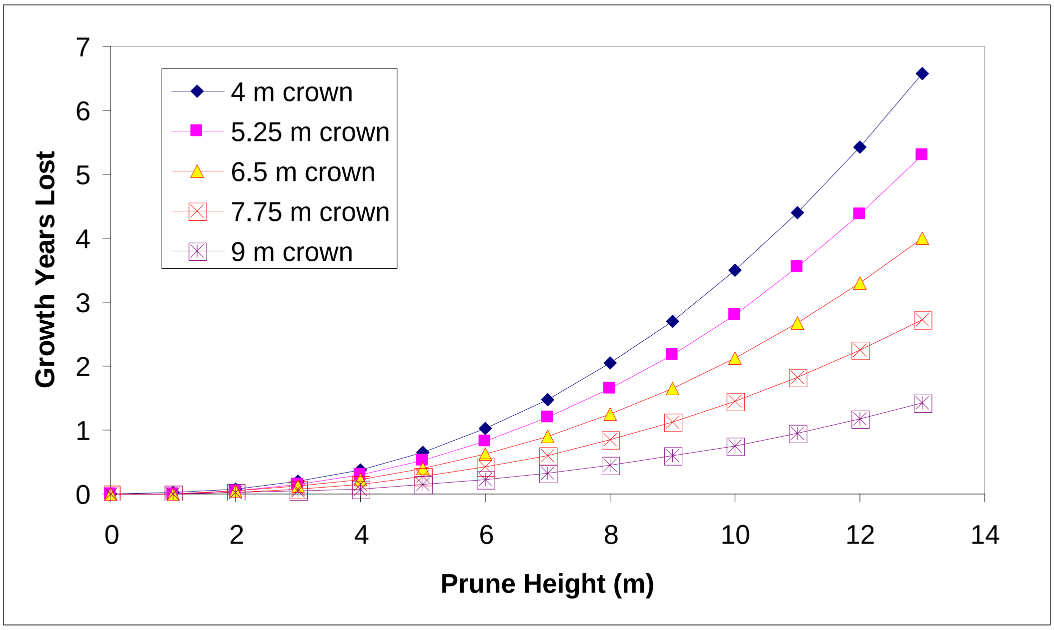

Figure 4. Model predicting growth years lost due to pruning as a function of prune height and crown length based on data from all four trials.

Comparison with 300 Index predictions

The ‘average site’ growth response expressed as reduction in DBH is shown where the values predicted by the 300 Index growth model for all treatments were compared to the actual values for the same treatments. Figure 5 shows the 300 Index to generally under-predict growth loss. This prediction across all sites is expected to be improved with the addition of this dataset to the 300 Index model.

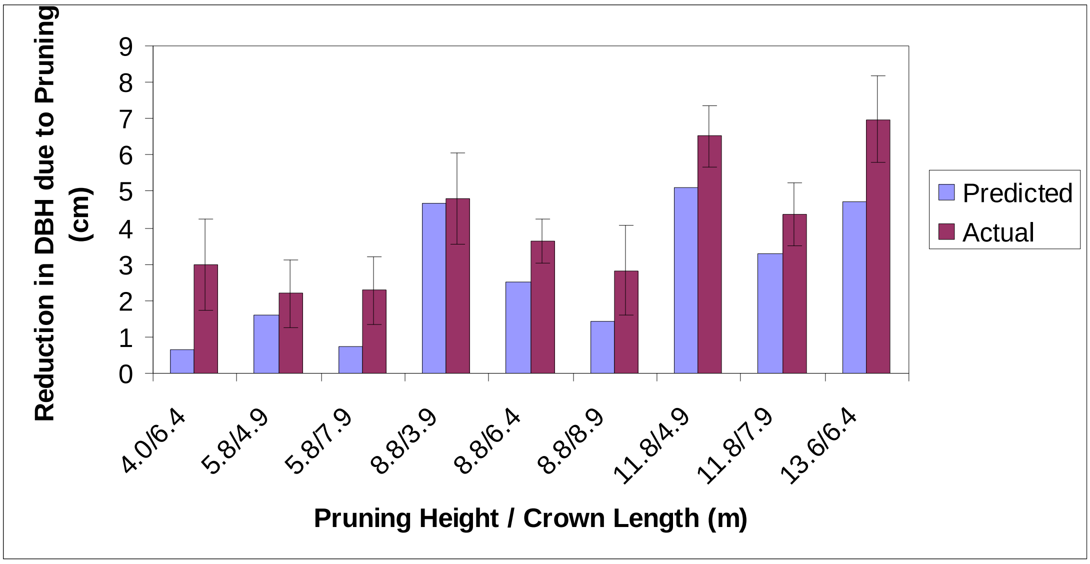

Figure 5. Comparison of actual loss in DBH due to pruning averaged across the four trials against predicted loss using the 300 Index growth model.

CONCLUSION

Generally, the models showed the variables stocking and mean prune height to be significant determinants of BA. However, the results varied with prescribed green crown remaining where three models suggested it to be a contributor to BA variation, while it was unnecessary in the remaining five. There was large variation in BA between trial sites. Each site appeared to have different underlying trends for each of the treatments; this stems from the range in trial site quality and tree stock genetic quality.

FR 241 was unique in that the three components of prescribed green crown remaining mean prune height and stocking used to model BA produced very poor results. The same components for the other sites produced models which provided acceptable explanations of BA. However, BA was modelled accurately with the inclusion of site index. The high variability between plots on the low quality site could have led to the site index having a higher contribution to BA compared to the stocking, pruned height and pruning intensity.

