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# AN EVALUATION OF THE ACCURACY OF THE AUCKLAND CLAYS GROWTH MODEL WITH FERTILISER EFFECT

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# AN EVALUATION OF THE ACCURACY OF THE AUCKLAND CLAYS GROWTH MODEL WITH FERTILISER EFFECTS.

## Introduction

Claysf is a model designed to estimate growth parameters of *Pinus radiata* on Auckland clay soils. These soils have a medium phosphorus retention and when foliar phosphorus falls below an arbitrary level, determined by economic factors, fertiliser application is justifiable. The model incorporates a phosphorus fertiliser response and uses foliar phosphorus to regulate growth. (Garcia 1979 and 1984).

The rise in foliar phosphorus following fertiliser application and its subsequent decay rate were simulated using data from seven trials established on Auckland Clays. (Hunter and Graham 1982).

In this evaluation we looked at how well the model estimates top height, stocking, basal area, foliar phosphorus and thinning over a range of fertiliser treatments. The data used in this study was drawn from the same data set used to simulate the fertiliser response in the model.

## Data base.

Out of the seven trials, three in Whangapoua, two in Riverhead, one in Glenbervie and one in Maramarua, only six were used in this analysis. Maramarua was considered unsuitable due to a nitrogen deficiency.

One of the control plots in Riverhead, plot 6, grew extremely slowly and it was not possible to simulate it without incurring massive errors. This plot was not used, so the total number of plots was 23, and for the analyses of variance, the whole trial was dropped, leaving only 20 plots.

A summary of the plots used is shown in Table 1 below:

Table 1 : Plots from the superphosphate response series used in this evaluation.

| Trial | Plots |
|---|---|
| Whangapoua A | 1,2,3,5 |
| Whangapoua B | 1,2,5,6 |
| Whangapoua C | 2,3,5,6 |
| Glenbervie | 2,4,7,8 |
| Riverhead (1) | (6),4,10,11 |
| Riverhead (2) | 12,17,18,19 |

Full details of plots used are listed in Appendix 1.

The ranges of site indices and fertilised site indices are shown in Table 2 below:

Table 2 : Site index and fertilised site index in the six areas of interest.

| Trial | Site index | Fertilised site index |
|---|---|---|
| Whangapoua A | 21.2 | 30.6 |
| Whangapoua B | 28.5 | 30.6 |
| Whangapoua C | 24.2 | 30.6 |
| Glenbervie | 30.0 | 30.3 |
| Riverhead (1),(2) | 16.7 | 29.0 |

Unfertilised site index was estimated from height measured at age 20, or in the case of Riverhead, by extrapolating current height at age 19, using current annual increment in height.

The fertiliser regimes of interest are shown in Table 3 below:

Table 3 : Details of the four fertiliser treatments used in this study.

| | |
|---|---|
| Control | no fertiliser. |
| 625 Kg/ha | 625 Kg/ha superphosphate at age 6 (at age 5 in Glenbervie and age 8 in Riverhead). |
| 1250 Kg/ha | 1250 Kg/ha as above. |
| 625 * 4 Kg/ha | 4 applications of 625 Kg/ha superphosphate at 5-yearly intervals. |

Within each of the six trials, there are no replicates of the different fertiliser treatments and foliar phosphorus values are not available for every year, hence the investigation is not as full as we would like it to be.

Running the Model.

In order to run a simulation, the model requires initial foliar phosphourus, fertilised site index, age, top height at this age, stocking and basal area.

The model predicts top height, stocking, basal area, mean diameter, volume and foliar phosphorus. Appendix 2 contains a sample of the print out.

Initial foliar phosphorus must be above 0.06% for the model to run. At 0.06%, growth is zero until it is fertilised. In practice, values below 0.06% are limited to very infertile sites e.g. Riverhead.

Fertiliser application can be carried out at any age. When foliar phosphorus falls below 0.11% growth begins to slow down substantially, so the model has been altered to prompt a fertiliser application.

This can be carried out in two ways;

(1) by applying kilograms of superphosphate per hectare, or

(2) by adjusting foliar phosphorus in the following year.

When the first option is used, rise in foliar P is estimated, then growth is calculated as a function of new foliar P. When the second option is taken , the equation simulating this rise is bypassed and the effect on growth is calculated directly. Phosphorus uptake commences immediately, and foliar P increases linearly over one year, so the maximum level of foliar P is reached one year after fertilising. The raw data does not provide any information as to whether or not, this is the case. The foliar phosphorus then decays, over time, with an exponential function towards 0.06%.

Thinning can be carried out at any time, by adjusting the stocking, or by adjusting the stocking and basal area. The first method invokes a thinning function while the second reduces the discrepancy between the model and the actual data and effectively removes the error after thinning.

By combining these different methods there are four ways of running the simulation with the same data. Looking at the different estimates should enable us to identify some of the error in the model. The four methods are described in Table 4 below:

Table 4 : Details of the four different methods used to simulate growth.

| Method | Description | Number of simulations: |
|---|---|---|
| METHOD 1 : | Fertilising with Kg/Ha, thinning with basal area and stocking. (Using the P uptake function). | 23 |
| METHOD 2 : | Fertilising by adjusting foliar P, thinning with basal area and stocking. | 8 |
| METHOD 3 : | Fertilising with Kg/Ha, thinning with stocking only. (Using the P uptake function and the thinning function). | 23 |
| METHOD 4 : | Fertilising by adjusting foliar P, thinning with stocking only. (Using the thinning function). | 8 |

Testing the Model.

To test the model we simulated the growth for all the selected plots, with thinning and fertiliser regimes as appropriate and compared the predicted values at age 20 to the Permanant Sample Plot data, (at age 19 in Riverhead).

The ratio between the estimated and actual data was the most useful:

RATIO= estimated/actual

Where R < 1 the model has underestimated the parameter

R > 1 the model has overestimated the parameter.

We looked at (a) the accuracy of all four methods over one fertiliser treatment, over each of the four fertiliser treatments and (b) at the accuracy of each individual method over the range of the four fertiliser treatments.

Because there were no replicates of different fertiliser treatments within each trial, we could not test the accuracy of the model against the variability of the growth responses in the six different areas.

RESULTS.

(1) Overall.

Using a two way ANOVA test we found (a) that for each method the estimates of basal area were neither consistently above nor below the actual value, over the range of fertiliser treatments i.e. each method is as accurate with no fertiliser as it is with multiple applications and the model did not consistently over or under estimate the value.

