NZ FRI PROJECT RECORD

NO. 1688

CLAYSFERT

AUCKLAND CLAYS GROWTH MODEL WITH PHOSPHORUS FERTILISER EFFECTS

DEVELOPMENT HISTORY AND PERFORMANCE

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FRI/INDUSTRY RESEARCH COOPERATIVES

EXECUTIVE SUMMARY

The objective of this report is to document the construction and evaluate the performance of 'CLAYSFERT', a computer model used to derive yield tables and predict growth of radiata pine in the Auckland region on 'classic' clay soils with varying levels of phosphorus fertility. The model can predict growth where the amount of phosphorus measured by foliar 'P' is known, and can predict the change in foliar 'P' through time, or as a result of added fertiliser.

It is one of the family of 'state-space' regional growth models. 'CLAYSFERT' was derived by adding 'fertiliser effects' to the existing 'CLAYS' model, which is restricted to stands on clay soils deemed to have an adequate amount of phosphorus.

CLAYSFERT has been evaluated against CLAYS. In fertilised situations, CLAYS marginally outperformed CLAYSFERT; however in unfertilised situations, CLAYSFERT demonstrated its special ability to make equally good predictions as in fertilised situations (ratios of predicted to actual between 90-100%).

It is suggested that CLAYSFERT replace CLAYS and be used by management. The release of CLAYSFERT is supported by the view that the model behaves logically and well, and has no inherent deficiencies precluding its use within the range of stand parameters described in this report. Future work to strengthen the 'fertiliser effects' relationships is suggested. However an over-riding concern is the uncertainty of whether or not natural variation in growth and foliar 'P' precludes development of more sensitive relationships.

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1.0 INTRODUCTION

The objective of this report is to document the construction and evaluate the performance of 'CLAYSFERT'; the Auckland clays growth model, 'CLAYS' (Shula 1987), as modified for the inclusion of phosphorus fertiliser effects. While CLAYS enables growth and yield predictions for radiata pine occurring on 'classic clay' soils with an 'adequate' phosphorus nutrient status (foliar 'P' > 0.11%), CLAYSFERT is able to make these predictions at all levels of phosphorus fertility (dependent on foliar 'P' level).

2.0 MODELLING METHODOLOGY

2.1 Background

The approach selected to model 'fertiliser effects' was suggested by Dr O. Garcia. The method involves:

(1) retaining all the critical growth relationships and ancilliary functions in the CLAYS model (Shula 1987),

(2) use of the basic form of the CLAYS model equations to predict top height, basal area and stocking. These predictions are modified by the 'fertiliser effects'.

The 'fertiliser effects' are produced by three distinct relationships:

(1) 'time-scale multipliers' (lambda values), or the time required to achieve a unit of growth are predicted as a function of foliar 'P',

(2) change in foliar 'P' (rise) as a result of fertilisation is predicted as a function of fertiliser rate,

(3) change in foliar 'P' (decay) as a result of natural decline in fertility is predicted as a function of time.

2.2 Site index and phosphorus fertility status

Retaining the CLAYS top height model requires site index to be input (or be determined from height and age) as top height at age 20 years for an adequately fertilised stand. In using CLAYSFERT, 'equivalent fertilised' site quality must be judged initially, after which the height curve is:

(a) maintained (adequately fertilised stand), or

(b) lowered ('P' deficient stand) as determined in the model by the affect of foliar 'P' on top height lambda values.

Site index in the CLAYS analysis ranged from 24 to 37 metres, indicating that site index is not solely influenced by fertility status.

In addition to equivalent fertilised site index, CLAYSFERT requires the input of the phosphorus fertility status of the stand, i.e., foliar 'P' (%). If the user is only aware of a subjective fertility rating, the following serves as a reasonable guide : high 0.15%; medium 0.11%; and low 0.07%. If foliar 'P' reaches 0.06% during programme execution, predicted growth is zero. This is a result of the model being conditioned to approach 0.06% as a lower limit of foliar 'P' for tree growth.

2.3 'Early growth' function

The 'early growth' function enables the user to start a simulation at age zero by inputting only site index and stocking. In practice, the function extrapolates to an initial basal area corresponding to a top height of 5 metres. Site index is used to determine stand age corresponding to 5 metres top height.

In CLAYSFERT, the 'early growth' function is only used if the user:

(1) inputs equivalent fertilised site index alone (without height and age), and

(2) initial foliar 'P' is > .13%.

If initial foliar 'P' is < .13%, the user must input height and age along with site index, thereby eliminating the need of the function. The function cannot be used when initial foliar 'P'is < .13% because it was derived using data above this limit.

2.4 Relationships supporting 'fertiliser effects'

2.4.1 Lambda values as a function of foliar 'P'

Predicted lambda values for each measurement pair in the data from the CLAYS model for basal area, top height, stocking, and site occupancy were examined with respect to the corresponding foliar 'P' value. Non-linear relationships were determined which predict lambda as a function of foliar 'P'. In the final analysis, basal area and top height relationships were also used for stocking and site occupancy relationships.

2.4.2 Change in foliar 'P' as a result of fertilisation

Following the application of phosphorus fertiliser, foliar 'P' rises in magnitude (as does soil 'P'). The determination of the timing and magnitude of the rise in foliar 'P' was based on data from FRI fertiliser trials (primarily super-phosphate). Timing of the rise corresponded to the first measurement after fertilisation, i.e., one year. The magnitude of the rise was described as non-linear based on logarithmic transformation of the independent and dependent variables, fertiliser rate (kg/ha) and rise (final-initial), respectively.

2.4.3 Change in foliar 'P' as a result of natural decline in fertility

Following the rise in magnitude of foliar 'P' after fertilisation, foliar 'P' is assumed to decline as soil 'P' declines (depleted, leached, mineralised). Data from FRI fertiliser trials provided the basis for determining a yearly exponential decay rate for foliar 'P'. The exponential decay was conditioned to approach a foliar 'P' of 0.06% as a lower limit for tree growth based on trial data and the recommendation of I. Hunter, FRI.

3.0 DATA BASE

3.1 General description

3.1.1 Plot data

The data is entirely from the NZ Forest Service Permanent Sample Plot system originating from FRI fertiliser trial AK 286 (Hunter, et al., 1985, 1982). The data base is a sub-set of the data base used in the development of the CLAYS model, limited in extent by the requirement of corresponding measurements of stand parameters and foliar 'P'. 'New' data is included representing:

1. measurements of unfertilised controls, and

2. Riverhead Forest plots unsuitable for use in the CLAYS model, yet suitable for use in the analyses of change in foliar 'P'.

Four forests from the former Auckland Conservancy are represented (***Figure 1***), i.e., Whangapoua, Glenbervie, Maramarua and Riverhead. Specific descriptions of the data from each forest are provided in sections 3.2.1-3.2.3 with respect to each particular analysis. For the principle analysis of lambda values vs foliar 'P', the data is represented by 36 plots, 331 individual measurements, and 241 paired measurements.

3.1.2 Management history

The fertiliser trial covers a range of super-phosphate application frequencies and rates (including unfertilised controls). Frequency ranges from 1 to 4, while rates range from 625 to 2500 kg/ha.

Plots have been thinned 1 to 2 times between the ages 6-13 years. Fertiliser and thinning histories of the plots are described in ***Appendix 1***.

3.2 Data description - specific analysis

For indicative stand parameter descriptions, the reader is directed to Tables 2, 4, 5, 7, 8 and 10 in in the CLAYS report (Shula 1987). Stand parameters directly applicable to particular fertiliser effect analyses are presented below (Sections 3.2.1-3.2.3).

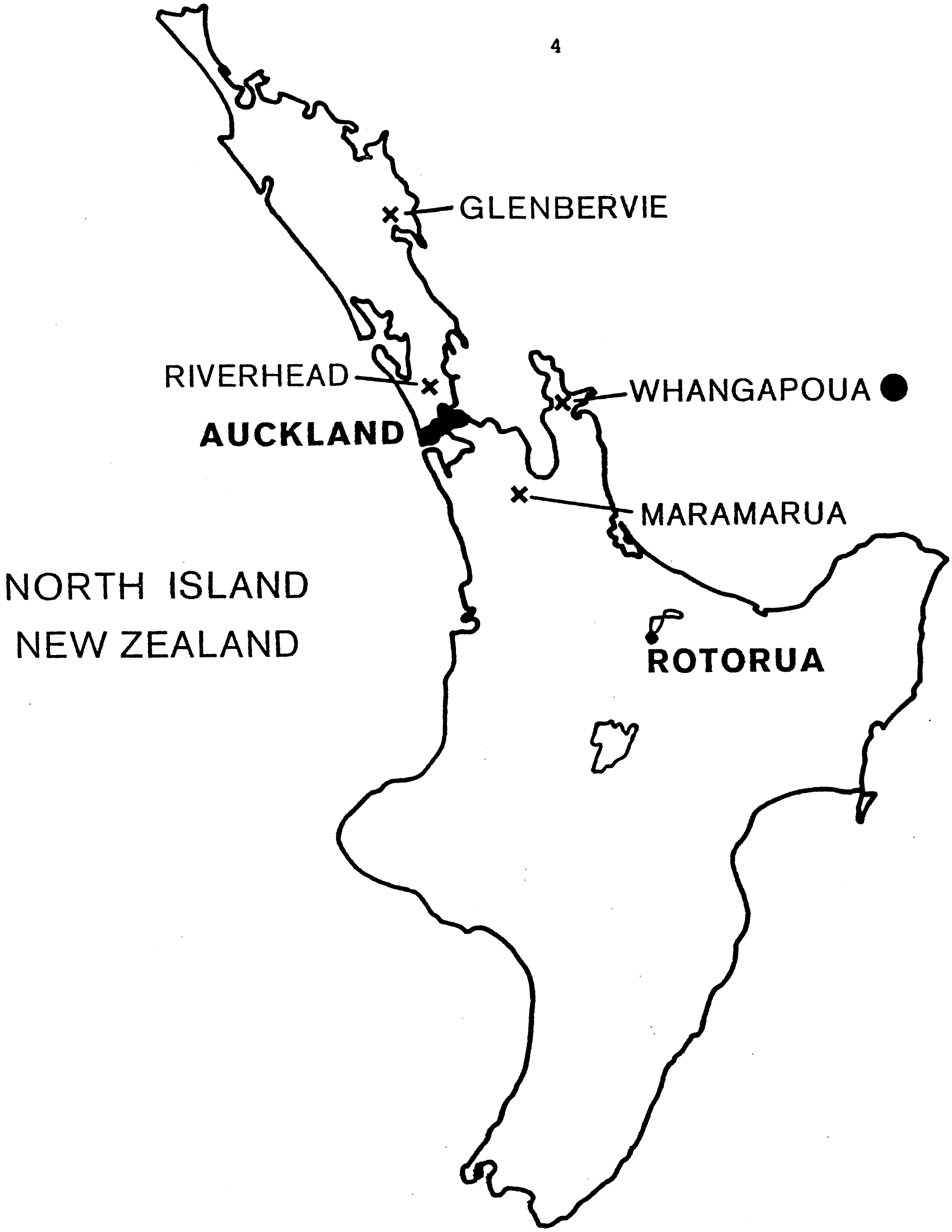

FIGURE 1: Auckland Conservancy Forests represented in the data

3.2.1 Lambda values as a function of foliar 'P'

Data selection in this analysis was dependent on the availability of corresponding measurements of stand parameters and foliar 'P'. Control plots excluded in the CLAYS analysis were included by calculating lambda values from consecutive measurements using CLAYS model coefficients. In so doing, lambda values calculated from unfertilised measurements have a relationship relative to those calculated from fertilised measurements; together they can be used to determine a lambda/foliar 'P' relationship over the range of fertility levels.

The final dataset represents 3 forests and 36 plots totalling 241 measurement pairs from 331 individual measurements. A descriptive breakdown on the basis of bulk of data by forest and fertiliser treatment (fertilised or unfertilised) is provided in *Table 1*. A list of plots by forest is provided in *Appendix 2*.

***TABLE 1**: Lambda value analysis - bulk of data by forest and fertiliser treatment*

Forest	Fertiliser treatment	Number of			% of total no. pairs
		Plots	Mea.	Pairs	
Whangapoua	Control	3	56	41	17
	Fertilised	17	174	138	57
	Total	20	230	179	74
Glenbervie	Control	1	10	6	2
	Fertilised	7	43	24	10
	Total	8	53	30	12
Maramarua	Control	1	8	5	2
	Fertilised	7	40	27	11
	Total	8	48	32	13
All Forests	Control	5	74	52	22
	Fertilised	31	257	189	78
	Total	36	331	241	100

On the basis of measurement pairs (from which lambda values are calculated, and a foliar 'P' value is applicable), 74% of the data is from Whangapoua Forest, while Glenbervie and Maramarua Forests contribute 12 and 13%, respectively. Overall, fertilised measurement pairs contribute 78% of the data.

TABLE 2: Lambda value analysis - Foliar 'P' and lambda values

Forest	Fertiliser treatment (n)	Foliar 'P'			BA Lambda (-)			HT Lambda (-)		
		min	mean (σ)	max	min	mean (σ)	max	min	mean (σ)	max
Whangapoua	Control (41)	.062	.090 (.015)	.127	1.498	.904 (.232)	.464	1.395	.741 (.327)	.059
	Fertilised (138)	.076	.129 (.024)	.199	1.885	1.331 (.254)	.746	2.246	1.006 (.362)	.027
Glenbervie	Control (6)	.101	.117 (.010)	.127	1.691	1.431 (.182)	1.228	1.000	.769 (.144)	.593
	Fertilised (24)	.101	.149 (.041)	.263	1.911	1.566 (.232)	1.069	1.477	.930 (.273)	.399
Maramarua	Control (5)	.084	.092 (.006)	.100	1.346	1.135 (.213)	.813	.904	.767 (.091)	.660
	Fertilised (27)	.067	.149 (0.32)	.251	1.874	1.411 (.198)	.950	1.385	.985 (.311)	.261

A descriptive breakdown of the data by forest and fertiliser treatment on the basis of foliar 'P' and lambda values (basal area and top height) is provided in *Table 2*. Mean age increment for the 241 measurement pairs is 1.7 years with a range of 0.8 to 4 years. The range in values for unfertilised and fertilised foliar 'P' and lambda values is given below.