When the site and stocking influence was removed from the analysis by using DBH as the dependant variable across all sites, the significance of prune height and intensity became evident. Growth years lost due to pruning could then be successfully modelled and thus provide for scenario analysis of second-log pruning regimes. Growth years lost increased with higher prune heights and higher pruning intensities. The predictions made with the 300 Index were found to generally under-predict growth loss when compared to actual site values. This prediction is expected to be improved with the addition of this dataset to the 300 Index model.

Growth response to the different treatments is still evident in the latest measurements (especially in the ultra high prune height treatments), so further re-measurement is recommended to ensure this is captured and included in future growth models (Appendix 4). Although current market conditions may not be a driver towards clearwood production, the data from this trial provide the extreme treatments needed in all biological growth models, and are of sufficient quality to provide for any future analysis.

ACKNOWLEDGEMENTS

This report would not have been possible without the establishment of trials by G. West, M. Dean and M. Carter.

The willing contribution of staff and pruning contractor time by Juken Nissho, Tasman Forestry and Wenita Forestry is gratefully acknowledged.

Furthermore, the authors appreciate the time and effort of the FFR Technical Steering Team (TST) to review and make comment on early drafts of this report.

REFERENCES

Dean M. 1995. Second log pruning trials – installation report. Forest and Farm Plantation Management Cooperative. Report No. 22.

Dean M., Kimberley M. 2002. The effect of pruned height, pruning intensity, and timing on tree growth and quality – an interim analysis. Forest and Farm Plantation Management Cooperative. Meeting Proceedings, Rotorua, 21-22 May. Pg. 6. (Report No. 83, not completed).

APPENDICES

Appendix 1: Response Surface Regression Models

Full Response Surface Regression Sas Output: Trial 247

The RSREG Procedure

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|	Parameter Estimate from Coded Data
Intercept	1	3.007052	23.141104	0.16	0.0719	43.027045
SPH	1	0.220375	0.074434	2.96	0.0110	8.665567
Mean_PrHt	1	0.741709	2.249019	0.33	0.7469	-3.610306
prescribed_GCR	1	-0.103496	0.370450	-0.28	0.7843	3.999863
SPH*SPH	1	-0.000204	0.000100	-2.03	0.0142	-3.755909
Mean_PrHt*SPH	1	0.002339	0.003201	0.73	0.4779	0.995103
Mean_PrHt*Mean_PrHt	1	-0.205456	0.090486	-2.27	0.0407	-2.812695
prescribed_GCR*SPH	1	-0.000217	0.000580	-0.37	0.7141	-0.624979
prescribed_GCR*Mean_PrHt	1	0.016770	0.016270	1.03	0.3215	1.551191
prescribed_GCR*prescribed_GCR	1	0.001421	0.002344	0.61	0.5547	0.888229

Factor	DF	Sum of Squares	Mean Square	F Value	Pr > F	Label
SPH	4	590.004955	147.521239	36.21	<.0001	SPH
Mean_PrHt	4	159.986998	39.996749	9.82	0.0007	Mean_PrHt
prescribed_GCR	4	115.046717	28.961679	7.11	0.0029	prescribed_GCR

The RSREG Procedure

Coding Coefficients for the Independent Variables

Factor	Subtracted off	Divided by
SPH	265.000000	115.000000
Mean_PrHt	8.300000	3.700000
prescribed_GCR	64.000000	25.000000

Response Surface for Variable BA: BA

Response Mean	39.925217
Root MSE	2.018294
R-Square	0.9482
Coefficient of Variation	5.0552

Regression	DF	Type I Sum of Squares	R-Square	F Value	Pr > F
Linear	3	902.426030	0.8825	73.85	<.0001
Quadratic	3	60.216274	0.0589	4.93	0.0168
Crossproduct	3	7.008448	0.0069	0.57	0.6424
Total Model	9	969.650751	0.9482	26.45	<.0001

Residual	DF	Sum of Squares	Mean Square	F Value	Pr > F
Lack of Fit	13	52.955623	4.073509	.	.
Pure Error	0	0	.		
Total Error	13	52.955623	4.073509		

Reduced Response Surface Regression Output For Trial 243

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|	Parameter Estimate from Coded Data
Intercept	1	12.970080	16.550204	0.78	0.4440	46.880418
SPH	1	0.192801	0.079456	2.43	0.0267	9.237649
Mean_PrHt	1	0.770868	2.493830	0.31	0.7610	-4.950831
SPH*SPH	1	-0.000142	0.000133	-1.06	0.3032	-1.871600
Mean PrHt*SPH	1	-0.004234	0.004429	-0.96	0.3526	-1.874454
Mean_PrHt*Mean_PrHt	1	-0.052010	0.120041	-0.44	0.6655	-0.702094

Factor	DF	Sum of Squares	Mean Square	F Value	Pr > F	Label
SPH	3	633.570071	211.190024	27.63	<.0001	SPH
Mean_PrHt	3	160.952482	53.650827	7.02	0.0028	Mean_PrHt

The RSREG Procedure

Coding Coefficients for the Independent Variables

Factor	Subtracted off	Divided by
SPH	265.000000	115.000000
Mean_PrHt	8.850000	3.850000

Response Surface for Variable BA: BA

Response Mean	44.791304
Root MSE	2.764510
R-Square	0.8678
Coefficient of Variation	6.1720