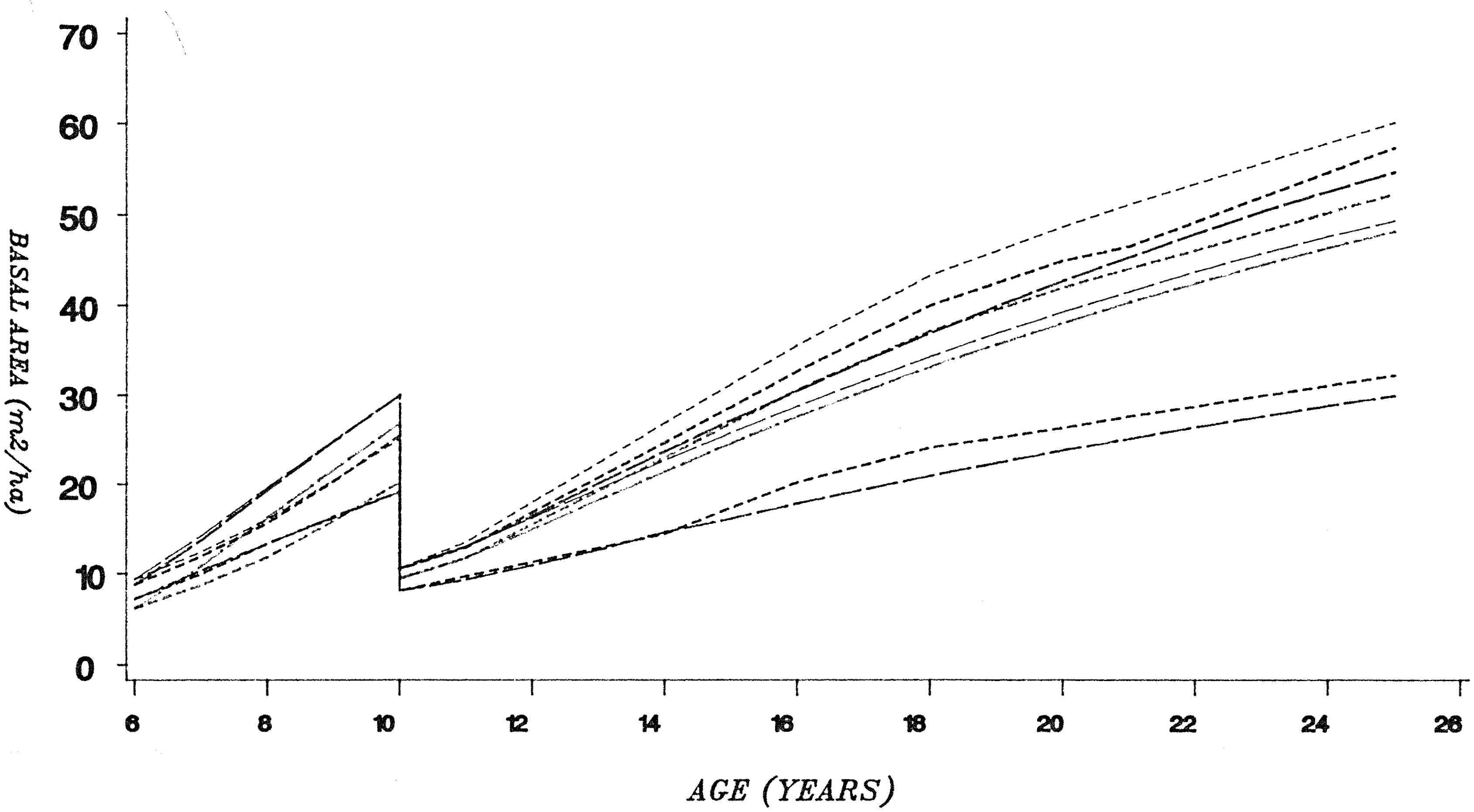
We found (b) that for each method there was no significant difference in its accuracy in estimating basal area over the range of treatments i.e. all four methods were equally accurate under the same conditions.

Appendix 3 contains the results of the two tests of analysis of variance.

Graphs 1-3 illustrate the model's performance, under Method 1, at each trial over the range of fertiliser treatments.

# *GRAPH 1 : Comparison of Actual and Estimated Basal Area*

***Whangapoua A – Plots 3, 5, 1, and 2***

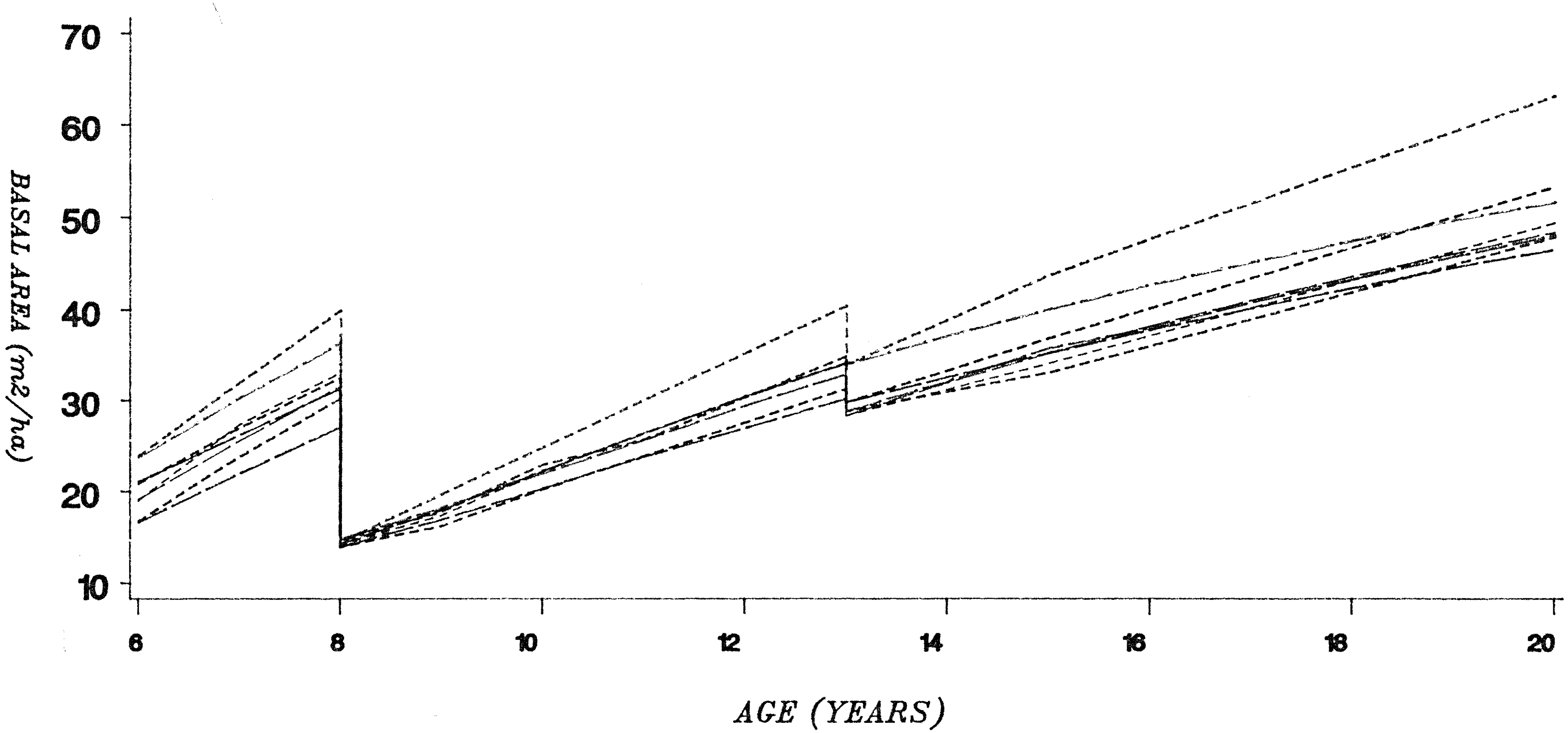



*LEGEND: ....... ACTUAL ____ESTIMATED*

*CONTROL______ 625 Kg/ha @ 6______ 1250 Kg/ha @6______ 625 @ 6,11,16 & 21________*

