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TITLE: COMPARISON OF BUTT-LOG BRANCHING CHARACTERISTICS OF IMPROVED PINUS RADIATA BREEDS AT CPT 1218 KAINGAROA

AUTHOR(S): J.A. BROWN AND M.J. CARSON DATE: 10/87

KEYWORDS: IMPROVED BREEDS, MULTINODAL, LONG INTERNODE, PRUNING, BRANCHING HABIT

ABSTRACT

Radiata pine varies in the number of whorls produced each year and from this tree improvement research has developed two distinct tree types, multinodal and long internode trees. Data collected at a Kaingaroa Forest site on age seven trees showed gains in height and diameter growth of multinodal trees over a climbing select seedlot. There were no significant gains in these traits in the long internode trees. Multinodality has been shown to be positively correlated with good growth and form.

Multinodal trees are characterised by many whorls and fine branches. Long internode trees have fewer whorls and heavier branches. Long internode trees are quicker and cheaper to prune above the first lift because there are fewer whorls. The effect on pruning of the relative difference between breeds in number of whorls in the first lift is out weighed by smaller branches on multinodal trees. DOS prediction for the improved breeds may be accomplished using two variables, diameter of the tree and diameter of the branches.

The mean internode for long internode trees was 0.65 m compared to 0.39 m for multinodal trees. 45% of the internodes in a long internode tree are longer than 0.60 m, which suggests that large amounts of clearwood can be produced without pruning. Delaying thinning should prevent excessive branch development with selection intensities high enough to ensure final crop trees of good form.

INTRODUCTION

Radiata pine grown in New Zealand produces up to five branch whorls each year depending on environmental and genetic factors. Tree improvement research has developed two distinct tree types - a multinodal tree that produces many whorls per year with small branches, and a long internode tree that produces fewer whorls with larger branches. The emphasis on clearwood production has led to the development of the long internode tree which has the potential to provide short clears between the whorls. The multinodal tree was developed to reduce knot size in sawn timber and provide better strength qualities for structural purposes. Multinodality is positively correlated with growth rate, stem straightness and freedom from malformation. Multinodal trees tend to be on average superior in form and size to long internode trees. This study has characterised in detail the branching habit of the butt log for the two tree types.

Four seedlots were compared: a Kaingaroa climbing select seedlot which represents relatively unimproved trees; an "870" series seedlot, representing open pollinated seed orchard progeny of long internode trees; a "268" series seedlot, and an "875" series seedlot, both representing open pollinated seed orchard progeny of the multinodal tree type. The "268", "875" and "870" series seedlots were composed of mixed seed of different controlled crosses which were expected to simulate the performance of future open-pollinated seed orchard progeny.

DATA COLLECTION

The data for this study were collected from a trial in Kaingaroa Forest, (compartment 1218) planted in 1979. The original trial was established by the Genetics and Tree Improvement group to compare six different seedlots (experiment number RO 1664/6). Within the existing design circular plots of 0.05 ha were established in four seedlots.

Kaingaroa climbing select
268 polycrosses
875 diallel crosses
870 polycrosses

There were a total of 20 plots representing five replications of the four seedlots.

The initial stocking of the stand was 1111 spha and the trial had been thinned to 600 spha. The trees had been low pruned and were 'overdue' for another lift. Trees were marked for final thinning down to 300 spha leaving 15 crop trees per plot. Data for the crop element only were used in subsequent analysis.

The following measurements were taken for each tree:

- diameter at height 1.4 m (cm)
- total tree height (m)
- height of pruning (m)
- diameter over stubs (DOS) (cm)
- height to the DOS whorl (m); (usually the lowest branched whorl)
- diameter of the largest branch in the DOS whorl (cm)
- number of branches in the DOS whorl

- degree of epicormic growth (class 0-2)[1]
- heights to top and bottom of each whorl to height 5.7 m (m)
- whorl class for each branched whorl to height 5.7 m (class 1-5)[2]
- meanwhorl expressed as the mean whorl class
- number and height of stem cones

Data were analysed using SAS procedures on the VAX computer.

1. GROWTH CHARACTERISTICS

The tree improvement programme at the FRI aims to improve the profitability of growing wood in New Zealand's exotic forest plantations. One of the basic goals is to improve yield both quantitatively (size of tree, volume of wood per hectare) and qualitatively (stem straightness, lack of malformation) which in combination will lead to improved profitability. Quantitative growth characteristics were collected in this study and compared between the improved and unimproved seedlots. (Table 1).