Regression	DF	Type I Sum of Squares	R-Square	F Value	Pr > F
Linear	2	836.323156	0.8508	54.72	<.0001
Quadratic	2	9.730911	0.0099	0.64	0.5412
Crossproduct	1	6.982037	0.0071	0.91	0.3526
Total Model	5	853.036104	0.8678	22.32	<.0001

Residual	DF	Sum of Squares	Mean Square	F Value	Pr > F
Lack of Fit	13	104.344957	8.026535	1.26	0.4517
Pure Error	4	25.577800	6.394450		
Total Error	17	129.922757	7.642515		

Reduced Response Surface Regression Output For Trial 241

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|	Parameter Estimate from Coded Data
Intercept	1	-5.191210	21.267593	-0.24	0.8084	22.211867
SPH	1	0.200727	0.117373	1.71	0.0950	4.877992
Mean_PrHt	1	-0.390105	2.617685	-0.15	0.8823	-4.456589
SPH*SPH	1	-0.000033581	0.000196	-0.17	0.8646	-0.524697
Mean_PrHt*SPH	1	-0.017362	0.006825	-2.54	0.0149	-10.091431
Mean_PrHt*Mean_PrHt	1	0.254918	0.130693	1.95	0.0581	5.511954

Factor	DF	Sum of Squares	Mean Square	F Value	Pr > F	Label
SPH	3	459.992387	153.330796	3.73	0.0188	SPH
Mean_PrHt	3	442.953726	147.651242	3.59	0.0218	Mean_PrHt

The RSREG Procedure

Coding Coefficients for the Independent Variables

Factor	Subtracted off	Divided by
SPH	275.000000	125.000000
Mean_PrHt	8.250000	4.650000

Response Surface for Variable BA: BA

Response Mean	22.964783
Root MSE	6.415562
R-Square	0.2737
Coefficient of Variation	27.9365

Regression	DF	Type I Sum of Squares	R-Square	F Value	Pr > F
Linear	2	232.669887	0.1026	2.83	0.0711
Quadratic	2	121.327891	0.0535	1.47	0.2412
Crossproduct	1	266.364205	0.1175	6.47	0.0149
Total Model	5	620.361983	0.2737	3.01	0.0211

Residual	DF	Sum of Squares	Mean Square	F Value	Pr > F
Lack of Fit	14	1539.119490	109.937106	26.65	<.0001
Pure Error	26	107.258075	4.125311		
Total Error	40	1646.377565	41.159439		

Reduced Response Surface Graph For Trial 201

Parameter	DF	Estimate	Standard Error	t Value	Pr > |t|	Parameter Estimate from Coded Data
Intercept	1	47.475733	32.225918	1.47	0.1590	45.304557
SPH	1	0.075415	0.114088	0.66	0.5175	6.826321
Mean_PrHt	1	-2.823585	4.895493	-0.58	0.5717	-4.442826
SPH*SPH	1	-0.000107	0.000146	-1.20	0.2101	-2.692005
Mean_PrHt*SPH	1	0.008746	0.007663	1.14	0.2695	3.148428
Mean_PrHt*Mean_PrHt	1	-0.051735	0.227173	-0.23	0.8226	-0.465611

Factor	DF	Sum of Squares	Mean Square	F Value	Pr > F	Label
SPH	3	422.434823	140.811608	15.03	<.0001	SPH
Mean_PrHt	3	140.400322	40.409441	5.20	0.0033	Mean_PrHt

The RSREG Procedure

Coding Coefficients for the Independent Variables

Factor	Subtracted off	Divided by
SPH	260.000000	120.000000
Mean_PrHt	9.000000	3.000000

Response Surface for Variable BA: BA

Response Mean	42.440435
Root MSE	3.060344
R-Square	0.8014
Coefficient of Variation	7.2109

Regression	DF	Type I Sum of Squares	R-Square	F Value	Pr > F
Linear	2	610.799150	0.7621	32.61	<.0001
Quadratic	2	19.285271	0.0241	1.03	0.3784
Crossproduct	1	12.200468	0.0152	1.30	0.2695
Total Model	5	642.284888	0.8014	13.72	<.0001

Residual	DF	Sum of Squares	Mean Square	F Value	Pr > F
Lack of Fit	17	159.217007	9.365706	.	.
Pure Error	0	0	.		
Total Error	17	159.217007	9.365706		

Appendix 2: Response Surface Graphs

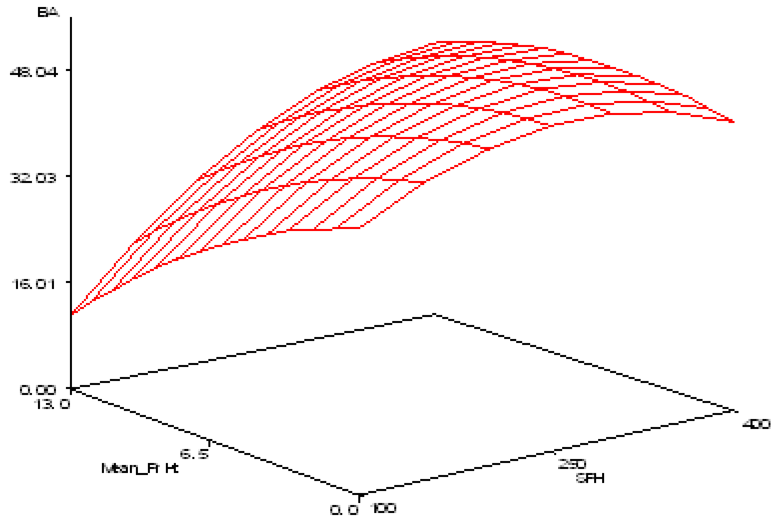

Figure 2.1.1. Response Surface Graph displaying the relationship between stocking and mean prune height for Trial 247.