## GRAPH 2 : Comparison of Actual and Estimated Basal Area

*Glenbervie – Plots 8, 7, 2, and 4*

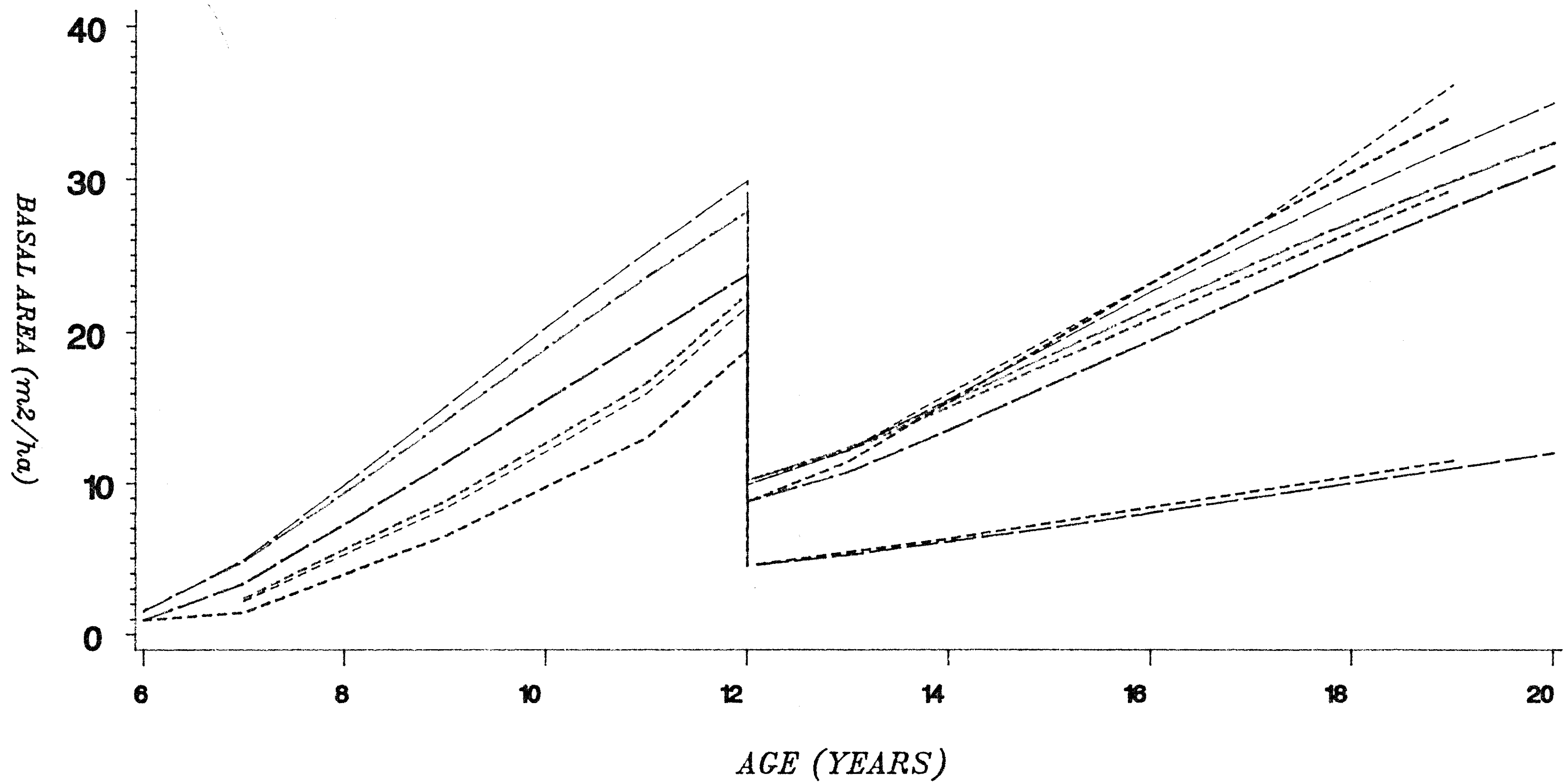



LEGEND:....... ACTUAL ___ESTIMATED

CONTROL______ 625 Kg/ha @ 5______ 1250 Kg/ha @ 5______ 625 @ 5,10,15 & 20________

# *GRAPH 3 : Comparison of Actual and Estimated Basal Area*

*Riverhead – Plots 12, 4, 10, and 11*




*LEGEND: ....... ACTUAL ___ESTIMATED*

*CONTROL______ 625 Kg/ha @ 6______ 1250 Kg/ha @6______ 625 @ 6,11,16 & 21________*

Overall the model performed well. When tested over a range of fertiliser treatments, using Kg/ha and thinning by stocking only, ie Method 3 (the most likely method for determining future regimes),the parameters were estimated with the accuracies shown in Table 5:

Table 5 : Accuracy of the Claysf Model (using Method 3)

| Parameter<br>Statistic | Top height | Stocking | Basal area | Volume |
|---|---|---|---|---|
| Mean ratio | 1.007 | 1.016 | 0.958 | 0.980 |
| Number of samples | 23 | 23 | 23 | 23 |
| Coefficient of variance | 0.009 | 0.016 | 0.025 | 0.030 |
| 95% confidence limit | 0.991-1.022 | 0.989-1.043 | 0.915-1.001 | 0.928-1.032 |
| Range of ratios | 0.923-1.140 | 0.951-1.283 | 0.739-1.177 | 0.761-1.428 |

LEGEND Ratio = estimated / actual

Appendix 3 shows details of each method's estimates of parameters for comparison.