Treatment	Foliar 'P' (%)	BA lambda (-)	HT Lambda (-)
Unfertilised	.062 - .127	1.69 - .46	1.40 - .06
Fertilised	.076 - .263	1.91 - .75	2.25 - .03

3.2.2 Change in foliar 'P' as a result of fertilisation

Data selection in this analysis was dependent on successive foliar 'P' measurements at time of fertiliser application and after one year. There was no information on whether the rise in foliar 'P' attained its maximum in less than one year. Rise in foliar 'P' extending beyond one year since application was ignored. Observations from Riverhead Forest were accepted due to the appropriate nature of the parameter as opposed to a 'growth' parameter precluding use in the CLAYS and lambda value analyses. Due to only a single observation at the highest application rate (2500 kg/ha), one additional 'measurement' at this rate was included; a mean value from two estimated observations. The additional 'measurement' is based on estimated foliar 'P' values one year after application obtained by applying the decay function to actual foliar 'P' values available 3 years after application. The additional 'measurement', although estimated, provides balance to the one existing observation which appears to be an 'outlier' (I. Hunter, pers. com.).

The final dataset represents 4 forests and 30 plots totalling 34 observations. The number of observations is limited primarily due to remeasurement scheduling, i.e. there is a total of 83 potential remeasurements, one year after each application. A descriptive breakdown on the basis of bulk of data by forest and fertiliser application rate is provided in *Table 3*. A list of plots by forest is provided in *Appendix 2*.

TABLE 3: Rise in foliar 'P' analysis - Bulk of data by forest and fertiliser application rate

Application rate (kg/ha)	Number of observations				Total
	WHAP	GLNB	MARA	RVHD	
625	13	5	6	2	26
1250	3	1	0	2	6
2500	0	1	0	1*	2
Total	16	7	6	5	34

* estimated

On the basis of number of observations, nearly 50% of the data is from Whangapoua Forest, while Glenbervie, Maramarua and Riverhead Forests contribute nearly equal numbers of remaining observations. On the basis of fertiliser application rate, 76% of the observations are at the rate of 625 kg/ha, 18% at 1250 kg/ha, and only 6% at 2500 kg/ha.

A descriptive breakdown of the data by fertiliser application rate on the basis of rise in foliar 'P' is provided in ***Table 4***.

TABLE 4: Rise in foliar 'P' analysis - Magnitude of rise by fertiliser application rate

Fertiliser application rate, kg/ha (n)	Rise in foliar 'P'		
	min	mean (σ)	max
625 (26)	.002	.039 (.020)	.099
1250 (6)	.019	.050 (.026)	.090
2500 (2)*	.072	.113 (.041)	.154

* one measurement estimated, i.e., the minimum.

3.2.3 Change in foliar 'P' as a result of natural decline in fertility

Data selection in this analysis was dependent solely on the availability of successive foliar 'P' measurements beyond one year since fertiliser application. Observations from Riverhead Forest were accepted for similar reasons as stated in Section 3.2.2. The analysis assumes a natural <u>decline</u> in foliar 'P' with successive measurements, however <u>rises</u> in foliar 'P' were present and are included. These observations of rise are attributed to foliar 'P' sampling variation, delayed response to fertiliser, and a potential indirect 'fertiliser' effect occurring directly after a waste thinning (nutrient availability from foliage, etc). Inclusion of rise observations in this analysis is rationalised on the basis of averaging out these effects. The statistical appropriateness of including rise observations in this analysis is described in section 4.1.3.

The final dataset represents 4 forests and 54 plots totalling 383 observations. A descriptive breakdown on the basis of bulk of data by forest and relative change in foliar 'P' (decay or rise) is provided in ***Table 5***. A list of plots by forest is provided in ***Appendix 2***.

TABLE 5: Decay in foliar 'P' analysis - Bulk of data by forest and relative change in foliar 'P'

Relative change in foliar 'P'	Number of observations				Total
	WHAP	GLNB	MARA	RVHD	
Decay	122	29	26	47	224
Rise	75	26	21	37	159
Total	197	55	47	84	383

On the basis of number of observations, Whangapoua Forest contributes 51% of the data followed by Riverhead Forest with 22%; Glenbervie and Maramarua, contribute 14 and 12%, respectively. Overall, observations of decay represent 58% of the data indicating that the relative change in foliar 'P' is nearly as often positive as negative in the years following fertilisation.

A descriptive breakdown of the data by relative change in foliar 'P' % on the basis of magnitude of change (yearly basis) is provided in ***Table 6***. On average the magnitude of change in foliar 'P' is negative (-.001) with minimum (decay) and maximum (rise) values of -.082 and +.061, respectively. Analysed separately, decay and rise observations have similar absolute mean values, i.e., 0.011 and 0.013, respectively.

TABLE 6: Decay in foliar 'P' analysis - Magnitude of relative change in foliar 'P' (yearly basis)

Relative change in foliar 'P' (n)	Magnitude of change		
	min	mean (σ)	max
All mea (383)	-.082	-.0008 (.017)	.061
Decay (224)	-.082	-.0110 (0.12)	0
Rise (159)	.0004	.013 (.014)	.061

4.0 RESULTS

4.1 Specific analyses

4.1.1 Lambda values as a function of foliar 'P'

Non-linear relationships between foliar 'P' and lambda values for basal area and top height were determined using an 'equation generating graphics' programme developed by O. Garcia (FRI) on a personal computer. This method enabled flexibility in selecting initial and mid-point coordinates through which the predicted curve should pass. The initial coordinate represents a lower limit for growth, selected as foliar 'P', 0.06% and lambda value, 0 (no growth). The mid-point coordinate (representing the average fertility status of the data used in the CLAYS analysis) was selected as foliar 'P', 0.13% and lambda value 1.0. Resultant equations and coefficients were cross-checked and compared with GENSTAT non-linear regression estimates. The final form of the relationship is:

$$L = [a*(\frac{P - .06}{P - .06 + b})]*C$$

where L = 'fertiliser effect' lambda (for either basal area or top height),

a = 1.25 or 1.15) coefficients for BA and HT,

b = .0175 or .0105) respectively;

and, P = foliar 'P' %,

C = -1.31629 or -1.0, mean BA and HT lambda values from CLAYS.

Figures 2 and 3 present the data and lambda regression curves for basal area and top height, respectively. While the comparison is not shown, curves generated from GENSTAT derived coefficients are very similar (even though the mid-point coordinate was not specified). The relationships for basal area and height account for 34% and 2% of the variance in lambda, respectively. Although the scatter in the data is large, the regressions provide an adequate, sensitive measure of lambda as a function of foliar 'P'.

Figures 2 and 3 also illustrate the distribution of lambda residuals around each curve. The distribution of BA and HT lambda residuals is fairly even with 58% positive and 56% negative, respectively. The sum of residuals are +13 and -3, respectively.

As a check on the adequacy of the lambda regression, predicted lambdas were used to estimate the second measurement of BA and HT given the first measurement of the 241 pairs in the dataset. Residuals for BA and HT are presented in ***Figures 4 and 5***, respectively. Mean age increment in the predictions is 1.7 years with a range from 0.8 to 4.0 years.

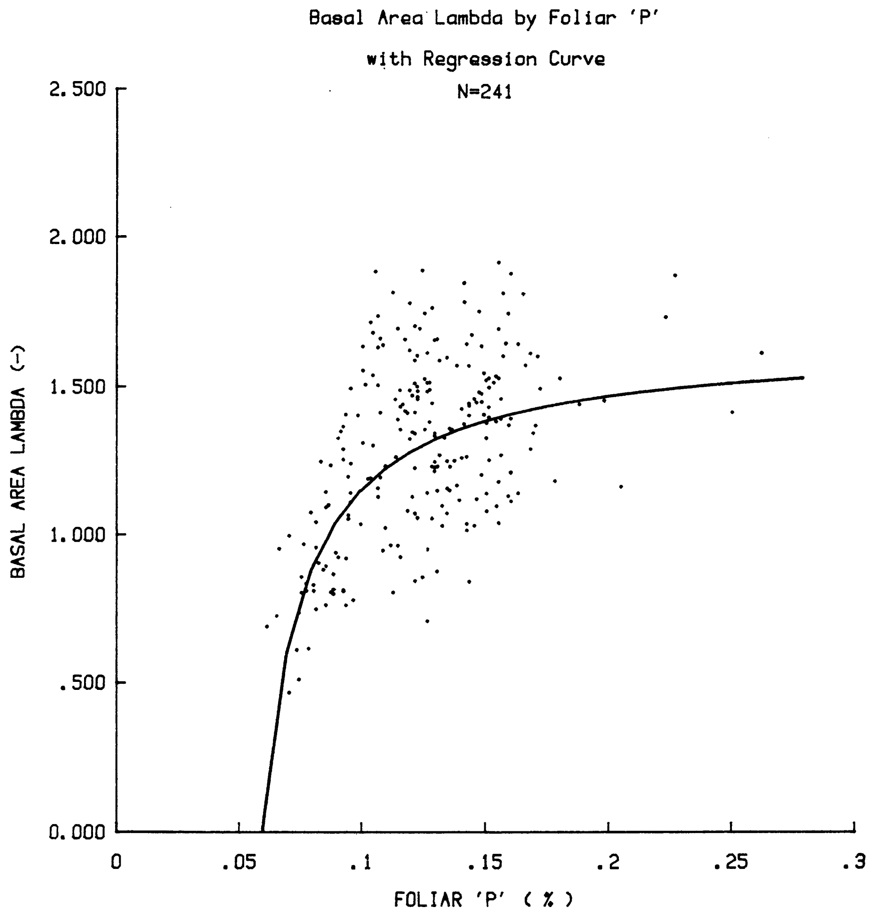

Figure 2 - Basal area lambda by foliar 'P'

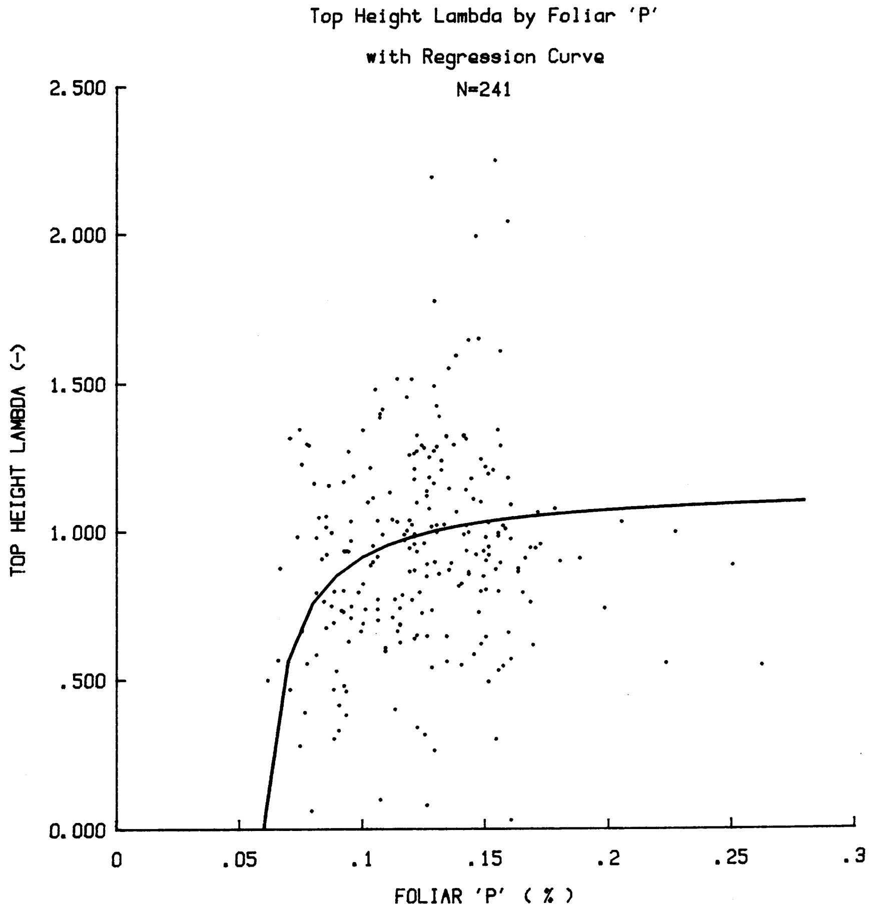

Figure 3 - Top height lambda by foliar 'P'