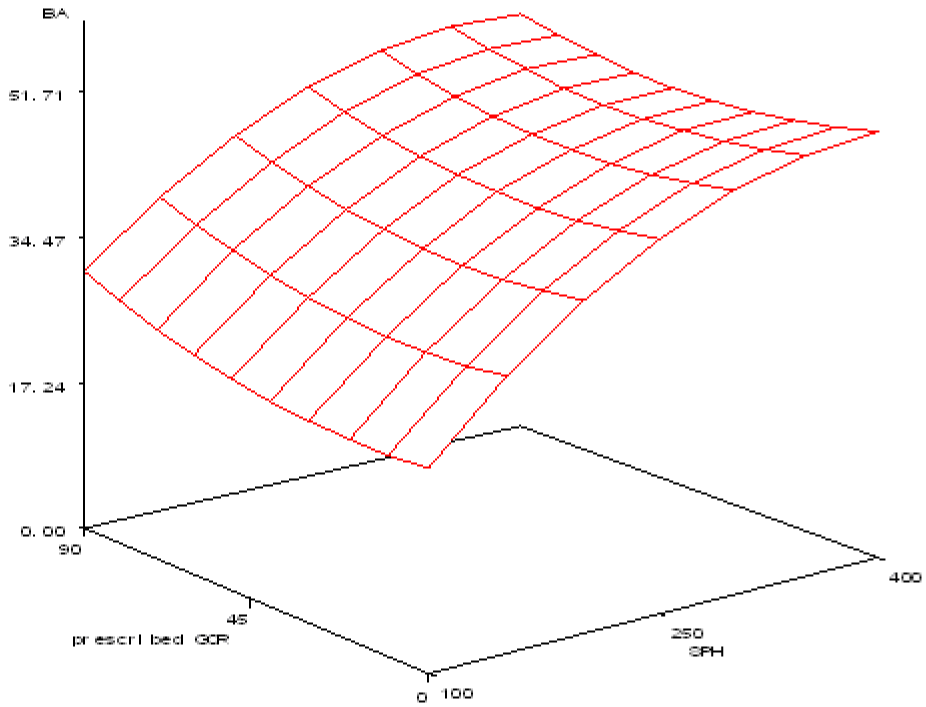

Figure 2.1.2. The Relationship between stocking and prescribed green crown emaining for Trial 247 through the response surface design.

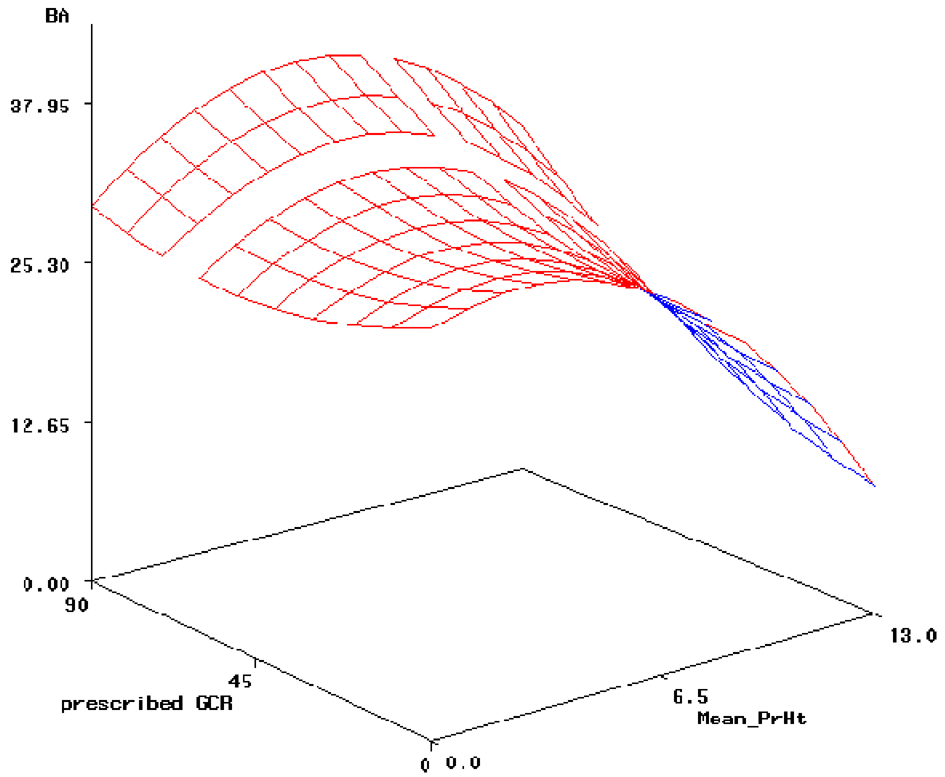

Figure 2.1.3. The relationship between prescribed green crown remaining and mean prune height for Trial 247 through the response surface design.