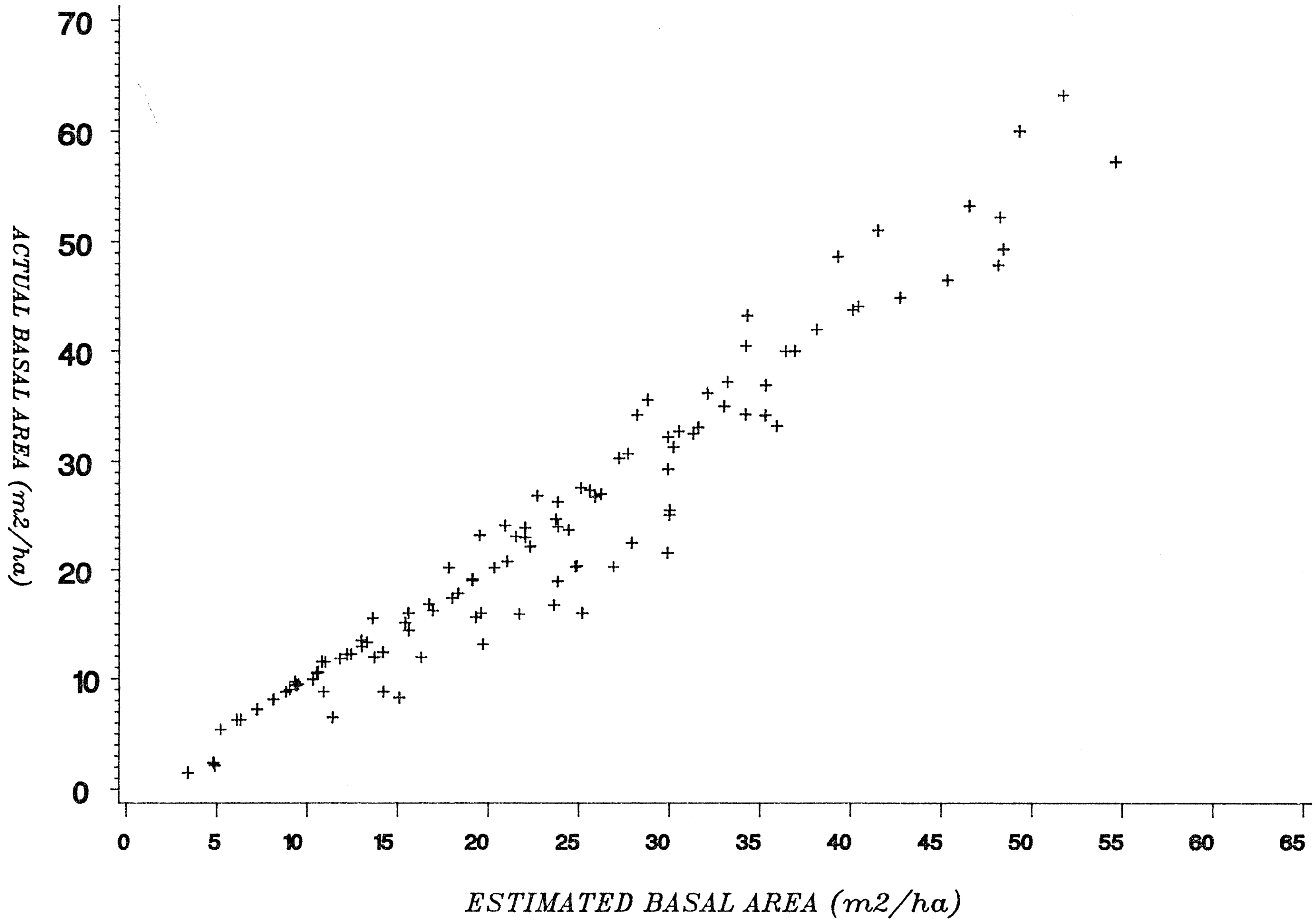
Graph 4 shows Actual vs Estimated basal area for a series of simulations, under Method 1. For a selection of points r^2=0.911, (one from each plot so that each measurement is random).

(2) Effect of fertilised site index.

Fertilised site index is the top height at age 20 of a stand which has been adequately fertilised.

Different estimates of fertilised site index can induce an error throughout the simulation. Table 6 shows the effect of three different estimates of fertilised site index on

*GRAPH 4 : Actual versus Estimated Basal Area.*



some predicted parameters of a stand with the following plot details:

Plot details: Initial foliar P = 0.08 AGE = 6 FSI = 28-32
Top Height = 7m Basal Area = 6 m^2/ha
Initial stocking = 2000 stems/ha
Fertilised at age 6, 625 Kg/ha
Thinned at age 10 to 500 stems/ha

Table 6 : Effect of different estimates of fertilised site index on top height and basal area (under Method 3).

| Fertilised site index | Predicted top height m | Predicted basal area m^2/ha | Predicted volume m^3/ha |
|---|---|---|---|
| 28 | 27.0 | 36.7 | 330 |
| 30 | 28.4 | 39.6 | 372 |
| 32 | 29.9 | 42.5 | 416 |

In this case the effect on basal area is quite marked, but the effect on volume is greater due to the combined effect of error in basal area and error in height.

(3) Fertiliser Response.

Fertilised site index is the top height at age 20 of a stand which has been adequately fertilised. In the model, this means that if foliar phosphorus remains close to 0.13% throughout its first 20 years, it will be very close to this site index. If foliar phosphorus is lower, it will be less, and vice versa.

Tables 7.1 and 7.2 show the effect of different levels of fertiliser on top height:

Plot details: Initial foliar P = 0.08 FSI = 30.0 AGE = 6
Top Height = 7m Basal Area = 6 m^2/ha
Initial stocking = 2000 stems/ha
Fertilised at age 6
Thinned at age 10 to 500 stems/ha

Table 7.1 : Effect of increased fertiliser applications on growth at age 20, estimated under method 3.

| Fertiliser Kg/ha @ 6 | Foliar P % @ age 20 | Maximum foliar P% @ age 7 after fert. | Top height m | Basal area m^2/ha |
|---|---|---|---|---|
| 0 | 0.07 | 0.080 | 22.9 | 24.2 |
| 250 | 0.09 | 0.108 | 27.1 | 35.4 |
| 500 | 0.10 | 0.127 | 28.2 | 38.7 |
| 750 | 0.11 | 0.140 | 28.6 | 40.2 |
| 1000 | 0.11 | 0.147 | 28.8 | 40.8 |
| 1250 | 0.11 | 0.150 | 28.9 | 41.1 |
| 1500 | 0.11 | 0.150 | 28.9 | 41.1 |

Graph 5 shows the effect on top height.