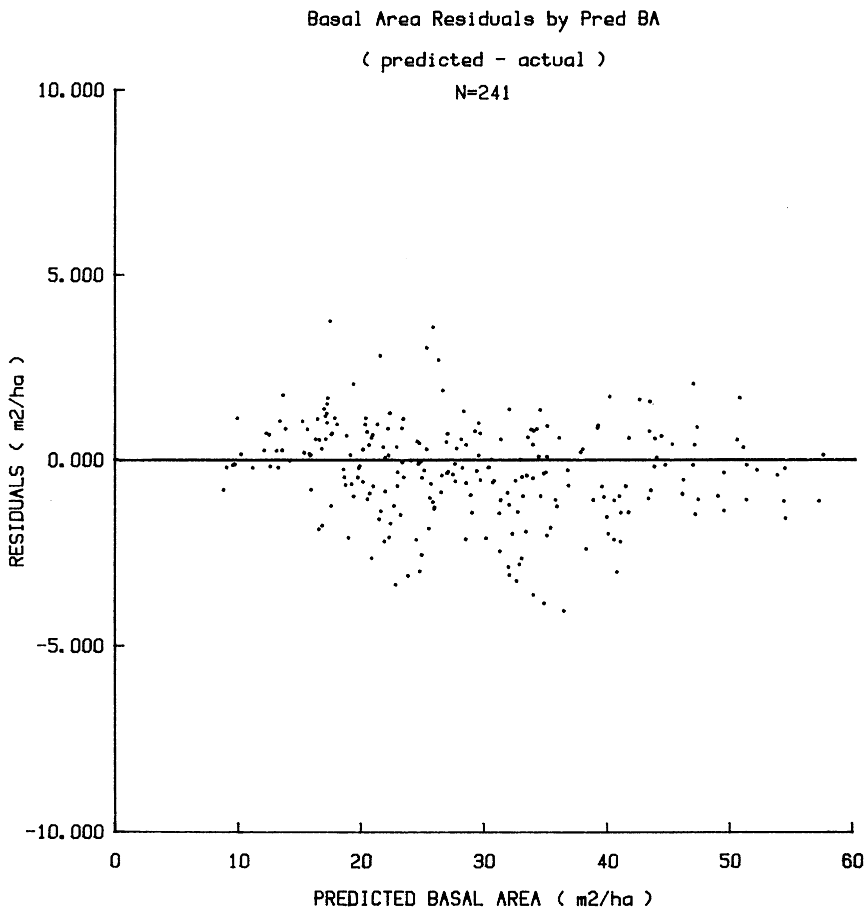

Figure 4 - Basal area residuals

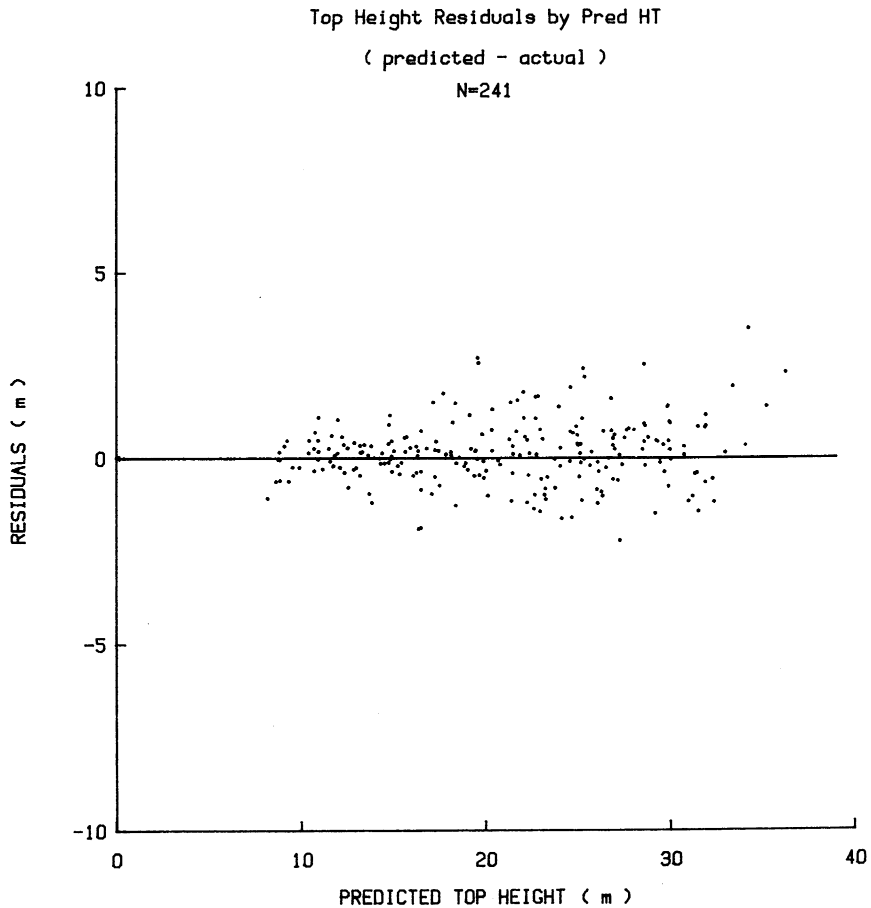

Figure 5 - Top height residuals

Basal area and top height residuals are examined in extended detail in *Table 7* with respect to prediction model (CLAYSFERT vs CLAYS) and fertiliser treatment (all mea., fert mea., unfert mea.). Examination of residuals from the fertilised only measurements reveals that predictive abilities of CLAYSFERT and CLAYS are about equal (as would be expected). Examination of the unfertilised only measurements reveals that CLAYSFERT has the special ability to make equally as good predictions for unfertilised measurements as for fertilised measurements. As expected, CLAYS is unable to make reliable predictions for unfertilised measurements.

TABLE 7: Basal area and top height residuals analysis with respect to prediction model and fertiliser treatment

Predictive model	Data-set*	Basal Area: % of residuals within 2 m²	Basal Area: % of residuals within 10%	Basal Area: % dist. of residuals	Top Height: % of residuals within 1.5 m	Top Height: % of residuals within 10%	Top Height: % dist. of residuals
CLAYSFERT	241	87	94	57+	91	96	56+
CLAYS	241	83	86	53-	88	95	61+
CF	189	86	94	60-	92	97	53+
C	189	87	93	62-	91	97	56+
CF	52	90	92	54+	90	94	67+
C	52	67	62	81+	81	88	81+

* n = 241; fertilised + unfertilised measurement pairs; mean age increment = 1.7 years.
n = 189; fertilised only measurement pairs; mean age increment = 1.8 years.
n = 52; unfertilised only measurement pairs; mean age increment = 1.6 years.

4.1.2 Change in foliar 'P' as a result of fertilisation

The form of the relationship is:

$$R = EXP(a) * F^b$$

where,

R = rise in foliar 'P' (final-initial) one year since fertilisation,

a = -7.8251,

b = 0.68134, and

F = fertiliser rate (kg/ha, super-phosphate).

Figure 6 presents the data and regression curve. The relationship accounts for 13% of the variance in R. Inclusion of the additional independent variable, initial foliar 'P' increased the percentage of variance accounted by only 3%, and produced unrealistic estimates at foliar 'P' values less than 0.08%. *Figure 6* also illustrates the distribution of residuals around the regression curve. Although the scatter in the data is large, the regression provides a measure of the magnitude of the rise in foliar 'P' as a function of fertiliser rate (proportional to) which is consistent with that expected (I. Hunter, pers. com.).

4.1.3 Change in foliar 'P' as a result of natural decline in fertility

The form of the relationship is:

$$P = EXP\ (-a)^{T} * (P_0 - .06) + .06$$

where,

P = foliar 'P' a specified number of years since an initial value,

a = 0.04194 = decay coefficient,

T = time-lapse (years), and

P_0 = initial foliar 'P' %.

Figure 7 presents the data and regression curves starting at four initial 'P' values. The regression accounts for 75% of the variation in final 'P'. Mean time-lapse for paired observations in the dataset is 1.5 years with a range of 0.9 to 5.0 years. Regression curves are conditioned to approach a lower limit of 0.06% foliar 'P'.

Figure 7 identifies some 'decay' observations which actually represent <u>increases</u> in foliar 'P' (as described in Section 3.2.3). Increase in foliar 'P' due to thinning was investigated to determine the appropriateness of including these observations in the dataset occurring within 2 years since thinning. GENSTAT regressions were run on:

(1) the entire dataset, n = 383;

(2) a dataset without observations within 2 years since thinning, n = 322; and

(3) a dataset with only observations within 2 years since thinning, n = 61.

An 'F' test based on the combined data (hypothesis model, n = 383) and the separate data (complete or maximum model, n = 322 and n = 61) failed to support the hypothesis that the datasets should be kept separate (F = .042).