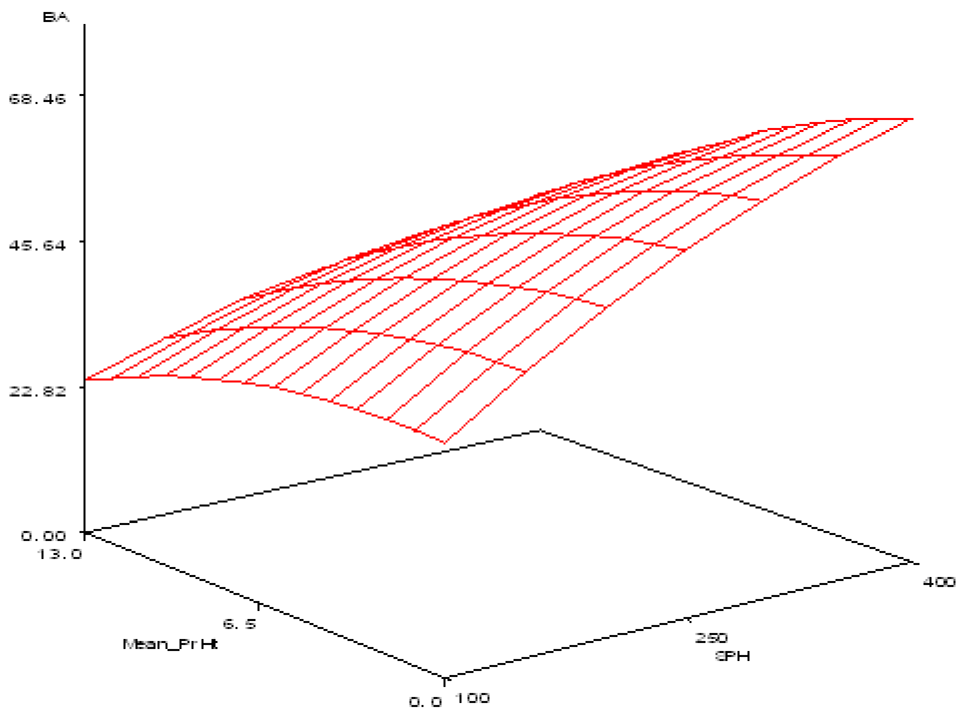

Figure 2.2.1. Response surface design displaying the relationship between stocking and mean prune height against basal area. Trial 243.

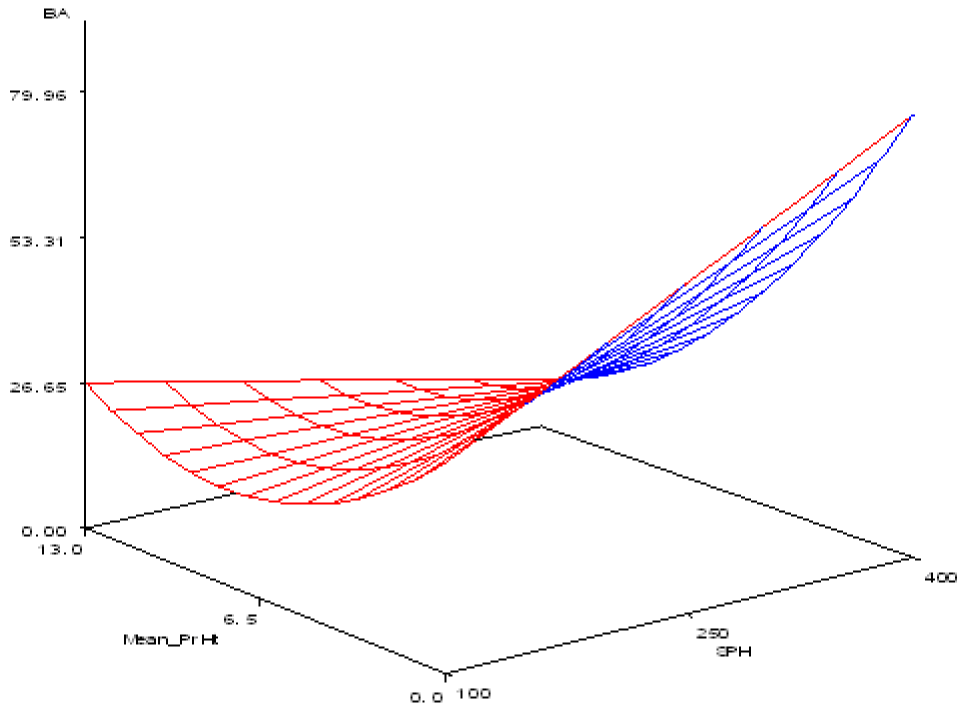

Figure 2.3.1. Response surface graph displaying the relationship between mean prune height and stocking for Trial 241.