The maximum value of foliar P in any of the plots ever sampled in this series was 0.26%. With higher initial values of foliar P the model predicts higher values of maximum foliar P after high fertiliser application, however this does not seem to have an adverse effect on the rest of the parameters. Above approximately 1500 kg/ha of superphosphate, the model behaves a little strangely as indicated in table 7.2:

*GRAPH 5 : The Effect of Increasing Fertiliser Applications on Top Height.*

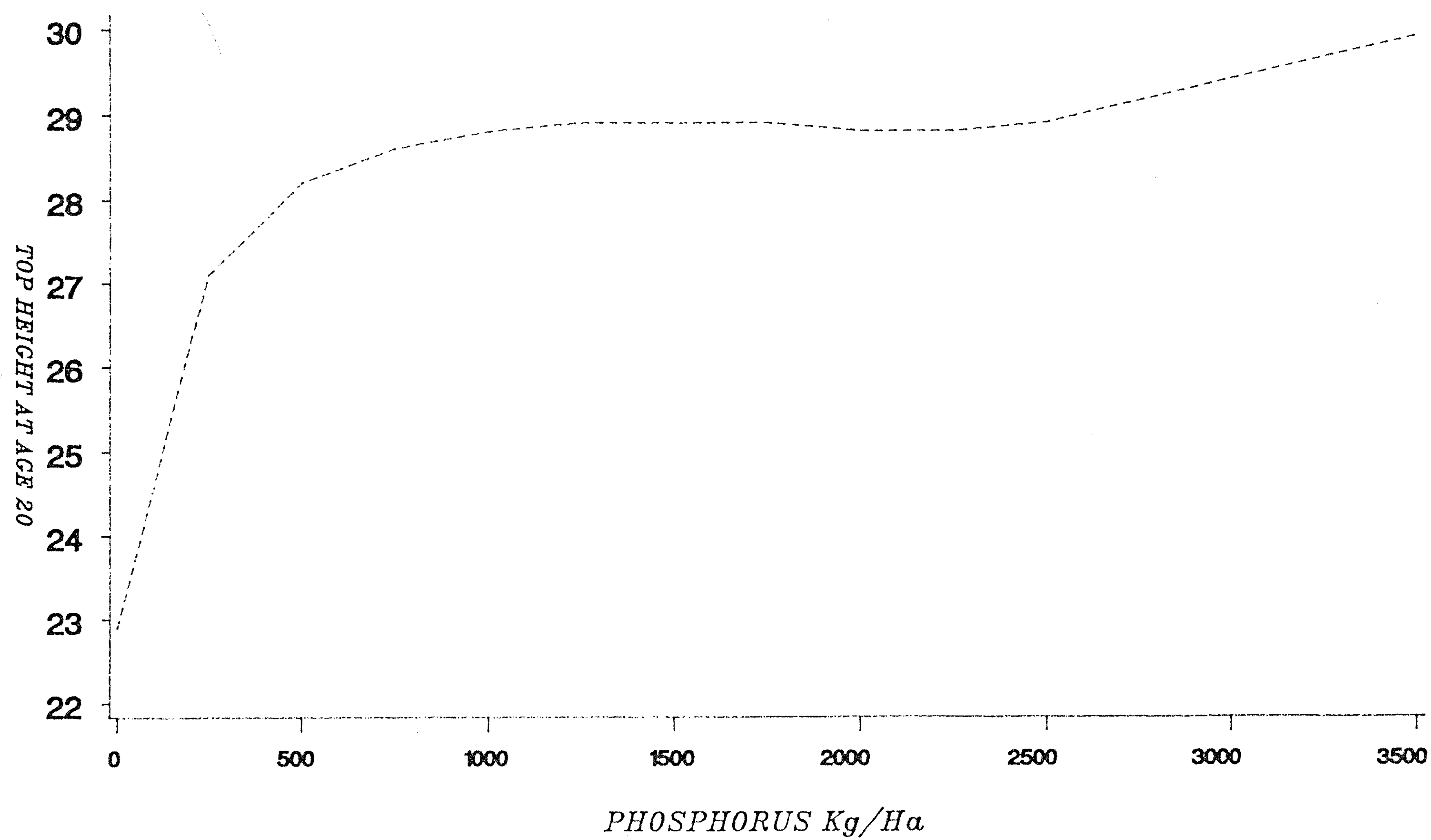


Table 7.2 : Effect of increased fertiliser applications on growth at age 20, estimated under method 3. Very high levels of fertiliser.

| Fertiliser Kg/ha @ 6 | Foliar P % @ age 20 | Maximum foliar P% @ age 7 after fert. | Top height m | Basal area m^2/ha |
|---|---|---|---|---|
| 1500 | 0.11 | 0.150 | 28.9 | 41.1 |
| 1750 | 0.11 | 0.148 | 28.9 | 40.9 |
| 2000 | 0.11 | 0.147 | 28.8 | 40.8 |
| 2250 | 0.11 | 0.146 | 28.8 | 40.8 |
| 2500 | 0.11 | 0.148 | 28.9 | 41.0 |
| 3500 | 0.14 | 0.209 | 29.9 | 44.2 |

(4) Foliar Phosphorus.

The model's estimates of foliar phosphorus are not expected to be extremely accurate, because in practise, values of foliar phosphorus have a large natural variation. Table 8 shows some raw data illustrating this natural variation.

When foliar phosphorus is above 0.13%, increased levels have a diminishing effect on improved growth, therefore errors in these estimates become even less important.Table 7 above shows how basal area increments decrease with rising fertiliser applications. Graph 6 illustrates these figures.

Table 8 below shows the range of foliar phosphorus in a sample of seven trees, analysed seperately before composite sampling was introduced, compared to the model's estimates:

*GRAPH 6 : The Effect of Increasing Fertiliser Applications on Basal Area.*

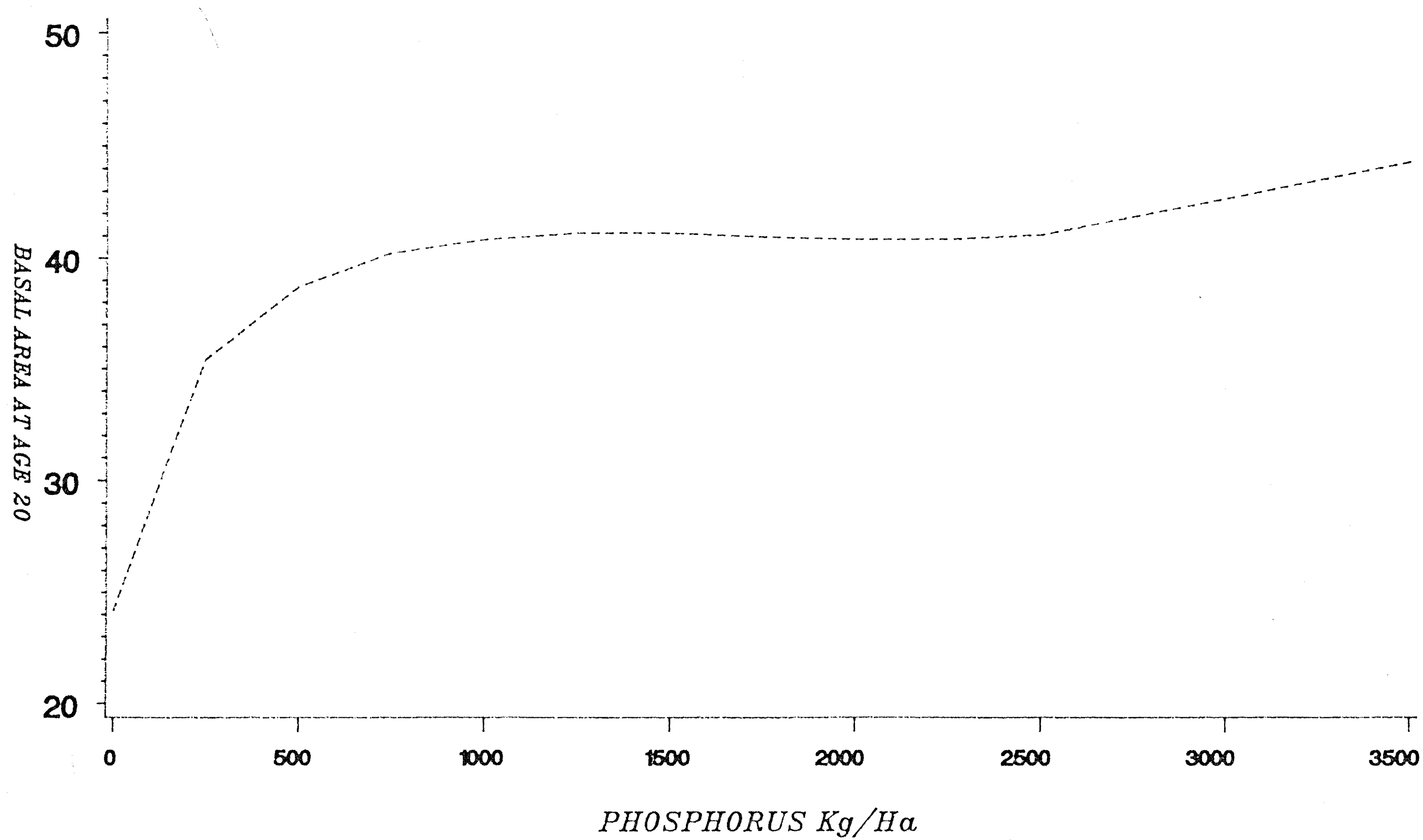


Table 8 : The variability found in foliar P in a sample of seven trees at age 16, compared to the model's estimates under the two methods of fertiliser application.

| Ref. | Actual Fol. P% at age: 6 | 16 | Sx | Range | Model's est at age 16: Kg/ha | Fol P |
|---|---|---|---|---|---|---|
| Whang.A plot 1 1250 Kg/ha | 0.078 | 0.126 | 0.027 | 0.095-0.176 | 0.121 | 0.098 |
| Whang.A plot 5 625 Kg/ha | 0.082 | 0.096 | 0.008 | 0.087-0.111 | 0.108 | 0.104 |

In plot 1, the estimate of foliar P after fertilisation with Kg/ha is more accurate than that with fertiliser application by adjusting foliar P, whilst the situation is reversed in plot 5. In the first case there is quite a difference in the two estimates, but they are all within the natural range.

The model estimates foliar P at age 20, under Method 3, with the following accuracy:

Table 9 : Estimates of foliar phosphorus by Claysf, (under method 3).
Ratio = estimated / actual

| | |
|---|---|
| Mean ratio | 0.974 |
| Number of samples | 23 |
| Coefficient of variance | 0.031 |
| 95% confidence limit | 0.924-1.024 |
| Range of ratios | 0.662-1.511 |

(5) The Thinning Function.

Table 10 shows the accuracy of the thinning function :

Table 10 : Accuracy of the thinning function in estimating basal area when given stocking.
Ratio = estimated / actual

| | |
|---|---|
| Mean ratio | 1.056 |
| Number of samples | 23 |
| Coefficient of variance | 0.031 |
| 95% confidence limit | 1.002-1.110 |
| Range of ratios | 0.855-1.489 |

The variability of estimates by the thinning function is on a par with that of the foliar phosphorus estimates, (coefficient of variance =0.031 in both cases) however errors in basal area after thinning have a more direct effect on the model's subsequent accuracy:

An underestimate of basal area removed in thinning of, for example 2 m^2/ha, is not only carried through to the end of the simulation, but it also has an immediate effect on the next and all subsequent calculations of basal area. An underestimate in foliar P of, for example 0.02% has a smaller effect as foliar P rises, especially above 0.13%. The effect is not as marked because the model is not as sensitive to changes in foliar P, and over time the exponential decay decreases the underestimate and therefore reduces its effect.

(6) The four methods.

In order to look more closely at the accuracy of the thinning model and fertiliser effect, we analysed the difference in the four methods. By running the simulation with the same set of data, altering either the method of fertiliser application or the method of thinning, we attempted to identify some of the error. Graph 7 shows the four methods including their sligthly different errors.

Due to the lack of complete records of foliar phosphorus, in the years after fertiliser application, it was not possible to come to any conclusion about the simulation of fertiliser uptake.

Using a simple sign test to compare the magnitude of the error generated under different thinning methods, we found that thinning with stocking and basal area was significantly more accurate than thinning by stocking alone. The results of the sign test are shown in Table 11 below:

Table 11 : Results of sign test:

| | M1 vs M3 | M2 vs M4 |
|---|---|---|
| + | 15 | 7 |
| - | 5 | 1 |
| 0 | 2 | 0 |
| Total | 22* | 8 |
| Significance level | 0.03 | 0.03 |

LEGEND:

+ = |1-(BAm3/BApsp)| > |1-(BAm1/BApsp)|

- = |1-(BAm3/BApsp)| < |1-(BAm1/BApsp)|

0 when they are equal.

psp = Permanant Sample Plot.

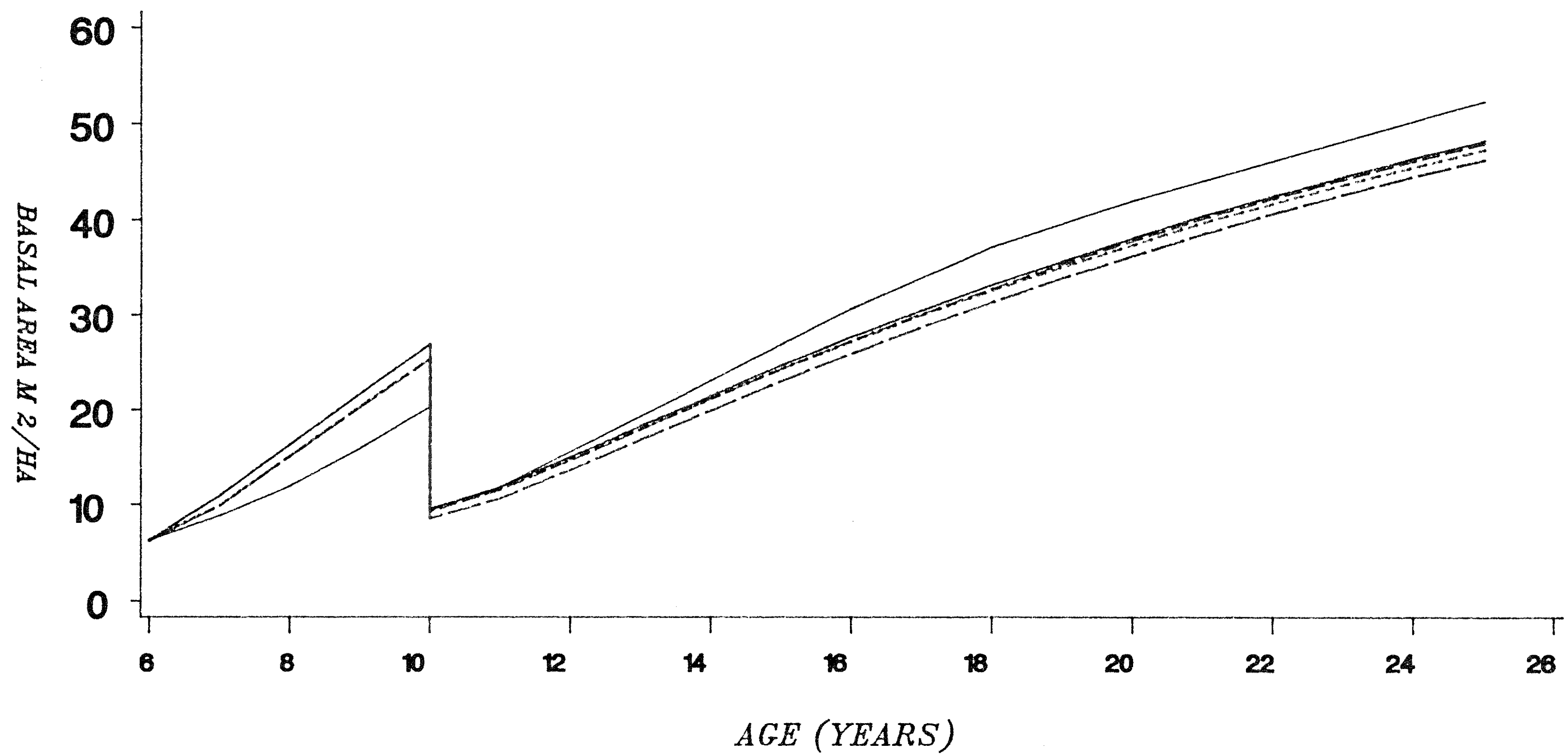
m3 = Thinning with stems/ha.