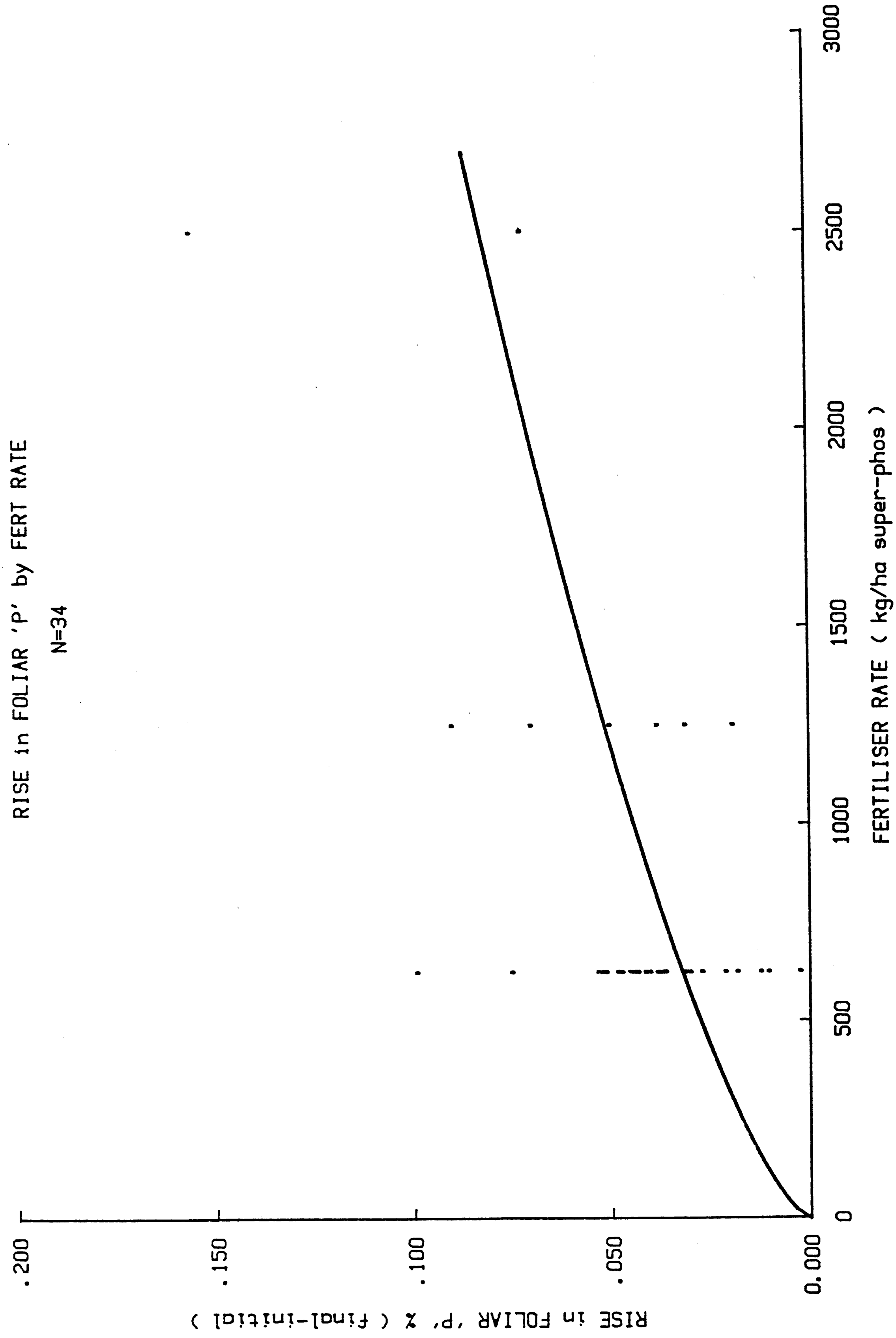

Figure 6 - Rise in foliar 'P' by fertiliser rate

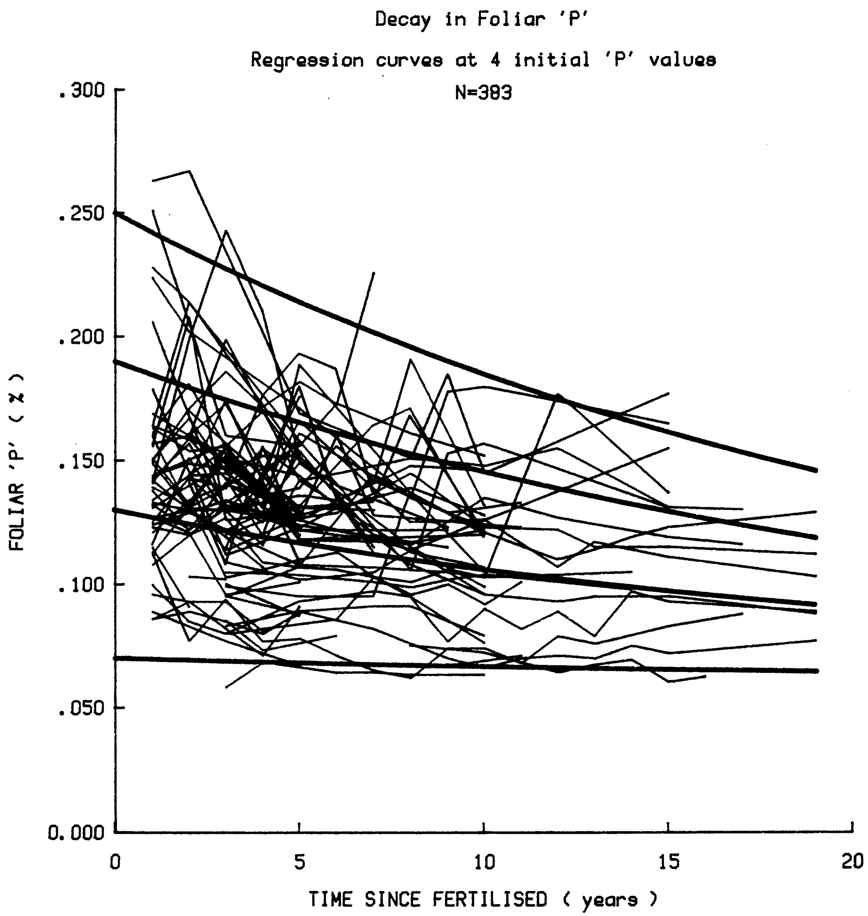

Figure 7 - Decay in foliar 'P' with time

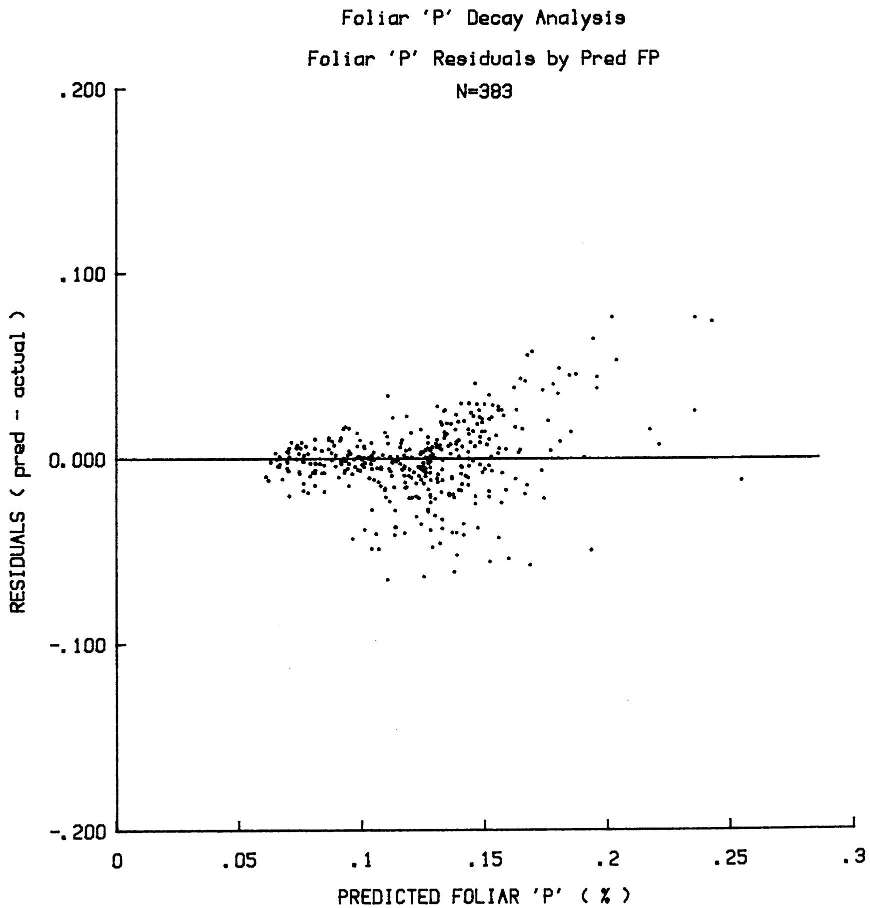

Figure 8 - Foliar 'P' residuals in the decay analysis

Foliar 'P' residuals are presented in ***Figure 8***. Mean time-lapse in the predictions is 1.5 years with a range of 0.9 to 5.0 years. Seventy-five (75) percent of the residuals are within 0.02 % units of the actual, while 57% are within 10% of the actual. Although the residuals are evenly distributed around zero (53% negative), foliar 'P' is over-predicted on 91% of the observations when initial 'P' is above 0.18% (65% significantly over-predicted).

5.0 PERFORMANCE EVALUATIONS

5.1 Background

Following preliminary acceptance by the author of an early version of CLAYSFERT, an evaluation of the accuracy of predictions was undertaken by Mr G. Phillips (visiting undergraduate student completing an honours degree, Aberdeen University). Mr Phillips produced an FRI project record (Phillips 1987) in which he concluded that the model estimated all parameters (top height, stocking, basal area, volume and foliar 'P') with acceptable accuracy. However, Mr Phillips' report also highlighted a pecularity in the relationship predicting rise in foliar 'P' following fertilisation. Upon inspection by Dr Garcia and the author, the original regression was replaced with a simpler relationship (Section 4.1.2). At that stage of evaluation, a slight modification was also made to the decay regression.

The following performance evaluations are based on the final accepted version of CLAYSFERT. The basic approach employed by Mr Phillips has been adopted by the author, although modified as deemed necessary.

5.2 Accuracy of stand parameter predictions

5.2.1 Background

As a measure of the accuracy of stand parameter predictions (i.e., HT, BA, SPH, VOL, foliar 'P'), the approach adopted was to simulate plot histories, and for the final stand parameters, calculate the ratio of the predicted to the actual.

5.2.2 Selection of plots and simulation input parameters

Selection of plots was based on obtaining a range of fertiliser treatments from the forests included in the lambda value analysis (Section 3.2.1). A total of 6 fertiliser treatments were simulated, i.e.,

(1) 625 kg/ha*1 application,
(2) 625*2,
(3) 625*4,
(4) 625*1 delayed application,
(5) 1250*1, and
(6) control.

Each treatment was represented 4 times, except for no. 1 in which the simulation failed (due to an inability to thin to the prescribed residual basal area). The 2500 kg/ha treatment was not included because the treatment lacked replication. Maramarua Forest is poorly represented because only 2 plots had record of initial foliar 'P' (required to start a simulation). A total of 23 plot histories were simulated. A list of plots by forest and fertiliser treatment is provided in ***Appendix 3***. ***Appendix 1*** can be used as cross-reference for management histories of the plots.

Simulation input parameters (initial) included:

(1) foliar 'P',
(2) site index,
(3) age,
(4) top height,
(5) stocking, and
(6) basal area.

For fertilised plots, site index was accepted directly as height at age 20 (available from PSP summaries), or height (age 19) adjusted to height at age 20 (based on CAI, age 19). For control plots, equivalent fertilised site index was accepted as the mean value for top height at age 20 from the fertilised plots (within a block for the WHAN plots).

During simulation, management histories were duplicated particularly with thinnings where both residual stocking and basal area were used as input. Using this approach, errors in using the thinning function were circumvented, thereby allowing the tests of accuracy to be solely a reflection of the reliability of the 'fertiliser effect' relationships.

5.2.3 Accuracy results

The accuracy of stand parameter predictions is presented in ***Table 8***. Time-lapse in the prediction of top height and foliar 'P' ranges from 11 to 19 years, while due to adjustments to basal area and stocking at time of thinning, time-lapse with respect to these parameter predictions ranges from 6 to 16 years.

All mean, stand parameter prediction ratios are between 90 and 100%; all represent under-predictions, as given below. Volume predicted by CLAYSFERT was evaluated against the 'actual' volume appearing on PSP summaries (which is in fact a 'prediction').

Parameter	% under-prediction (on average)
Stocking	0.4
Top height	1.7
Basal area	7.8
Volume	9.1
Foliar 'P'	9.5

TABLE 8: Accuracy of stand parameter predictions at stand age 19-25 years

Statistic	Ratio of predicted to actual*				
	Stocking	Top height	Basal area	Volume	Foliar 'P'
No. plots	23	22**	23	22**	23
Mean	.996	.983	.922	.909	.905
Range of mean @ 95%	.979-1.013	.956-1.010	.889-.955	.861-.957	.855-.955
Coefficient of variation (c.v.%)	4%	6%	9%	12%	13%
Range of observed ratios	.932-1.090	.827-1.081	.791-1.060	.696-1.121	.672-1.245

* Simulation run without the use of the thinning function.
** Sample reduced by 1 due to an unavailable 'actual' value.

5.2.4 Accuracy of CLAYS vs CLAYSFERT

Simulations were also run using CLAYS to provide a relative predictive measure with CLAYSFERT. A comparison of the accuracy of the models is provided in *Table 9*. Because CLAYS is not suited to making predictions for unfertilised conditions, accuracies for unfertilised and fertilised plots are presented separately.

TABLE 9: Accuracy of stand parameter predictions with respect to prediction model and fertiliser treatment

Stand parameter	Model	Ratio of predicted to actual*							
		Unfertilised**				Fertilised			
		n	Mean	Std. dev.	C.V. %	n	Mean	Std. dev.	C.V. %
Stocking	CLAYSFERT	8	.993	.041	4.1	15	.998	.036	3.6
	CLAYS	8	.962	.067	7.0	15	.994	.037	3.7
Top height	CF	7***	1.001	.050	5.0	15	.975	.062	6.4
	C	7	1.109	.125	11.3	15	.987	.056	5.7
Basal area	CF	8	.928	.083	8.9	15	.919	.079	8.6
	C	8	1.124	.229	20.4	15	.939	.068	7.2
Volume	CF	7***	.917	.102	11.1	15	.906	.116	12.8
	C	7	1.177	.343	29.1	15	.934	.095	10.2

* Simulations run without the use of the thinning function.
** Unfertilised includes delayed fertiliser treatment.
*** Sample reduced by 1 due to an unavailable 'actual' value.

Accuracies for the unfertilised condition are strongly in favour of the CLAYSFERT model (as would be hoped). While CLAYS predicts stocking with acceptable accuracy relative to CLAYSFERT (poorer by 3.1% points), predictions of top height; basal area; and volume are poorer than CLAYSFERT by 10.8%, 5.2%, and 9.4% points, respectively. As a measure of precision in the prediction of stand parameters, CLAYS also performs poorly relative to CLAYSFERT, as evidenced by much larger (3-18% points) coefficients of variation.

Accuracies for fertilised conditions are similar in magnitude for both models, although favoured by the CLAYS model. While both models predict stocking almost identically, the CLAYS model predicts top height, basal area, and volume slightly more accurately, i.e., 1.2%, 2.0%, and 2.8% points difference, respectively. On average, all predictions are under-predictions. Coefficients of variation are similar in magnitude for both models.

5.3 Plot history simulation graphics

5.3.1 Selection of plots and simulation input parameters

Eleven (11) plots were selected to simulate stand growth and provide a graphical presentation of the performance of CLAYSFERT. Selection of plots was based on obtaining a range of fertiliser treatments and including all three forests used in the lambda value analysis. A total of 6 fertiliser treatments were simulated, i.e.,

(1) 625 kg/ha*1 application,
(2) 625*4,
(3) 625 delayed application,
(4) 1250*1,
(5) 2500*1, and
(6) control.

Each treatment was represented twice except for No. 5 where only one plot had sufficient input parameters to start the simulation. One (1) 'new' plot was included with respect to the 'accuracy' analysis (Section 5.2). A list of plots by forest and fertiliser treatment is provided in ***Appendix 4***. ***Appendix 1*** can be used as cross-reference for management histories of the plots.

Simulation input variables were selected as discussed in Section 5.2.2. Simulations duplicated plot management histories, however in contrast to the 'accuracy' analysis (Section 5.2), thinning was input only to a residual stocking, not basal area. Using this approach, the thinning function was utilised, thereby producing simulations which represent the full capability of CLAYSFERT.

5.3.2 Simulation graphics

Simulation graphics presenting basal area by age are provided in ***Figures*** *9-15*. Allocation of simulations by fertiliser treatment and figure number are given below. ***Figure*** *15* is provided for a comparison of fertiliser effects.

Simulation No.	Fertiliser treatment	Figure No.
1 and 2	control	9
3 and 4	1250*1	10
5 and 6	625*1D	11
7 and 8	625*4	12
9 and 10	625*1	13
11	2500*1	14
1,4,8 and 9	as above	15

In order to provide a relative measure of accuracy with respect to viewing the simulation curves, ***Table*** *10* presents each simulation's ratio of predicted to observed basal area (final), and for comparison, the remaining stand parameters (top height, stocking, volume and foliar 'P'). Time-lapse in the predictions ranges from 11 to 20 years with 1-2 thinnings during the period.

All mean, stand parameter prediction ratios are between 90 and 100%, except foliar 'P' (.886). All mean ratios are within the confidence limits of the mean given in ***Table*** *8*, even though the current simulations include 1 new plot, <u>plus</u> a dependence on the thinning function.

Prediction of final basal area in simulations 1, 4, 9 and 10 are particularly poor (17, 22, 14 and 14% under-predictions, respectively). While sampling error inherent in small plot sizes contributes to prediction error, in simulations 1, 4, and 9 under-predictions may be attributed to a severe 'thinning effect' resulting from a large drop to the predicted residual basal area after thinning. Predicted foliar 'P' during simulation does not account for the final under-prediction (except in No. 4 where foliar 'P' is under-predicted directly after thinning). In simulation 10, the under-prediction of basal area appears to be related to an under-prediction in foliar 'P'. This begins at age 18 when actual foliar 'P' mysteriously rises from a lower level (in agreement with the predicted) to a higher level, consistently maintained (above the predicted) to the end of the simulation.

TABLE 10: Accuracy of stand parameter predictions at final age for simulations presented in Figures 9-15

Simulation No.	Fertiliser treatment	Ratio of predicted to actual*				
		Stocking	Top height	Basal area	Volume	Foliar 'P'
1	Control	.989	.984	.827	.779	.870
2	-	.986	1.055	.977	.982	.851
3	1250*1	.968	1.026	.952	1.000	.788
4	-	1.015	.892	.776	.682	.903
5	625 delayed	.993	.947	.927	.873	.905
6	-	.987	1.008	1.058	1.059	.857
7	625*4	.974	1.029	.955	.984	.977
8	-	.991	.927	.926	.848	1.032
9	625*1	.957	1.003	.857	.845	.966
10	-	1.000	.973	.857	.821	.853
11	2500*1	.965	1.009	1.065	1.119	.746
	Mean	.984	.987	.925	.908	.886
	Std Dev.	.017	.048	.091	.131	.083
	C.V.%	1.7	4.9	9.8	14.4	9.4

* Simulations run <u>with</u> the use of the thinning function.