Differences between seedlots for the variables diameter at breast height (DBH), tree height and basal area were tested against the hypothesis, HO: there is no difference between height, diameter and basal area for the four seedlots. Analyses of variance to test this hypothesis (Appendix 1) showed that tree height is significantly different among seedlots, at the 99% confidence level and DBH is significantly different at the 85% confidence level. The difference between the improved seedlots and the climbing select was tested as a prior hypothesis for height and DBH (equation 1).

$$Q = \bar{X}_{268} + \bar{X}_{875} + \bar{X}_{870} - 3\bar{X}_{CS} \qquad \text{equation 1}$$

where $\bar{X}_{268}$ = mean for the trait for the "268" seedlot

$\bar{X}_{875}$ = mean for the "875" seedlot

$\bar{X}_{870}$ = mean for the "870" seedlot

$\bar{X}_{CS}$ = mean for the "Kaingaroa climbing select" seedlot

Genetic selection has improved height growth, since for equation 1 $F(1, 12) = 10.50$ which is significant at the 99% confidence level. The hypothesis that there is no gain in diameter for the improved seedlots cannot be rejected, since the F value is 0.12, (not significant).

The posterior hypothesis that multinodal trees are no different from long internode trees in height growth was examined (equation 2) using Scheffe's test.

$$Q = \bar{X}_{268} + \bar{X}_{875} - 2\bar{X}_{870} \qquad \text{equation 2}$$

For height, the F value of 6.8 is significant indicating that there is a difference between multinodal and the long internode tree types. There is a similar trend for diameter but it was not significant.

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[1] Appendix 3

[2] Appendix 2

One of the aims of tree improvement is to increase uniformity for desired traits, and therefore to reduce phenotypic variation. The coefficient of variation is a measure of variation which removes the effect of scale. The coefficient of variation for diameter was not reduced for the improved seedlots, but the c.v. for height for the multinodal trees was less than for the climbing select and long-internode trees.

The "268" and "875" seedlots are more multinodal than the climbing select and "870" seedlots; in the 5.5 m butt log, they have 13 whorls on average, compared to nine whorls for the "870" seedlot and 10 whorls for the climbing select. Associated with an increased number of whorls, the multinodal trees have smaller branches. The coefficient of variation for number of whorls is reduced for the multinodal seedlots compared to the unimproved and is larger for the long internode seedlot (Table 1).

2. BRANCH FINENESS

Branch size and the corresponding knot defect is one of the most important factors determining the grade and value of timber outturn. Control of the size of branches without loss in growth is an effective way to improve value of the outturn from a stand.

Branch size is related to tree size, the larger the tree the larger the size of the branches (the coefficient of determination in this study was $r^2 = 0.50$). To examine more closely the effect of tree type on branch size the concept of fineness was used. This concept removes the effect of tree size, since fineness = branch size/DBH. Branch size is also affected by the number of whorls in the stem (the more whorls the finer the branches) and the two are strongly correlated ($r^2 = 0.57$). Covariance analysis was used to determine the variation between seedlots in fineness after removing the effect of number of whorls (Table 2). The covariance analysis indicates that fineness can largely be explained by number of whorls, but that the multinodal ("268" and "875") seedlots have slightly smaller branches than the long internode and climbing select seedlots after adjustment for number of whorls. These results show that although there is minor scope for selecting for small branches relative to diameter ("fineness"), much larger genetic gains in reduced branch size can be made by selecting for multinodality.

Additional benefits are associated with selection for multinodality because of the positive correlation between multinodality and good growth and form. Branch size is also a factor in the amount of damage from heavy snowfalls and wind (Guild, 1986). Long internode trees have heavier, steep-angled branches and tend to produce basket whorls which are weak points and can break under load. Multinodal trees with lighter branches are less prone to snow and wind damage.

TABLE 2 - Analysis of Covariance for testing variation in branch fineness of improved and unimproved radiata pine

Dependent Variable : Fineness of Branch

Source	DF	Type I SS[1]	F	Type IV SS[2]	MS	F	PR > F
Seedlot	3	0.0559	42.19	0.0085	0.0028	6.39	0.0003
Rep	4	0.0021	1.20	0.0021			
Seedlot x rep	12	0.0069	1.30	0.0089			
No. whorl	1	0.0243	54.92	0.0243	0.0243	54.92	0.0001
Error	279	0.1233					
Total	299	0.2125					

$R^2 = 0.42$

Seedlot	'Adjusted' mean fineness (cm)[3]
Climbing select	0.139
"268"	0.124
"875"	0.125
"870"	0.134

1 Type I SS - sequential sums of squares
2 Type IV SS - nonsequential sums of squares
3 i.e. reflecting the differences between seedlots in 'fineness' of branches after adjustment for the number of branch whorls.