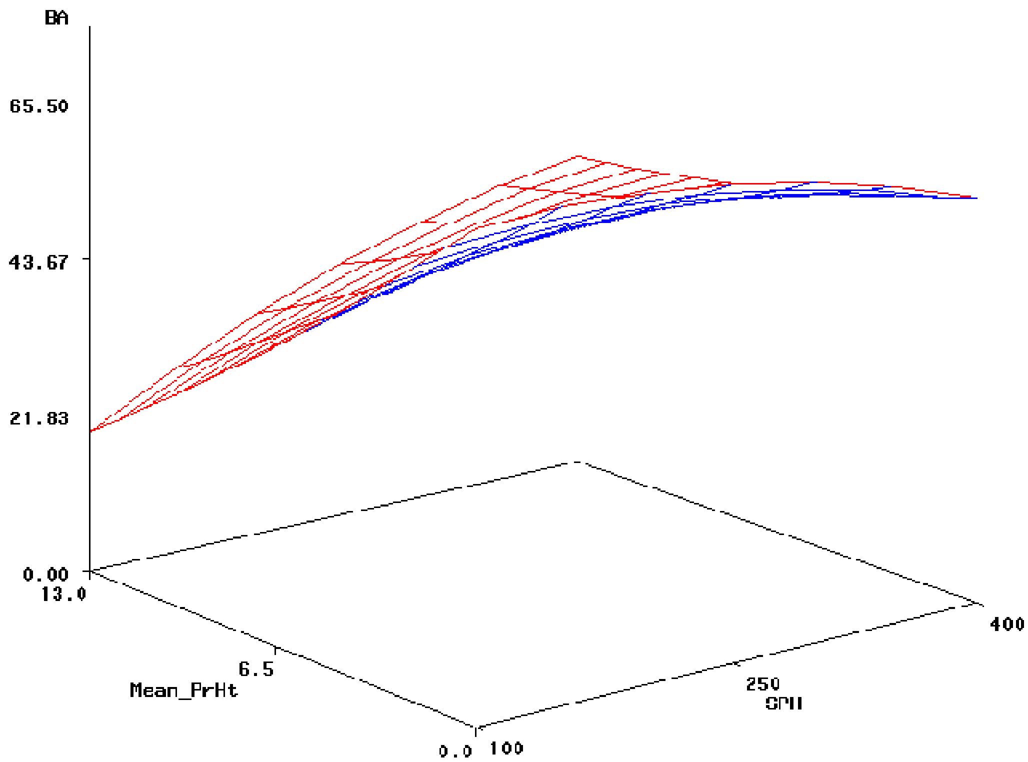

Figure 2.4.1. Relationship between mean prune height and stocking against basal area for Trial 201.

Appendix 3: General Linear Models

Full General Linear Model for Trial 247

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	902.426030	300.808677	47.56	<.0001
Error	19	120.180344	6.325281		
Corrected Total	22	1022.606374			

R-Square	Coeff Var	Root MSE	BA Mean
0.882476	6.299305	2.515011	39.92522

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SPH	1	669.2354039	669.2354039	105.80	<.0001
Mean_PrHt	1	126.0789896	126.0789896	19.93	0.0003
prescribed_GCR	1	107.1116364	107.1116364	16.93	0.0006

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SPH	1	552.0230302	552.0230302	87.27	<.0001
Mean_PrHt	1	129.3650306	129.3650306	20.45	0.0002
prescribed_GCR	1	107.1116364	107.1116364	16.93	0.0006

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	19.59505724	4.28561871	4.57	0.0002
SPH	0.07750320	0.00829623	9.34	<.0001
Mean_PrHt	-1.13974803	0.25202308	-4.52	0.0002
prescribed_GCR	0.17497212	0.04251973	4.12	0.0006

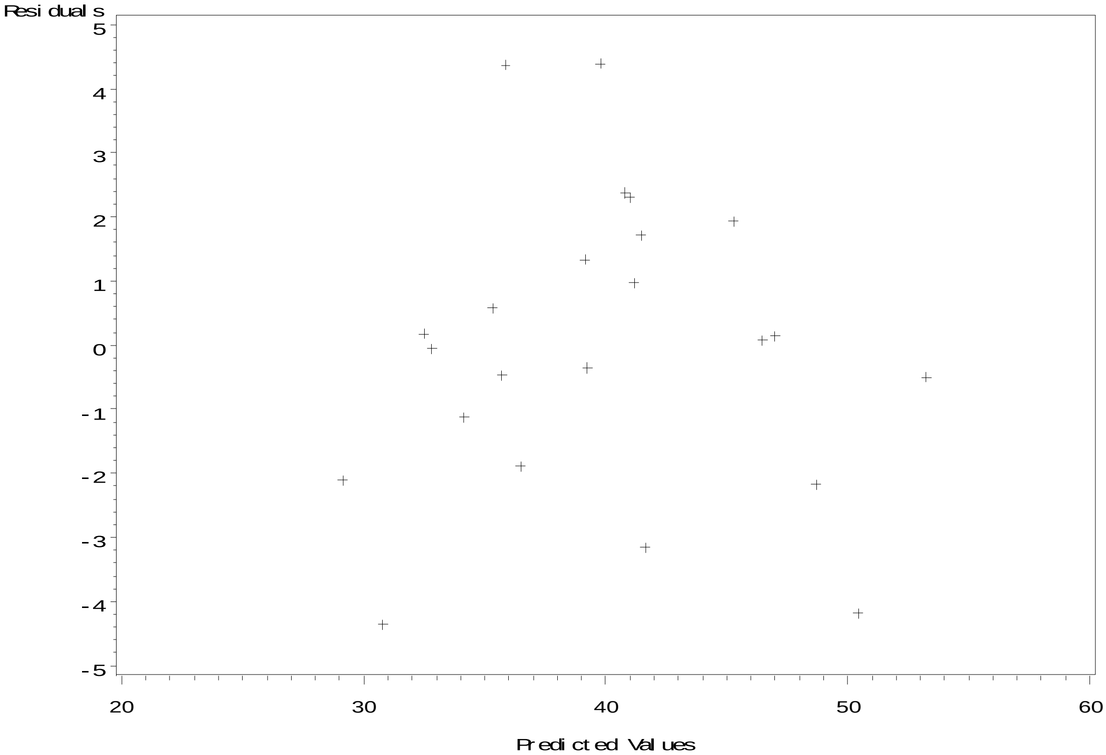

Figure 3.1.1. Scatter plot of residuals against predicted values for trial 247.