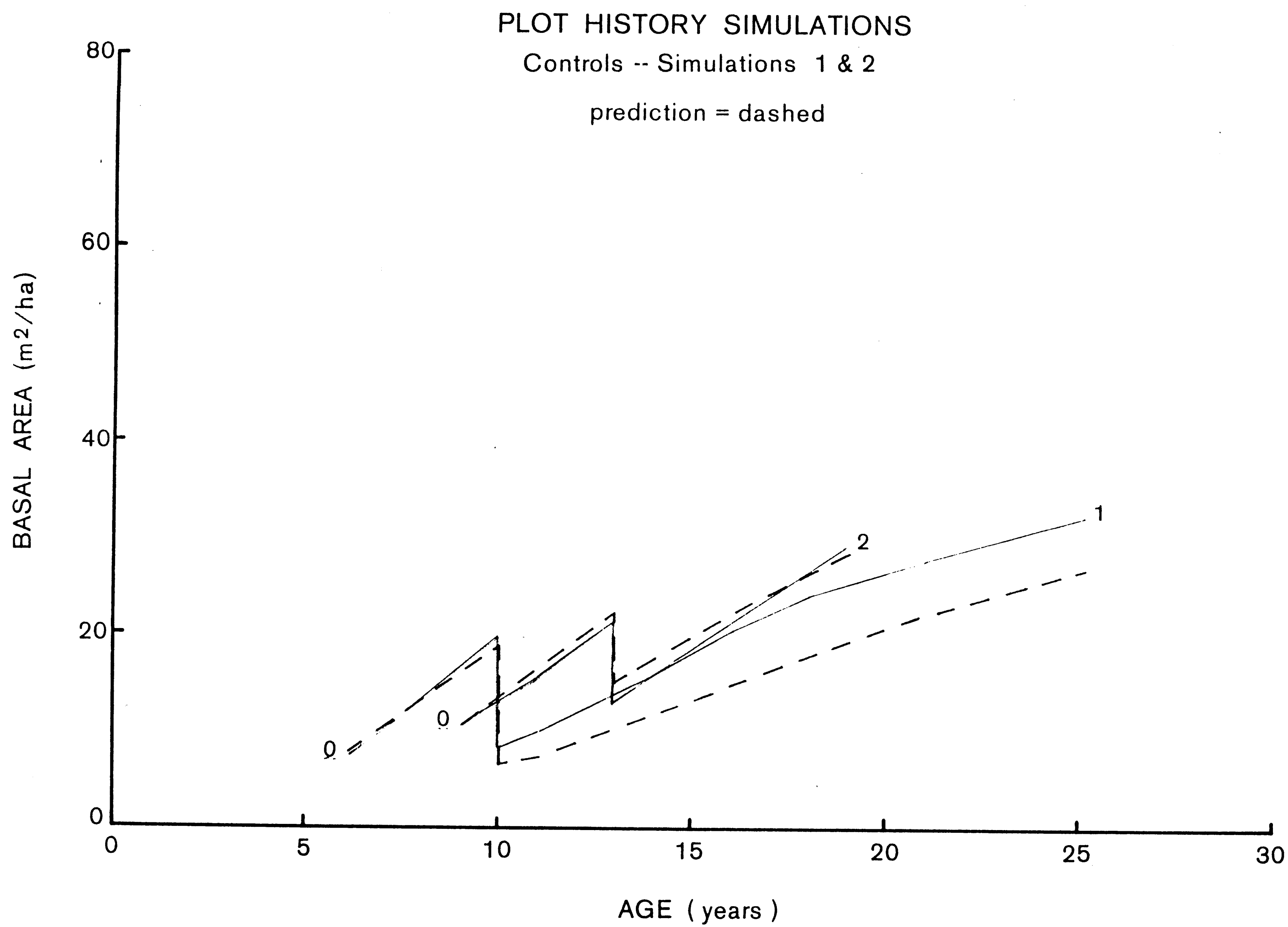

Figure 9 - Plot history simulations, part 1 of 7

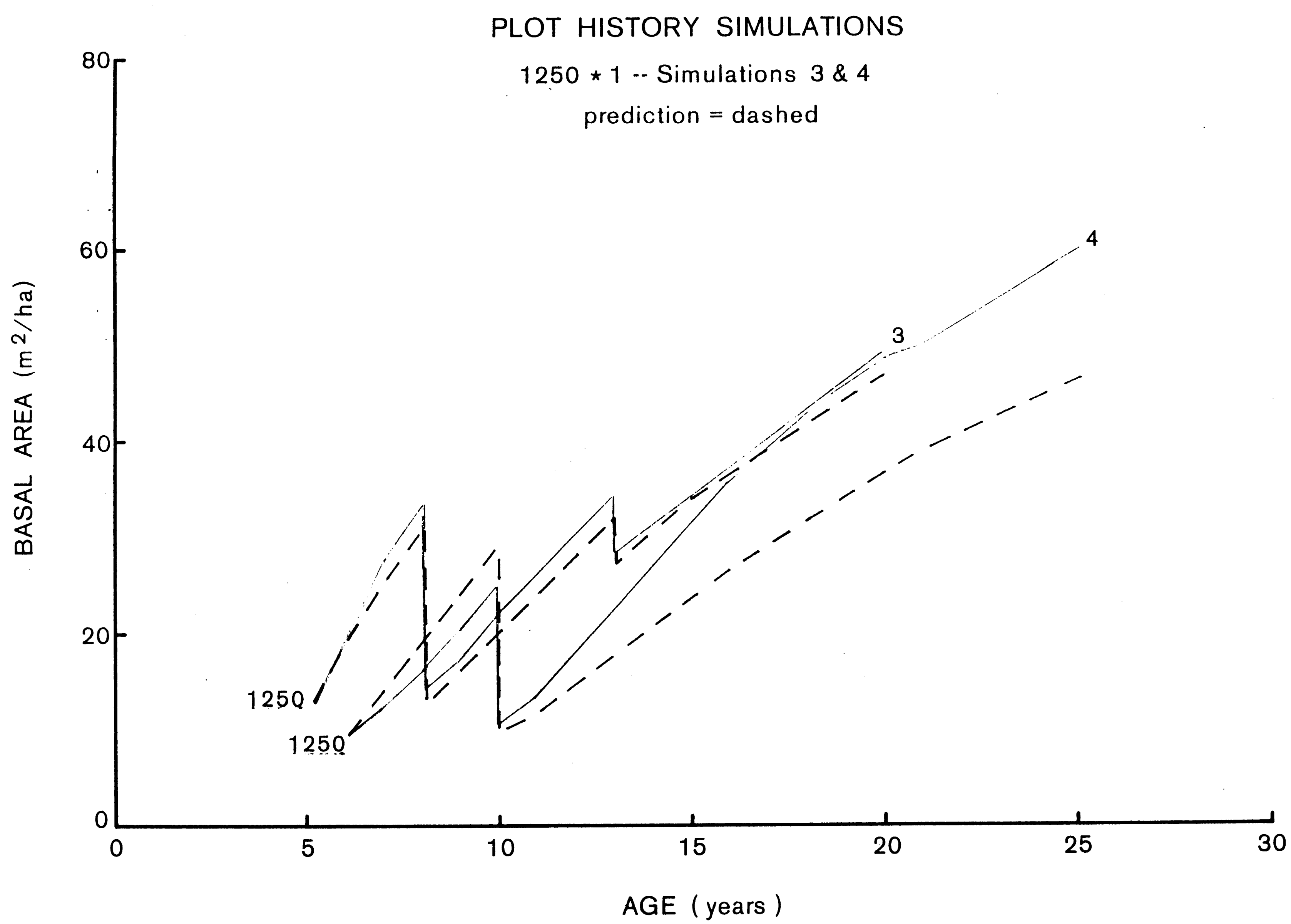

Figure 10 - Plot history simulations, part 2 of 7

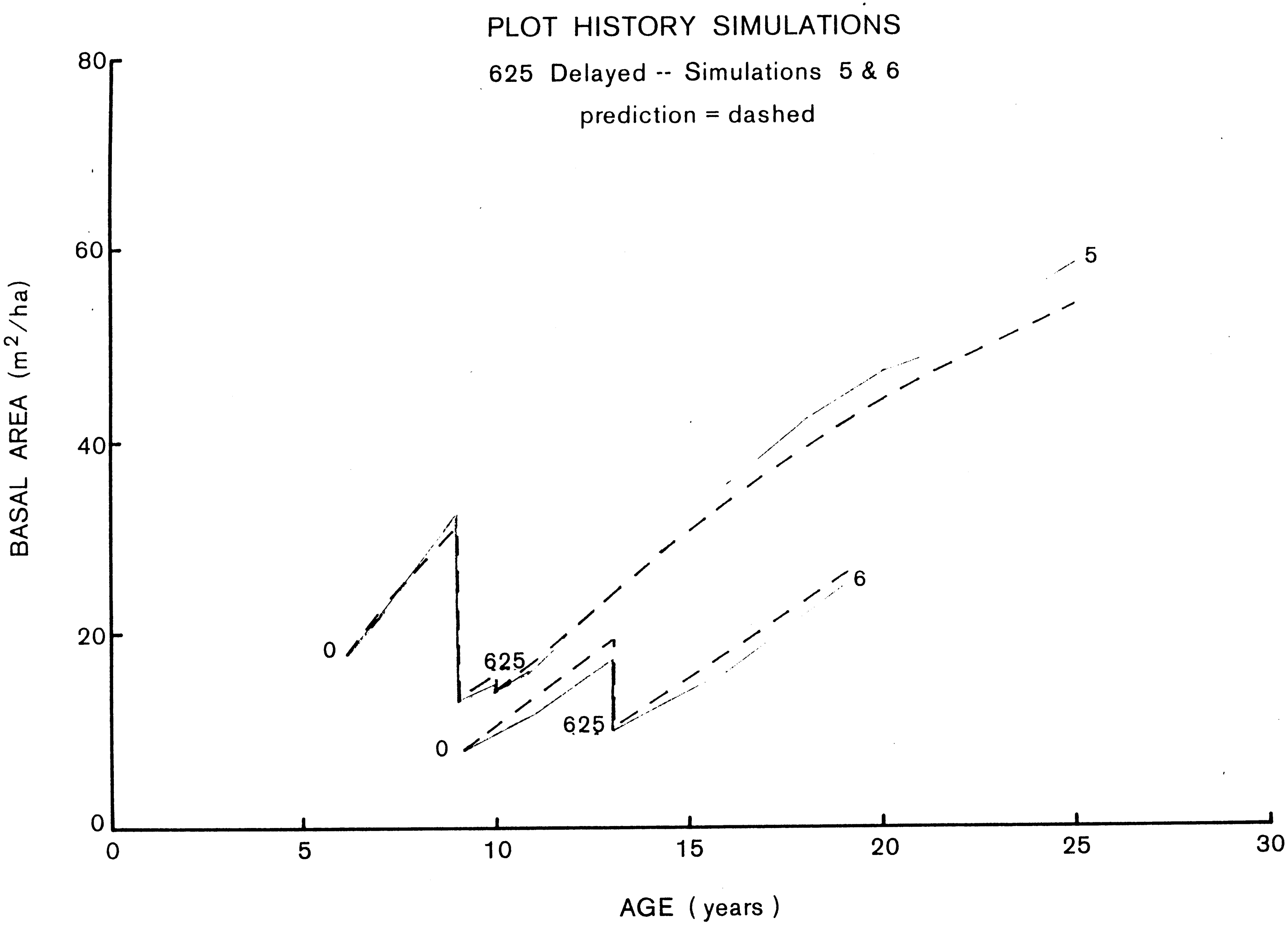

Figure 11 - Plot history simulations, part 3 of 7

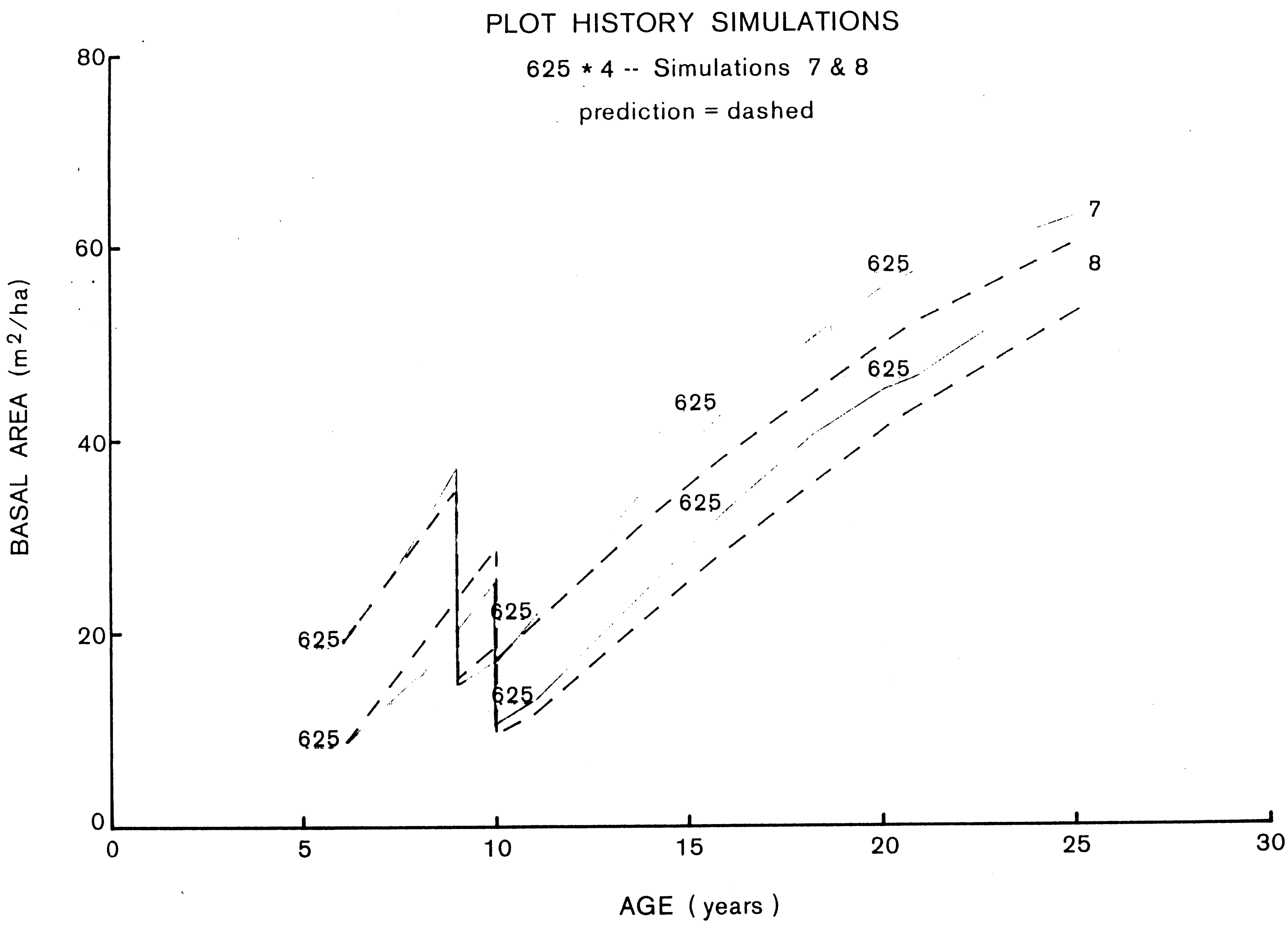

Figure 12 - Plot history simulations, part 4 of 7

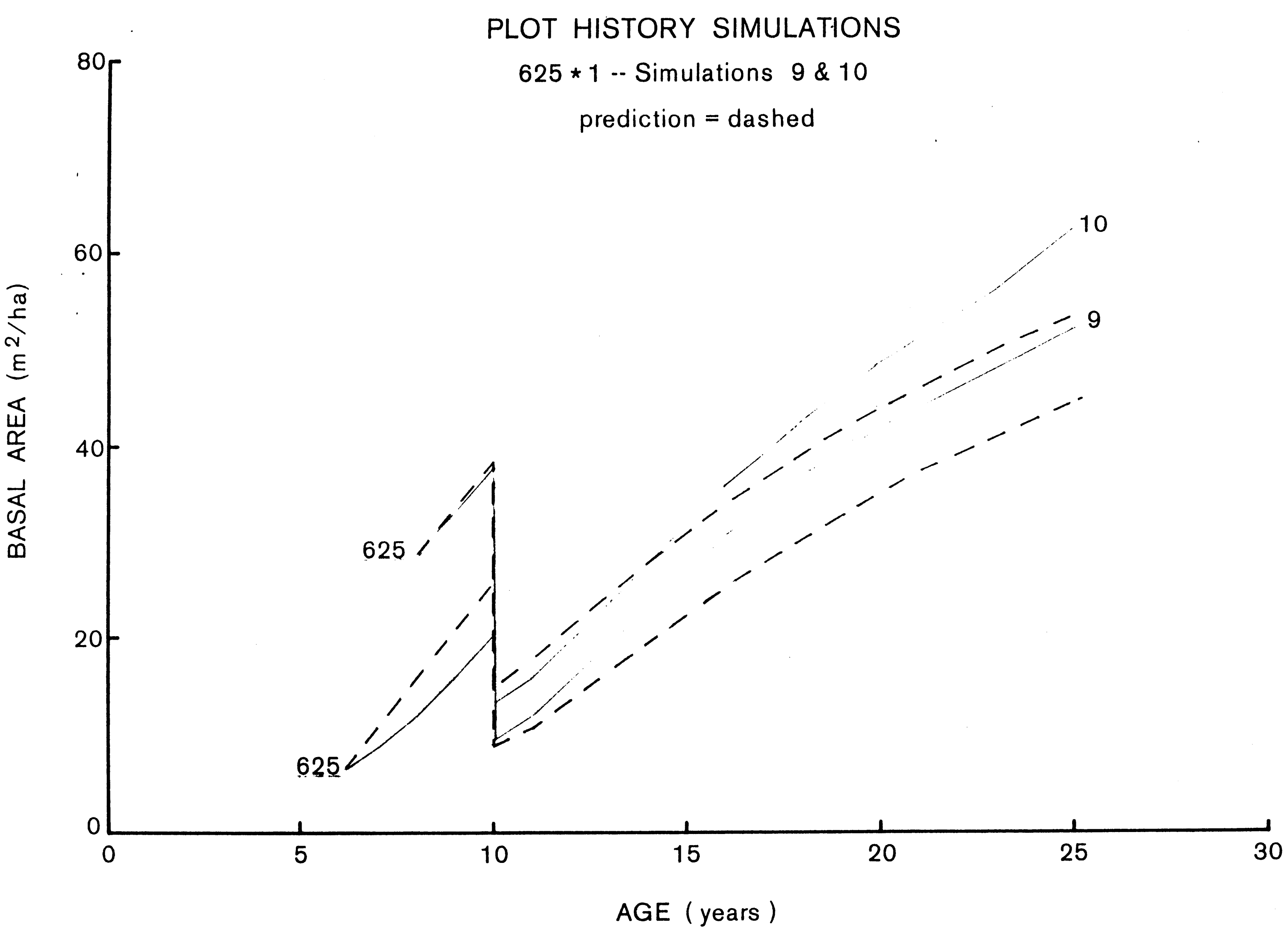

Figure 13 - Plot history simulations, part 5 of 7

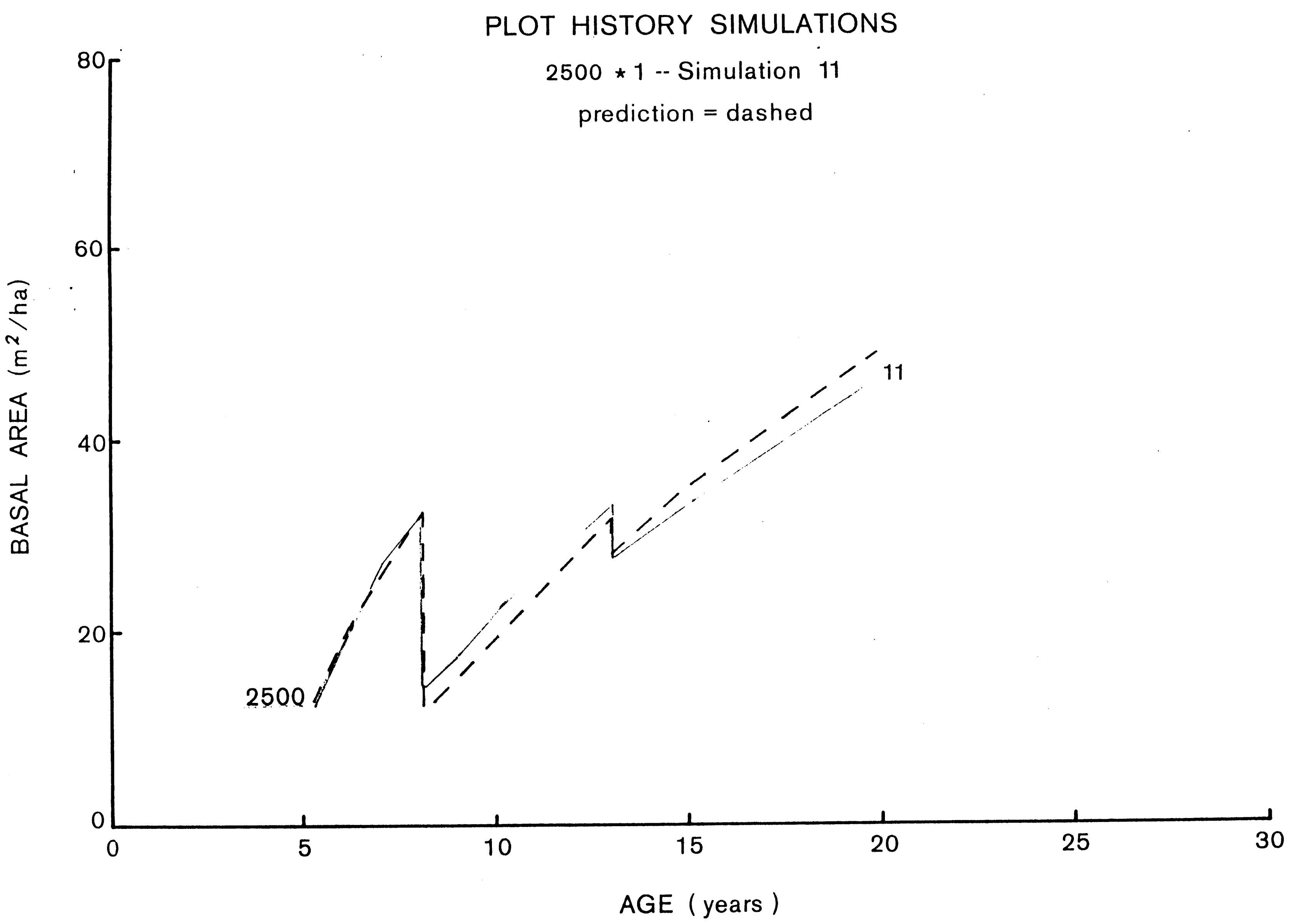