m1 = Thinning with stems/ha and basal area.

* Rvhd. plot 19 could not be simulated under Method 1.

GRAPH 7 : Comparison of Actual and Estimated Basal Area under Methods 1 to 4.

Whangapoua A Plot 5




LEGEND: ACTUAL METHOD 1 METHOD 2 METHOD 3 METHOD 4

So for both cases, M1 vs M3 and M2 vs M4, we can conclude that there was a difference between the two methods, and thinning by stocking and basal area was more accurate than thinnings using the thinning function.

Conclusions.

The model estimates all parameters with acceptable accuracy i.e. to within + 5% of the estimated mean. Table 12 below shows a summary of the mean ratios and the width of the 95% confidence interval, expressed as a percentage of the mean ratio.

Table 12 : Summary of mean ratios and 95% confidence intervals.

| Parameter | Mean ratio | 95% confidence interval |
|---|---|---|
| Top height | 1.007 | + 1.6% |
| Stocking | 1.016 | + 2.7% |
| Basal area | 0.958 | + 4.3% |
| Volume | 0.980 | + 6.2% |
| Foliar P | 0.974 | + 5.0% |

The analyses carried out here, used some of the foliar phosphorus data that the fertiliser model was constructed from. We do not have the data to test the fertiliser effect in other forests therefore our conclusions about accuracy are limited, although we feel that the model is suitable for use with out further modification.

Discussion.

Hunter et al (1984) reports that there is a weak trend for foliar phosphorus to rise after thinning. The model takes no account of this finding and, if more data becomes available, it might bear investigation. There appeared to be a slight tendancy to under estimate basal area in less fertile areas but this could not be confirmed statistically, because we have no measure of the variability of the growth responses to fertiliser treatments in the six different areas.

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_________ 1984; New class of growth models for even aged stands: Pinus radiata in Golden Downs forest. New Zealand of Forestry Science (14)1: 65-88.

Hunter, I. R.; Graham, J. D. 1982: Growth response of phosphorus-deficient Pinus radiata to various rates of superphosphate fertiliser. New Zealand Journal of Forestry Science 12: 229-38.

I. R. Hunter, J. D. Graham, S. S. Gallagher and K. T. Calvert 1985: Long-term foliar phosphorus response of Pinus radiata to superphosphate fertiliser. New Zealand Journal of Forestry Science 15(1): 89-100.

APPENDIX 1 : Data description.

| PLOT REF. | FERT.REGIME | STARTING AGE | AGE AT THINNING | AGE USED IN COMPARISONS | DATA USED IN METHOD: |
|---|---|---|---|---|---|
| Whang.A 3 | control | 6 | 10 | 20 | 1,3 |
| Whang.A 5 | 625 | 6 | 10 | 20 | 1,2,3,4 |
| Whang.A 1 | 1250 | 6 | 10 | 20 | 1,2,3,4 |
| Whang.A 2 | 625*4 | 6 | 10 | 20 | 1,3 |
| Whang.B 2 | control | 6 | 9 | 20 | 1,3 |
| Whang.B 1 | 625 | 6 | 9 | 20 | 1,2,3,4 |
| Whang.B 5 | 1250 | 6 | 9 | 20 | 1,2,3,4 |
| Whang.B 6 | 625*4 | 6 | 9 | 20 | 1,3 |
| Whang.C 3 | control | 8 | 10 | 20 | 1,3 |
| Whang.C 6 | 625 | 8 | 10 | 20 | 1,2,3,4 |
| Whang.C 5 | 1250 | 8 | 10 | 20 | 1,2,3,4 |
| Whang.C 2 | 625*4 | 8 | 10 | 20 | 1,3 |
| Glenb. 8 | control | 5 | 8, 13 | 20 | 1,3 |
| Glenb. 7 | 625 | 5 | 8, 13 | 20 | 1,2,3,4 |
| Glenb. 2 | 1250 | 5 | 8,13 | 20 | 1,2,3,4 |
| Glenb. 4 | 625*4 | 5 | 8,13 | 20 | 1,3 |
| Rivhd. 6 | control | 6 | 12 | --- | ----- |
| Rivhd. 4 | 625 | 6 | 12 | 19 | 1,3 |
| Rivhd. 10 | 1250 | 6 | 12 | 19 | 1,3 |
| Rivhd. 11 | 625*4 | 6 | 12 | 19 | 1,3 |
| Rivhd. 12 | control | 12 | 12 | 19 | 1,3 |
| Rivhd. 18 | 625 | 6 | 12 | 19 | 1,3 |
| Rivhd. 17 | 1250 | 6 | 12 | 19 | 1,3 |
| Rivhd. 19 | 625*4 | 6 | 12 | 19 | 3 |

| | Method 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Number of simulations | 22 | 8 | 23 | 8 |