Full General Linear Model for Trial 201

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	656.0968857	218.6989619	28.58	<.0001
Error	19	145.4050100	7.6528953		
Corrected Total	22	801.5018957			

R-Square	Coeff Var	Root MSE	BA Mean
0.818584	6.518281	2.766387	42.44043

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SPH	1	465.1648120	465.1648120	60.78	<.0001
Mean_PrHt	1	145.6343376	145.6343376	19.03	0.0003
prescribed_GCR	1	45.2977361	45.2977361	5.92	0.0250

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SPH	1	409.6322229	409.6322229	53.53	<.0001
Mean_PrHt	1	126.5885259	126.5885259	16.54	0.0007
prescribed_GCR	1	45.2977361	45.2977361	5.92	0.0250

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	33.54384736	5.86874696	5.72	<.0001
SPH	0.06622730	0.00905217	7.32	<.0001
Mean_PrHt	-1.54661893	0.38027610	-4.07	0.0007
prescribed_GCR	0.11734371	0.04823191	2.43	0.0250

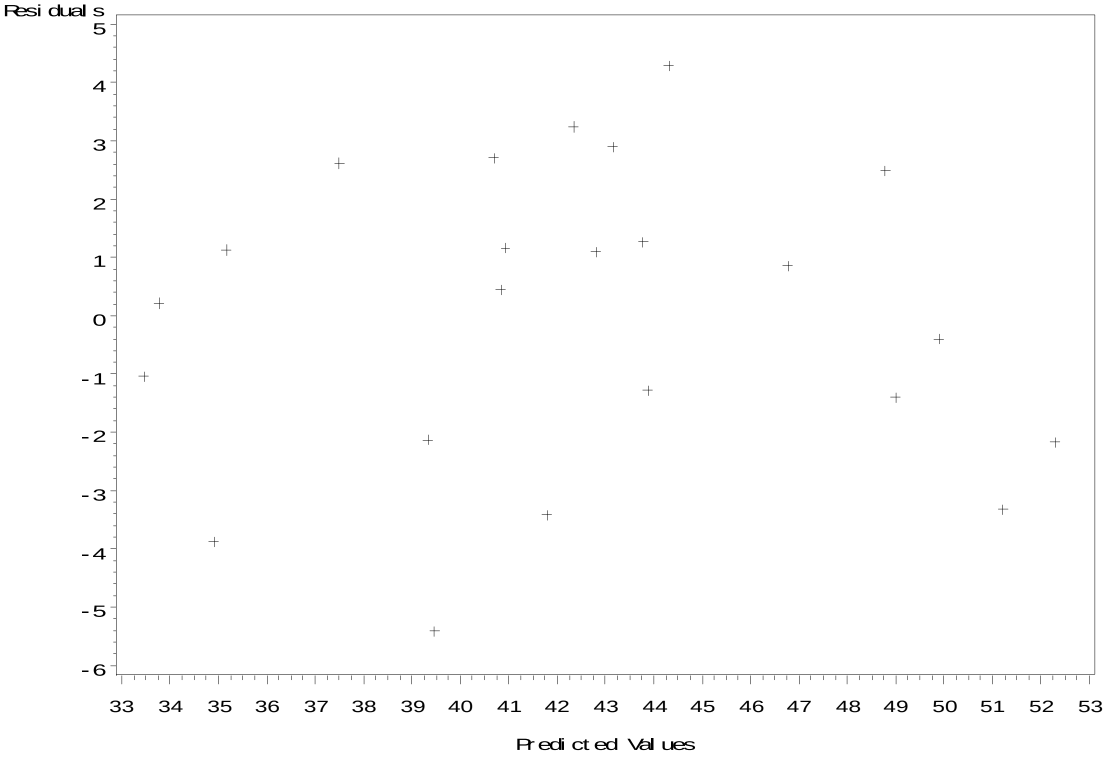

Figure 3.1.2. Scatter plot of residual against predicted values for Trial 201.

Updated General Linear Model for Trial 241

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	3	455.837633	151.945878	3.52	0.0229
Error	42	1810.901914	43.116712		
Corrected Total	45	2266.739548			

R-Square	Coeff Var	Root MSE	BA Mean
0.201098	28.59305	6.566332	22.96478

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SPH	1	165.0692942	165.0692942	3.83	0.0571
Mean_PrHt	1	67.6005933	67.6005933	1.57	0.2174
SPH*Mean_PrHt	1	223.1677460	223.1677460	5.18	0.0281

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SPH	1	309.1383669	309.1383669	7.17	0.0105
Mean_PrHt	1	164.1865113	164.1865113	3.81	0.0577
SPH*Mean_PrHt	1	223.1677460	223.1677460	5.18	0.0281

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-14.59797802	15.92731999	-0.92	0.3646
SPH	0.16516754	0.06168379	2.68	0.0105
Mean_PrHt	3.46181800	1.77401919	1.95	0.0577
SPH*Mean_PrHt	-0.01574305	0.00691984	-2.28	0.0281