Figure 14 - Plot history simulations, part 6 of 7

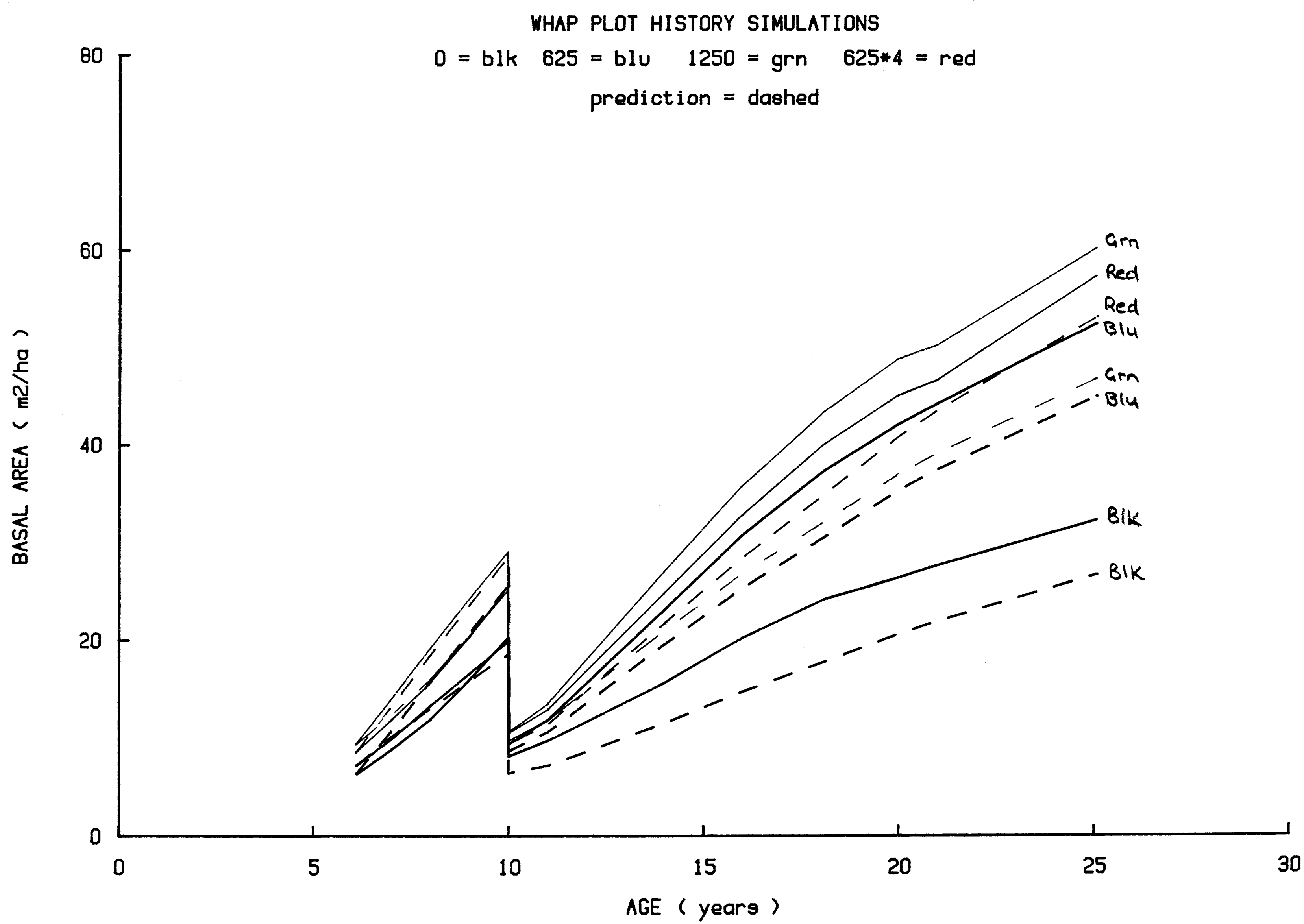
WHAP PLOT HISTORY SIMULATIONS
0 = blk 625 = blu 1250 = grn 625*4 = red
prediction = dashed
BASAL AREA (m2/ha)
AGE (years)
0
20
40
60
80
0
5
10
15
20
25
30
Grn
Red
Red
Blu
Grn
Blu
Blk
Blk

Fig 15

5.3.3 Accuracy of CLAYS vs CLAYSFERT

Simulations were also run using CLAYS as a comparison with CLAYSFERT. A comparison of the accuracy of the models is provided in ***Table 11*** with respect to unfertilised and fertilised treatments.