3. PRUNING OF THE BREEDS

Pruning of radiata pine in New Zealand is practised to add value to the timber outturn although it does involve considerable added costs to the regime. The two improved tree types have different branching habits and consequently may differ in the cost of pruning. They may also differ in their need for pruning - long internode trees can provide clearwood in long lengths without pruning.

3.1 Pruning Definition

Current recommended pruning practice in New Zealand is by variable lifts to ensure that all trees receive a similar pruning severity while still controlling the size of the DOS; it takes tree size into account by leaving a fixed crown length. The most practical way to achieve this is to prune to a specific stem diameter (Koehler, 1984). This method is applicable for multinodal trees but pruning to a set diameter may not be suitable for the long internode trees because of the greater mean length of internodes and resulting variation in pruned height. For example, in this study the trial had been prescribed to a fixed lift pruning to 2.2 m but the actual pruned height had a range of 2.0 m. It may be more appropriate for the long internode trees to define pruning to leave a fixed number of whorls.

3.2 Pruning Time

The time it takes to prune a tree is primarily a function of the number of whorls to prune, the number of branches in the whorl, and the size of the branches, but also includes other factors such as epicormic growth and stand hindrance. The amount of time to prune trees of different branching types will differ and it is important to relate this back to costs. Sensitivity analysis was used to explore the relationship of pruning time to pruning cost.

Pruning times were calculated using time standards from the NZFS work study group for the 2.2 to 6 m lift. Costs were derived on a per hectare basis from the target calculations; the cost to work a day for a two man crew including wages, travel time, equipment use, etc. was divided by the number of target trees to derive a cost per tree. The gang target was calculated as the time to prune a tree plus walk time between trees, time for tool maintenance, rests, etc.

The relationship of time to prune a tree and the cost to prune the tree calculated for this study is expressed in equation 4.

Pruning cost per tree = 0.31 + pruning time per tree x 0.3 equation 4

Costs of pruning are not particularly sensitive to time to prune a tree because of the addition of constants such as walk time, rests, etc. in the calculation. However, savings in pruning time will result in significant savings in costs when they are calculated on a per hectare basis.

The time taken to prune a tree is a affected by both mean whorl class and number of whorls. The relative importance of whorl class and number of whorls in this study was analysed using multiple regression

(Table 3). Results of the analysis indicate that the time to prune a tree is more sensitive to the number of whorls than to mean whorl class, but any reduction in either will reduce pruning costs.

A third factor (not covered by the work study standards) which might affect the time taken to prune a tree is the number of branches per whorl. Both the "875" and "268" seedlots had an average of 6.1 branches in the DOS whorl, while the average was 6.4 branches for the climbing select, and 6.6 branches for the long internode seedlot.

TABLE 3 - Multiple regression analysis relating prune time to branch size and number of whorls for all seedlots

Dependent Variable : Prune Time

Source	DF	Type I SS[1]	Type IV SS[2]	F	PR > F
Mean whorl	1	0.0322	1.0800	192.19	0.0001
No. whorl	1	1.5770	1.5770	280.63	0.0001
Error	297	0.0955			
Total	299	1.7048			

$R^2 = 0.94$

1 Type I SS - sequential sums of squares
2 Type IV SS - nonsequential sums of squares

3.3 Comparison of breeds for pruning

The three improved seedlots were estimated to be quicker to prune in the 2.2 m to 6 m lift than the climbing select seedlot and, of these, the long internode trees took the least time (Table 4). For multinodal trees the branches are smaller, but there are more whorls to prune. The difference between seedlots is significant at the 95% confidence level, (F = 5.49). When times calculated for jacksaws only are compared the differences between seedlots are even larger (F = 7.12, significant at the 99% level). The difference in branching habit has more effect when only jacksaws are used, the small branches on the multinodal trees are slower to remove with saws than porter pruners. Differences between breeds may have been smaller in the first lift because the absolute differences in the number of whorls relative to branch size are not as large. Differences in numbers of branches per whorl between seedlots would act to reduce the target tree/day estimates shown (Table 4) for "870" and climbing select seedlots relative to the multinodal seedlots.