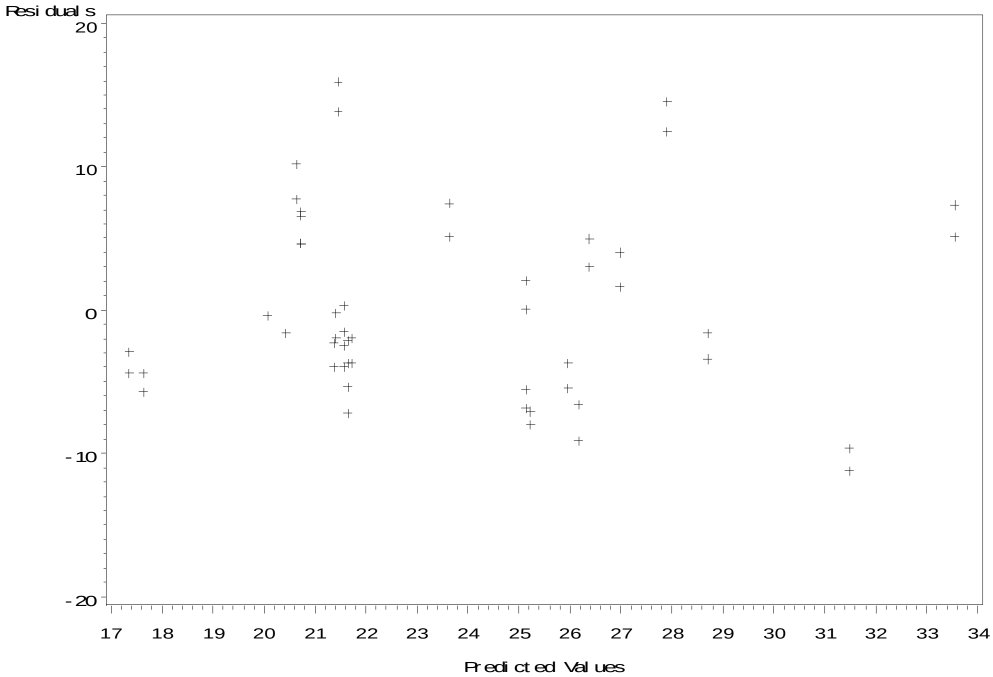

Figure 3.2.1. Updated residual against predicted value scatter plot for Trial 241.

An Updated Model for Trial 243

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	836.3231558	418.1615779	57.03	<.0001
Error	20	146.6357051	7.3317853		
Corrected Total	22	982.9588609			

R-Square	Coeff Var	Root MSE	BA Mean
0.850822	6.045207	2.707727	44.79130

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SPH	1	684.9543122	684.9543122	93.42	<.0001
Mean_PrHt	1	151.3688436	151.3688436	20.65	0.0002

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SPH	1	627.1756001	627.1756001	85.54	<.0001
Mean_PrHt	1	151.3688436	151.3688436	20.65	0.0002

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	35.16561116	3.49360047	10.07	<.0001
SPH	0.08184873	0.00884957	9.25	<.0001
Mean_PrHt	-1.21529392	0.26746561	-4.54	0.0002

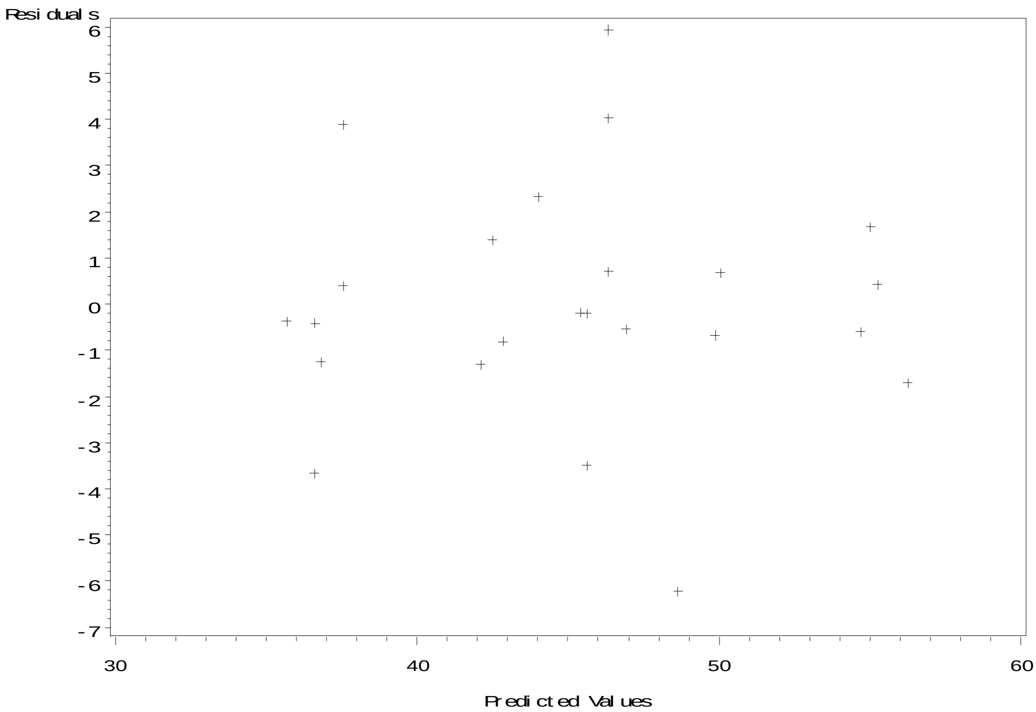

Figure 3.2.2. Scatter plot of residuals against predicted values for Trial 243.

Appendix 4: Proposed Trial Measurement

Table 4.1.1.
Trial detail showing proposed measurement detail under revised measurement frequency of 4 years as advised by FFR TST.

Trial	Last treatment	Last Measure	Proposed next Measure
FR 201	1998	2007	2011
FR 241	2005	2008	2012
FR 247	2001	2008	2012
FR 243	1998	2007	2011

The design of this trial is complex and looks at four levels of interaction between site, stocking, prune height and green crown remaining. More subtle responses to the treatments may not be sufficiently described by the response surface (e.g. height/stocking), so further remeasurement of other trial series which explore the limits of management options (the followers trial series) is recommended to ensure future models are robust and perform over a wide range of management.