In keeping with the accuracy analysis in Section 5.2.4, CLAYS and CLAYSFERT maintain the same relative predictive capabilities.

TABLE 11: Accuracy of stand parameter predictions with respect to prediction model and fertiliser treatment for simulations presented in Figures 9-15

Fertiliser treatment (n)	Mean ratio of predicted to actual*							
	Stocking		Top height		Basal area		Volume	
	CF**	C**	CF	C	CF	C	CF	C
Unfertilised*** (4)	.989	.973	.999	1.135	.947	1.238	.923	1.362
Fertilised (7)	.981	.978	.980	.990	.913	.928	.900	.920

* Simulations run with the use of the thinning function.
** CF = CLAYSFERT.
C = CLAYS.
*** Unfertilised includes delayed fertiliser treatment.

5.4 Effect of input variables on the prediction of top height and basal area

5.4.1 Effect of site index

As discussed in Section 2.2, simulations must be started with an equivalent fertilised site index. Simulation of an unfertilised stand (low foliar 'P') may be dependent, therefore, on a subjective judgement of equivalent fertilised site quality for the stand (provided fertilised stands do not exist nearby). The effect that site index has on predictions of top height and basal area was simulated, and is presented in ***Table 12*** (HT and BA) and ***Figure 16*** (BA). The simulation assumes an unfertilised stand with the initial stand parameters and management history described in ***Table 12***.

TABLE 12: ***Effect of site index on the prediction of top height and basal area****

Stand age (yrs)	Top height for site indices			Basal area for site indices		
	27	29	31	27	29	31
	(m)	(% change)		(m^2/ha)	(% change)	
20	19.8	+6	+11	18.4	+10	+20
25	23.0	+5	+11	24.1	+9	+18

* Initial stand parameters and management history given below.

Parameter	Statistic
age	6.1 years
top height	7.1 m
basal area	7.2 m^2/ha
stocking	1654 sph
foliar 'P'	0.075%
stocking (after thinning)	444 sph (age 10)
fertilisation	nil

The selection of site indices for the simulation is based on two assumptions:

(1) the given height-age pair represents SI 27 (directly), and

(2) a fertilised condition would have resulted in a greater initial height by 1 or 2 metres, i.e., 8 and 9 metres; thereby representing SI 29 and 31, respectively.

Site index 27 can be assumed to be in error, as the foliar 'P' indicates a nutrient deficient status, and by association, a deficient initial height. Site indices 29 and 31 are subjective estimates, assuming that had the site been adequately fertilised, better height growth would have resulted.

Table 12 presents predicted top height and basal area for site index 27, and the percentage change (relative to SI 27) in these parameters at site indices 29 and 31. At stand age 25, top height is increased 5-11% by a 2-4 metre increase in site index, respectively. Because foliar 'P' is low throughout the simulation (0.75-.067%, initial and final), top height at age 20 does not achieve the given equivalent fertilised site index 29. At stand age 25, basal area is increased 9-18% with the changes in site index. ***Figure 16*** graphically presents these effects of site index on basal area.

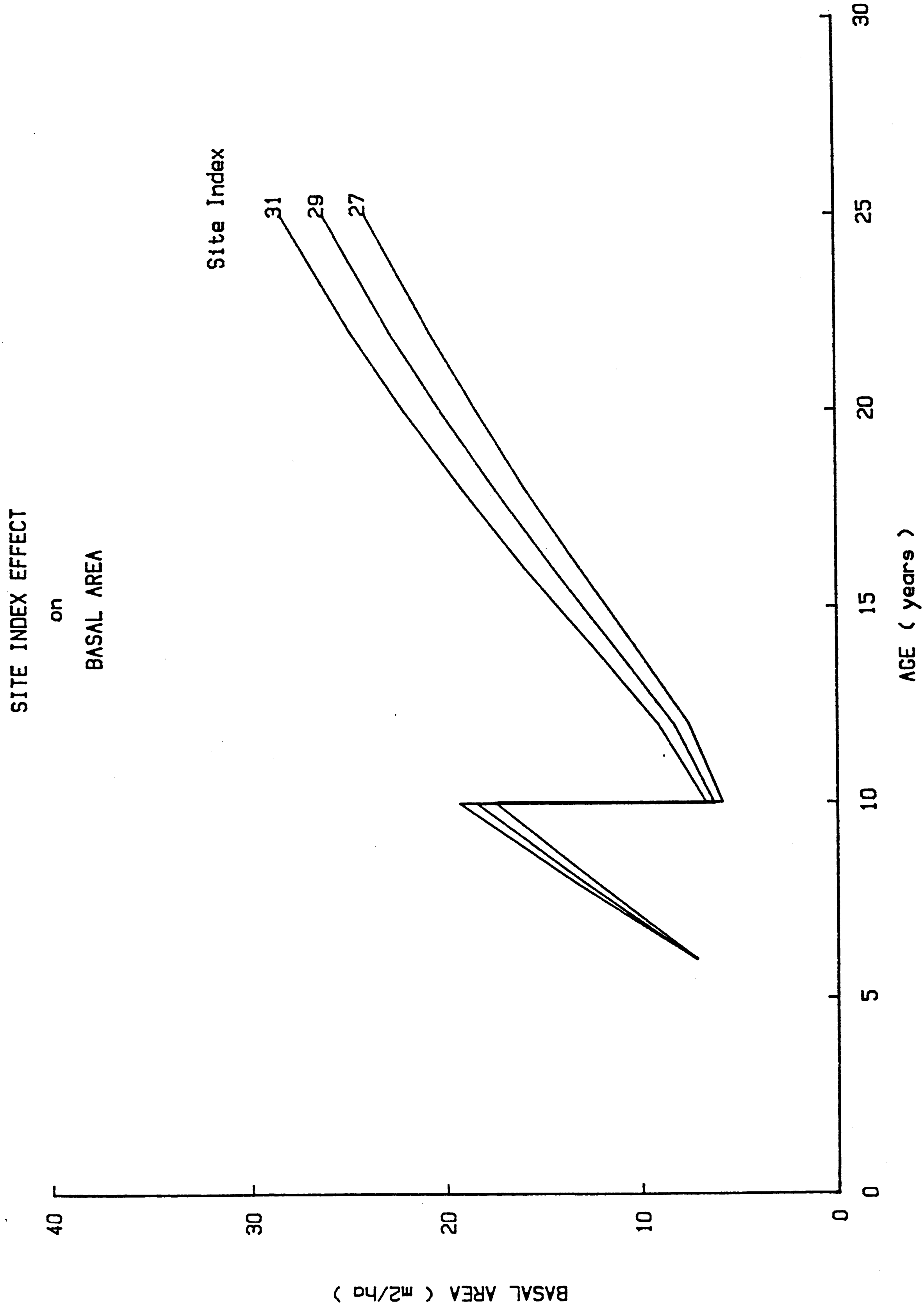

Figure 16 - Effect of site index on the
prediction of basal area

5.4.2 Effect of initial foliar 'P'

The following subjective ratings for the status of foliar 'P' when starting a simulation have been suggested (Section 2.2):

low @ 0.07%
medium @ 0.11%, and
high @ 0.15%.

The effect that initial foliar 'P' has on predictions of top height and basal area was simulated, and is presented in ***Table 13*** (HT and BA) and ***Figure 17*** (BA). The simulation assumes initial stand parameters and management history as used in the previous Section (5.4.1), however site index was set at 29 metres, and initial foliar 'P' varied as above.

TABLE 13: Effect of initial foliar 'P' on the prediction of top height and basal area*

Stand age	Top height for initial 'P'			Basal area for initial 'P'		
	L	M	H	L	M	H
	(m)	(% change)		(m2/ha)	(% change)	
20	18.4	+45	+54	15.3	+127	+160
25	21.2	+48	+58	20.0	+120	+150

* Initial stand parameters and management history given below.

Parameter	Statistic
site index	29 m
age	6.1 years
top height	7.1 m
basal area	7.18 m^2/ha
stocking	1654 sph
stocking (after thinning)	444 sph (age 10)
fertilisation	nil
foliar 'P'	low 0.07%; medium 0.11; high 0.15

Table 13 presents predicted top height and basal area for low initial foliar 'P', and the percentage charge in these parameters for medium and high initial 'P' (relative to low 'P'). At stand age 25, top height is increased 48-58% with medium and high 'P', respectively. Because foliar 'P' changes with time (decays) and does not remain high enough during the entire high 'P' simulation, top height at age 20 (28.3 metres) narrowly misses equivalent fertilised site index 29. At stand age 25, basal area is greatly increased 120-150% with the changes in foliar 'P'. ***Figure 17*** graphically presents these effects of initial foliar 'P' on basal area, and includes for comparison a simulation curve using CLAYS. The CLAYS and high 'P' simulations result in similar basal areas at age 25 (3% difference) indicating a similar approximate foliar 'P' status of the data in the CLAYS analysis. The effect of using CLAYS to predict growth and yield of deficient 'P' stands is strikingly apparent.

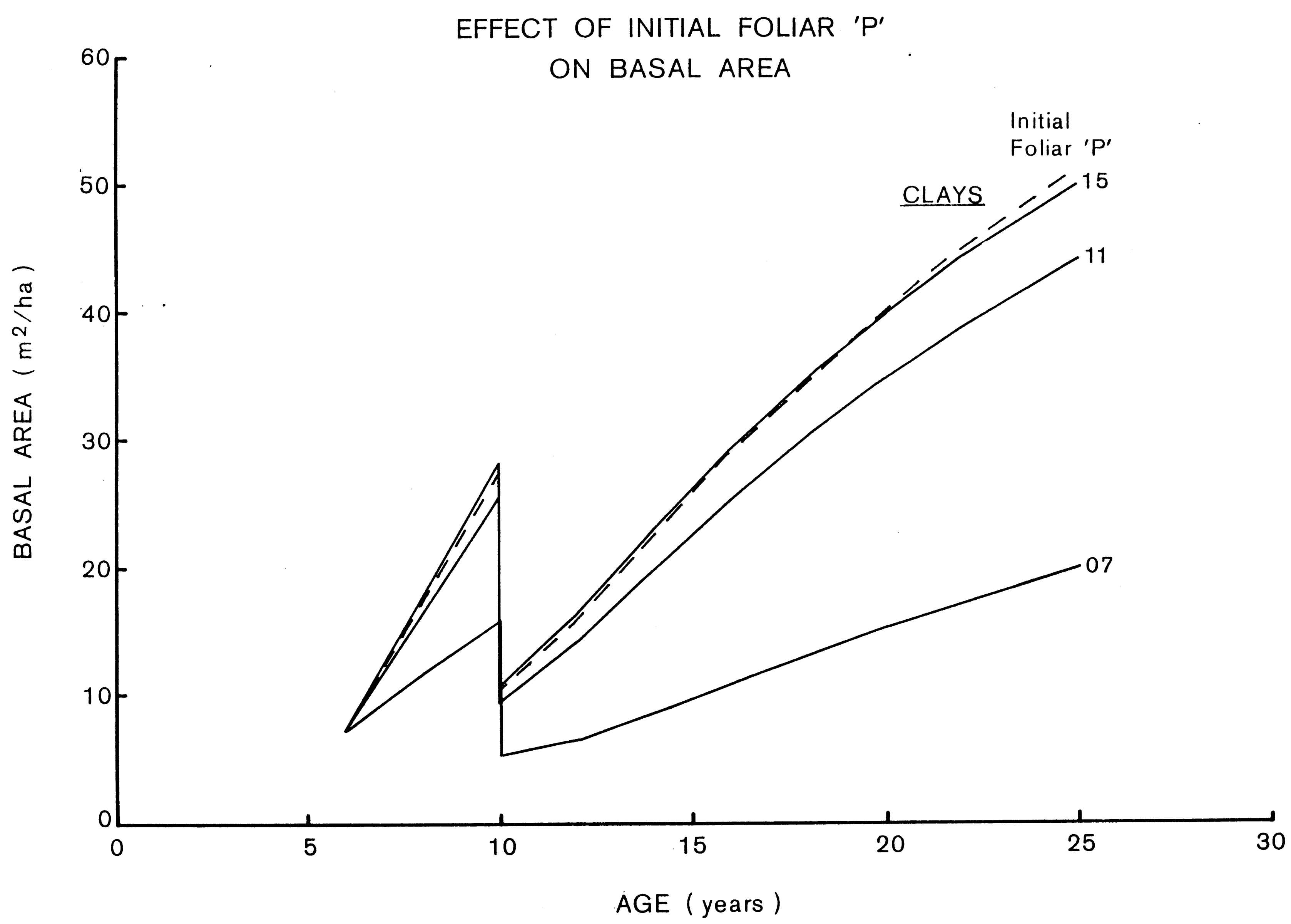

Figure 17 - The effect of initial foliar 'P' on the prediction of basal area.

5.4.3 Effect of fertiliser application rate

The effect that fertiliser application rate has on predictions of top height and basal area was simulated and is presented in ***Table 14*** (HT and BA) and ***Figure 18*** (BA). The simulation assumes initial stand parameters and management history as used in the previous section (5.4.2), however fertiliser is applied at rates from 0 to 2500 kg/ha at the start of the simulation. The direct effect of fertiliser application is the resultant rise in foliar 'P' to a new level influencing subsequent growth.