GROWTH MODEL FOR AUCKLAND CLAYS RADIATA PINE

WITH FERTILISER EFFECTS

Peter Garcia and Bob Shula, Dec, 1986

Note; fertiliser is kg of superphosphate per Ha,

Trial reference is Whangapoua a plot 5
starting folier p (%) 0,082
Site index (fertilised eqivalent) 30.5 age 6 top height 7,4
Starting stocking (sph) 1704
starting basal area (sq m/ha) 6,30

| AGE (yrs) | TOP HEIGHT (m) | STOCKING (sph) | BASAL ARIA (sq m / ha) | MEAN DBH (cm) | VOLUME (cu m / ha) | FOLIAR P (%) |
|---|---|---|---|---|---|---|
| 6 | 7,4 | 1704 | 6,3 | 6,9 | 21 | 0,08 |

Amount of superphosphate fertiliser (kg/?ha) 625
Rise in Fol,P New Fol,P
0,052 0,134

| AGE (yrs) | TOP HEIGHT (m) | STOCKING (sph) | BASAL AREA (sq m / ha) | MEAN DBH (cm) | VOLUME (cu m / ha) | FOLIAR P (%) |
|---|---|---|---|---|---|---|
| 6 | 7,4 | 1704 | 6,3 | 6,9 | 21 | 0,08 |
| 7 | 9,2 | 1701 | 10,9 | 9,0 | 43 | 0,13 |
| 8 | 11,1 | 1697 | 15,8 | 11,1 | 74 | 0,13 |
| 9 | 12,9 | 1691 | 21,7 | 12,8 | 109 | 0,13 |
| 10 | 14,7 | 1684 | 26,9 | 14,3 | 149 | 0,12 |

Residual stocking (sph) 395 residual basal area (sq m/ha) 0

Stocking; 1289 sph Basal area; 17,7 sq m / ha
Mean DBH; 13,2 cm Volume, 97 cu m / ha

| AGE (yrs) | TOP HEIGHT (m) | STOCKING (sph) | BASAL AREA (sq m / ha) | MEAN DBH (cm) | VOLUME (cu m / ha) | FOLIAR P (%) |
|---|---|---|---|---|---|---|
| 10 | 14,7 | 395 | 9,2 | 17,2 | 51 | 0,12 |
| 11 | 16,4 | 394 | 11,5 | 19,2 | 65 | 0,12 |
| 12 | 18,1 | [illegible] | [illegible] | 21,7 | 95 | 0,12 |
| 13 | 19,5 | 392 | [illegible] | [illegible] | 124 | 0,12 |
| 14 | 21,[illegible] | 391 | [illegible] | 26,2 | 156 | 0,11 |
| 15 | 22,5 | 390 | 24,1 | 28,1 | 185 | 0,11 |
| 16 | 24,0 | 390 | 27,3 | 29,9 | 223 | 0,11 |
| 17 | 25,3 | 389 | 30,1 | 31,4 | 257 | 0,11 |
| 18 | 26,6 | 386 | 32,8 | 32,[illegible] | 292 | 0,11 |
| 19 | 27,9 | 385 | 35,4 | 34,2 | 327 | 0,10 |
| 20 | 29,0 | [illegible] | 37,8 | 35,[illegible] | 361 | 0,10 |
| 21 | 30,2 | [illegible] | [illegible] | 36,5 | 395 | 0,10 |
| 22 | 31,[illegible] | [illegible] | [illegible] | 37,6 | 429 | 0,10 |
| 23 | [illegible] | [illegible] | [illegible] | [illegible] | 463 | 0,10 |
| 24 | [illegible] | [illegible] | [illegible] | [illegible] | 495 | 0,10 |
| 25 | [illegible] | [illegible] | [illegible] | [illegible] | 527 | 0,09 |

# APPENDIX 3 : A summary af each method's accuracy in estimating parameters

METHOD 1:

| Parameter / Statistic | Top height | Stocking | Basal area | Volume |
|---|---|---|---|---|
| Mean ratio | 1.007 | 1.016 | 0.942 | 0.980 |
| Number of samples | 22 | 22 | 22 | 22 |
| Coefficient of variance | 0.009 | 0.016 | 0.019 | 0.030 |
| 95% confidence limit | 0.991-1.022 | 0.989-1.043 | 0.902-0.982 | 0.928-1.032 |
| Width of 95% confidence interval | ± 1.5% | ± 2.7% | ± 4% | ± 5.2% |
| Range of ratios | 0.923-1.140 | 0.951-1.283 | 0.804-1.177 | 0.761-1.428 |

METHOD 2:

| Parameter / Statistic | Top height | Stocking | Basal area | Volume |
|---|---|---|---|---|
| Mean ratio | 1.001 | 0.987 | 0.919 | 0.908 |
| Number of samples | 8 | 8 | 8 | 8 |
| Coefficient of variance | 0.015 | 0.010 | 0.037 | 0.038 |
| 95% confidence limit | 0.966-1.036 | 0.963-1.011 | 0.831-1.007 | 0.818-0.998 |
| Width of 95% confidence interval | ± 3.5% | ± 2.4% | ± 8.8% | ± 9.0% |
| Range of ratios | 0.938-1.055 | 0.962-1.026 | 0.848-1.074 | 0.814-1.104 |

METHOD 3:

| Parameter / Statistic | Top height | Stocking | Basal area | Volume |
|---|---|---|---|---|
| Mean ratio | 1.007 | 1.016 | 0.958 | 0.980 |
| Number of samples | 23 | 23 | 23 | 23 |
| Coefficient of variance | 0.009 | 0.016 | 0.025 | 0.030 |
| 95% confidence limit | 0.991-1.022 | 0.989-1.043 | 0.915-1.001 | 0.928-1.032 |
| Width of 95% confidence interval | ± 1.5% | ± 2.7% | ± 4.3% | ± 5.2% |
| Range of ratios | 0.923-1.140 | 0.951-1.283 | 0.739-1.177 | 0.761-1.428 |

METHOD 4:

| Parameter / Statistic | Top height | Stocking | Basal area | Volume |
|---|---|---|---|---|
| Mean ratio | 1.001 | 0.987 | 0.902 | 0.908 |
| Number of samples | 8 | 8 | 8 | 8 |
| Coefficient of variance | 0.015 | 0.010 | 0.042 | 0.038 |
| 95% confidence limit | 0.966-1.036 | 0.963-1.011 | 0.803-1.001 | 0.818-0.998 |
| Width of 95% confidence interval | ± 3.5% | ± 2.4% | ± 9.9% | ± 9.0% |
| Range of ratios | 0.938-1.055 | 0.962-1.026 | 0.708-1.081 | 0.814-1.104 |

APPENDIX 4 : Results of analysis of variance.

1) F-test for significant difference in estimates for different fert regimes

| method | F3,12 | F1,7 |
|---|---|---|
| 1 | 0.602 | |
| 2 | | 0.008 |
| 3 | 0.006 | |
| 4 | | 0.158 |
| 95 % sig. | 3.49 | 5.59 |

2) F-test for significant difference in estimates for each method over fertiliser range

| Fert regime | F3,12 | F1,7 |
|---|---|---|
| Control | | 0.016 |
| 625kg/ha | 0.186 | |
| 1250kg/ha | | 2.192 |
| 625kg/ha*4 | 0.025 | |
| 95 % sig. | 3.49 | 5.59 |