TABLE 4 - Pruning time and costs for 2.2-6 m on improved and unimproved radiata pine

	Climbing Select	"268"	"875"	"870"
Jacksaw and porter pruners				
Target trees/manday	106	109	108	123
Cost/tree - $	5.72	5.43	5.50	4.86
Cost/ha[1] - $	343	326	330	292
Jacksaw only				
Target trees/manday	97	98	96	112
Cost/tree - $	6.15	6.08	6.16	5.32
Cost/ha - $	369	366	369	318

1 Calculated for 300 spha

Pruning costs per plot were calculated from the number of target trees, and they reflected the trends already noted for target tree estimates, i.e. lower pruning costs for the long internode tree.

Although long internode trees were quicker to prune, this could be a result of their smaller average tree size and consequently relatively smaller branches, since the relationship between diameter and mean whorl class is relatively strong. To establish if there was any variation in mean whorl class due to genetic differences, analysis of covariance was used to remove the effect of tree diameter (Table 5). Tree diameter is three times more important in explaining the variation in mean whorl than seedlot (compare mean squares). Seedlot is still significant, however, for variation in mean whorl class with the effect of diameter removed. For the same tree size, the long internode and climbing select trees have branches that are approximately 0.5 cm larger than for the multinodal trees.

TABLE 5 - Analysis of covariance adjusting branch size for stem diameter over all seedlots

Dependent Variable : Mean Whorl Class

Source	DF	Type I SS	Type IV SS	MS	F	PR > F
Seedlot	3	10.7089	16.0747	5.3582	34.08	0.0001
Rep	4	1.1081	0.6375			
Seedlot x rep	12	2.0831	2.0420			
Diameter	1	15.7958	15.7958	15.7958	100.45	0.0001
Error	279	43.8709				
Total	299	73.5668				

$R^2 = 0.40$

Seedlot	'Adjusted' mean whorl class
Climbing select	2.51
"268"	2.00
"875"	2.04
"870"	2.48

Finally, consideration should be given to the incidence of epicormic growth and stem cones, both of which affect costs since they are removed in pruning. Epicormic growth can be controlled by silviculture: heavy pruning, wide spacing and pruning in spring will all encourage epicormic growth (Crowe, 1976). Epicormic growth allowances were included in the tree target calculations according to work study standards. These standards classify epicormic growth into three groups (Appendix 3). Of the 75 trees in each seedlot, for the long internode breed, 16 had epicormic growth that caused a definite delay in pruning, four for the "268 seedlot", zero for the "875 seedlot" and 10 for the climbing select seedlot. Of these, four long internode trees and two climbing select trees were in class two. (A tree with class two epicormic growth will delay pruning by up to half a minute, which can be significant on a per hectare basis.) The incidence of excessive epicormic growth was relatively low in this study even for the long internode breed, where only one fifth of the trees were affected. Multinodal trees had less pruning delay due to epicormic growth than the unimproved trees while the long internode trees had more; the difference in incidence can be related to differences in the branching habit, although the underlying physiological basis for these differences is not yet understood.

Stem cones are removed in pruning and cause a slight delay. Their incidence was highest on the multinodal trees and particularly on the "875 seedlot" (probably representing some genetic selection for early flowering). Of the 75 trees per seedlot there were 20 and 14 cone whorls on the "875" and "268" seedlots respectively, and five and 11 cone whorls on the "870 seedlot" and climbing select seedlot, respectively.

The multinodal tree type compared to climbing select will cause less pruning delay due to removal of epicormic growth, but there may be additional stem cones. For the long internode trees, there is more epicormic growth but fewer stem cones.

4. PREDICTING DOS

Radiata pine is pruned to produce quality timber grades by containing the defects within a central core and producing defect free outerwood. Diameter over stubs (DOS) is kept to a minimum to maximise this outer clearwood sheath. A predictive model for DOS has been produced to use in a simulation model to evaluate alternative silvicultural regimes (Knowles et al, 1987).

Sufficient data have been collected to predict DOS for each breed of radiata and for an overall comparison. The DOS model published by Knowles and West is a five variable model using the variables diameter at DOS (DADOS) in cm, maximum branch in the DOS whorl (MAXB) in mm, MAXB^2, height of the DOS whorl (DOSHT) in m, and DOSHT^2. Models with one to five variables were compared using these five and other variables that intuitively seemed important, including; DBH, total height and length of green crown. DBH is highly correlated with DOS, $r^2 = 63\%$. Total tree height is not as important, $r^2 = 5\%$. The relationship of length of green crown with DOS is weak, $r^2 = 3\%$.