TABLE 14: Effect of fertiliser application rate on the prediction of top height and basal at stand age 25 years for three initial foliar 'P' levels*

Initial foliar 'P'	Top height for fertiliser rates				Basal area for fertiliser rates			
	0	625	1250	2500	0	625	1250	2500
(%)	(m)	(% change)			(m^2/ha)	(% change)		
.07	21.2	+45	+52	+58	20.0	+111	+133	+151
.11	31.4	+6	+8	+10	44.0	+12	+16	+20
.15	33.5	+2	+3	+4	49.9	+5	+7	+9

* Initial stand parameters and management history given below.

Parameter	Statistic
site index	29 m
age	6.1 years
top height	7.1 m
basal area	7.18 m^2/ha
stocking	1654 sph
stocking (after thinning)	444 sph (age 10)
fertilisation	varies as above
foliar 'P'	varies as above

Table 14 presents predicted top height and basal area for an unfertilised stand (age 25) at low, medium and high initial foliar 'P' levels; and the percentage change in these predictions at varying rates of fertiliser application (relative to no fert application). At the low initial foliar 'P' level, the minimum rate of 625 kg/ha has a dramatic effect on top height and basal area (+45 and 111%), while higher rates induce similar, though marginally superior effects (an additional 7-13% and 22-40%). At medium and high initial 'P' levels, the effects of fertiliser application are minimised as a result of adequate nutrition prior to fertilisation. ***Figure 18*** presents these effects of fertiliser application rate on top height and basal area.

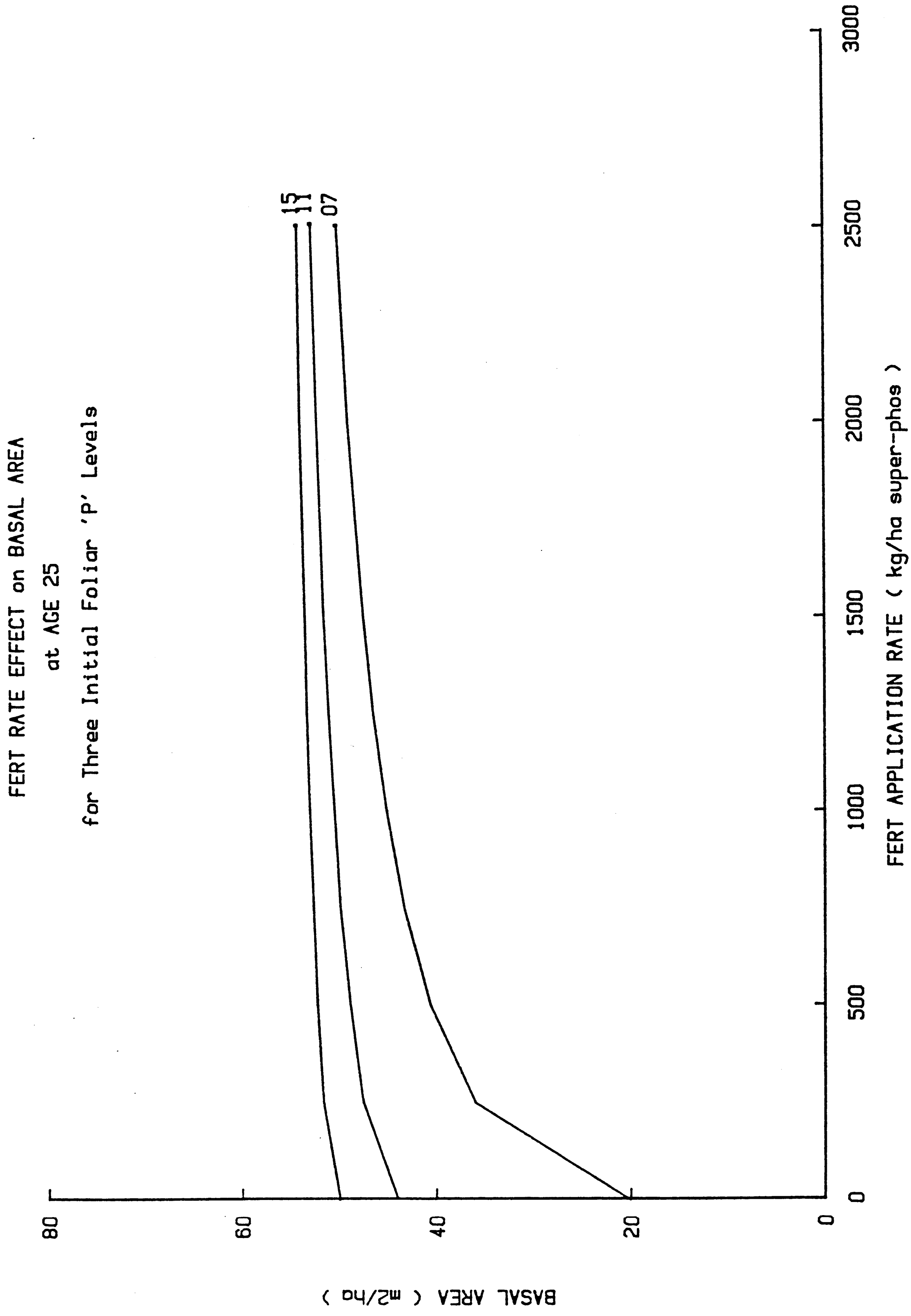

Figure 18 - The effect of fertiliser rate on the prediction of basal area

6.0 DISCUSSION

6.1 General

The objectives of this report were to document the construction and evaluate the performance of CLAYSFERT. These objectives have been met resulting in detailed descriptions of the model's make-up and reliability of prediction. The ability of CLAYSFERT to make predictions at a full range of phosphorus fertility levels is dependent on the 'fertiliser effect' relationships drawn from the data base.

6.2 Relationships supporting the 'fertiliser effects'

CLAYS growth relationships were already determined, however they were unrelated to fertility level. While the regression that was developed for CLAYSFERT to relate growth to fertility is not particularly strong, it does provide a relative measure providing an acceptable sensitivity in describing growth as a function of fertility level.

The relationships describing the rise and decay in foliar 'P' represent simplistic rationales of the relative changes in stand fertility with fertilisation and time-lapse. Rise may not occur, nor be completed within one year since fertilisation; decay may not be solely dependent on time-lapse. However, an over-riding concern related to future work attempting to strengthen these relationships (e.g., inclusion of environmental, thinning, or soil factors) is the uncertainty of whether or not natural variation in growth and foliar 'P' precludes development of more sensitive relationships of 'fertiliser effects' (i.e., simplicity may be sufficient).

6.3 Data Base

CLAYSFERT 'fertiliser effects' are constrained to the effects drawn from a single fertiliser trial (albeit, a well executed trial over 4 forests). Super-phosphate was the only fertiliser used (as opposed to triple super or PARR), and application rates below 625 kg/ha are non-existent, and above, poorly represented.

With respect to cost-efficient forest practices, fertilisation at minimum rates with least cost fertiliser begs the question of the effect on stand growth. CLAYSFERT is constrained within the limits of the trial data representing the use of super-phosphate and application rates of no less than 625 kg/ha. CLAYSFERT can be run at fertilisation rates less than 625 kg/ha, however these rates are not represented in the data. CLAYSFERT can also be run assuming the use of triple super (20% P) or PARR (17% P), as opposed to super-phosphate (9% P). Allowance for other phosphorus fertilisers is made simply by requesting the user to alter the application rate in proportion to the % P of the chosen fertiliser to super-phosphate. This proportional allowance is based on the recommendation of I. Hunter, FRI.

6.4 Performance

The performance of CLAYSFERT has only been evaluated using the data from which it was constructed. It is hoped that the release of CLAYSFERT will result in vigorous testing by the users, and feedback to the author.

Based on the evaluations in Section 5.0, it is suggested that CLAYSFERT replace CLAYS and be used by management. While on average, CLAYS in fertilised situations marginally out-performs CLAYSFERT, the marginal difference is small. In phosphorus deficient situations, CLAYSFERT is the only reasonable choice.

The release of CLAYSFERT is supported by the view that the model behaves logically and well, and has no inherent deficiencies precluding its use within the range of stand parameters, as described herein.

7.0 ACKNOWLEDGEMENTS

The author would like to acknowledge the assistance of the following persons: Mr Mike Dunn for compiling, keypunching and editing data; Mrs Judy Dunlop for providing PSP summary listings; Mr Ian Hunter and Dr Chris Goulding for technical support and encouragement; Mr Gareth Phillips for his evaluation of the performance of CLAYSFERT; and most importantly Dr Oscar Garcia for guidance in the development of the 'fertiliser effects' methodology.

8.0 REFERENCES

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APPENDIX 1 - Plot Management History

Forest	Fertiliser regime	Age		
		Plot (all)	Fertilised	Thinned (all)
WHAP A.	control	6-25	-	10
	625 delayed		11	
	625		6	
	625*2		6, 16	
	625*4		6, 11, 16, 21	
	1250		6	
WHAP B.	control	6-25	-	9
	625 delayed		11	
	625		6	
	625 (P%)*		6, 14	
	625*2		6, 16	
	625*4		6, 11, 16, 21	
	1250		6	
WHAP C.	control	8-25	-	10
	625 delayed		13	
	625		8	
	625 (P%)		8, 14	
	625*2		8, 18	
	625*4		8, 13, 18, 23	
	1250		8	
GLNB	control	5-20	-	8, 13
	625 delayed		10	
	625		5	
	625 (P%)		5, 11	
	625*2		5, 15	
	625*4		5, 10, 15, 20	
	1250		5	
	2500		5	
RVHD	control	6-16	-	6, 12
	625 delayed		11	
	625		6, 16	
	625 (P%)		6, 9	
	625*2		6, 16	
	625*4		6, 11, 16, 21	
	1250		6	
	1250 (P%)		6, 9; 6, 11	
	2500		6	
MARM	control	8-19	-	13
	625 delayed		13	
	625		8	
	625 (P%)		8, 12	
	625*2		8, 18	
	625*4		8, 13, 18, 23	
	1250		8	
	2500		8	

* fertilised initially, thereafter when foliar 'P' < 0.11%

APPENDIX 3 - Plots by forest and fertiliser treatment in the accuracy of stand parameter prediction analysis

Fertiliser treatment	Plot numbers by forest					No. of plots
	WHAN A	WHAN B	WHAN C	GLNB	MARM	
625*1	100500	200100	300600	400700*	-	3
625*2	100400	200700	300400	400600	-	4
625*4	100200	200600	300200	400400	-	4
625*1D	100600	200400	-	400100	500400	4
1250*1	100100	200500	300500	400200	-	4
Control	100300	200200	-	400800	500500	4
No. of plots	6	6	4	5	2	23

* Simulation failed due to inability to thin to prescribed residual basal area.

APPENDIX 4 - Plots by forest and fertiliser treatment in the plot history simulation graphical analysis

Fertiliser treatment	Plot numbers by forest					No. of plots
	WHAN A	WHAN B	WHAN C	GLNB	MARM	
625*1	100500	-	300600	-	-	2
625*4	100200	200600	-	-	-	2
625*1D	-	200400	-	-	500400	2
1250*1	100100	-	-	400200	-	2
2500*1	-	-	-	400500	-	1
Control	100300	-	-	-	500500	2
No. of plots	4	2	1	2	2	11

APPENDIX 2 - Plots by forest in the 'fertiliser effects' analyses

Lambda value

Whangapoua Forest

1. 100100*
2. 100200
3. 100300
4. 100400
5. 100500
6. 100600
7. 200100
8. 200200
9. 200300
10. 200400
11. 200500
12. 200600
13. 200700
14. 300100
15. 300200
16. 300300
17. 300400
18. 300500
19. 300600
20. 300700

Glenbervie Forest

1. 400100
2. 400200
3. 400300
4. 400400
5. 400500
6. 400600
7. 400700
8. 400800

Marmarua Forest

1. 500100
2. 500200
3. 500300
4. 500400
5. 500500
6. 500600
7. 500700
8. 500800

Change in foliar 'P' (fertilisation)

Whangapoua Forest

1. 100100
2. 100200
3. 100400
4. 100500
5. 200100
6. 200300
7. 200500
8. 200600
9. 200700
10. 300100
11. 300200
12. 300400
13. 300500
14. 300600

Glenbervie Forest

1. 400200
2. 400300
3. 400400
4. 400500
5. 400600
6. 400700

Marmarua Forest

1. 500200
2. 500300
3. 500400
4. 500700

Riverhead Forest

1. 600100
2. 600300
3. 600500**
4. 600700
5. 601600
6. 602000**

Change in foliar 'P' (natural decline)

Whangapoua Forest

1. 100100
2. 100200
3. 100300
4. 100400
5. 100500
6. 100600
7. 200100
8. 200200
9. 200300
10. 200400
11. 200500
12. 200600
13. 200700
14. 300100
15. 300200
16. 300300
17. 300400
18. 300500
19. 300600
20. 300700

Glenbervie Forest

1. 400100
2. 400200
3. 400300
4. 400400
5. 400500
6. 400600
7. 400700
8. 400800

Marmarua Forest

1. 500100
2. 500200
3. 500300
4. 500400
5. 500500
6. 500600
7. 500700
8. 500800

Riverhead Forest

1. 600100
2. 600200
3. 600300
4. 600400
5. 600500
6. 600600
7. 600700
8. 601000
9. 601100
10. 601200
11. 601500
12. 601600
13. 601700
14. 601800
15. 601900
16. 602000
17. 602100
18. 602200

* complete plot no. is 286100100

** plots used to provide a single estimated 'measurement'