All possible regressions were compared and three simple criteria were used to select the "best" equation. The size of the R^2 or coefficient of multiple determination, is a measure of the proportionate reduction in total variation in the Y (or dependent variable) associated with the use of the set of X variables. The size of the mean square of the error (MSE) is another criterion which takes into account the number of parameters in the model through the degrees of freedom. MSE will actually increase with the addition of parameters into the model if the reduction in sum of square of the error (SSE) becomes too small to offset the loss of an additional degree of freedom. "Mallow's Cp" is concerned with the total squared error in the model and includes both a bias and random error component (Neter and Wasserman, 1974).

The best models using one to five variables to predict DOS based on all 300 trees are shown in Table 6. There is little improvement in reducing total error and removing bias for this data set beyond a two variable model. The diameter of the largest branch in the DOS whorl and a measure of the girth of the tree were the two variables most important in predicting DOS. Using DBH compared to DADOS has reduced the total error in the model and it has a smaller bias component (Figure 2). The model using DBH and MAXB was chosen as being the best predictor of DOS for this dataset.

$$DOS = 2.6815 + 0.8140\ DBH + 0.0731\ MAXB \qquad \text{equation 5}$$

TABLE 6 - Rating of prediction models for DOS using three criteria

	Model					R^2	Cp	MSE
1	DADOS					0.51	361	
	DIAM					0.63	184	2.02
2	DADOS	MAXB				0.76	34	1.35
	DIAM	MAXB				0.77	8	1.28
3	DADOS	MAXB	$DOSHT^2$			0.77	13	
	DADOS	MAXB	DOSHT			0.77	16	
	DIAM	MAXB	DOSHT			0.77	4	1.25
4	DADOS	MAXB	$MAXB^2$	DOSHT		0.78	9	1.23
5	DADOS	MAXB	$MAXB^2$	DOSHT	$DOSHT^2$	0.78	6	1.22

In multiple regression equations the assumption of independence of variables should be maintained where possible. In reality this is rarely achieved, for example in equation 5 correlated variables have been used, and in other models variables are used to derive other variables (as with DADOS from DOSHT). The inclusion of correlated variables in the five variable model has produced (for some variables) unstable estimates of regression coefficients for the dataset used in this study. These range for DOSHT from -22.2 to -0.8 (Table 7). However, the predicted DOS from using treatment means from the full five variable model of Knowles et al., is very close to that predicted from equation 5 and the actual DOS (Table 8). On a plot basis (Figure 3) the error is within the acceptable ± 1.5 cm quoted in the report, but there is a definite bias towards underprediction for the climbing select seedlot and the long internode breed (both of which are characterised by large branches). Plotting residual DOS on MAXB showed that the bias is greatest for branches 5 cm or greater.

TABLE 7 - Regression parameters from 5-variable models, derived for each seedlot

		ß coefficients				
	Intercept	DADOS	MAXB	$MAXB^2$	DOSHT	$DOSHT^2$
Climbing select	6.24	0.67	0.16	-0.84	- 1.02	0.30
"268"	25.73	0.87	0.16	-1.13	-20.06	4.13
"875"	27.09	0.86	0.23	-2.06	-22.17	4.54
"870"	0.71	0.98	0.08	-0.18	- 0.84	0.49

TABLE 8 - DOS predictions for all seedlots using seedlot means

	Actual DOS	Predicted DOS	
		2 variable model[1]	5 variable model[2]
Climbing select	20.08	19.84	19.55
"268"	19.45	19.50	19.38
"875"	19.32	19.43	19.29
"870"	19.35	19.43	19.13

[1] DBH and MAXB - as in equation 5
[2] From Knowles et al, 1986.

5. EFFECTS OF BREED DIFFERENCES ON WOOD PRODUCTS

Tree improvement has developed two separate tree types by modifying the branching habit of radiata pine. Any gains should be judged in terms of the final product from the tree arising from the additional volume or better quality of the wood produced. The multinodal tree type with small numerous branches will produce higher quality structural timber while the long internode tree has been bred to yield increased clear cuttings; the ability of the long internode tree to produce such clearwood depends on the length and distribution of the internodes within the tree.

5.1 Internode length

Internode length is defined as the length between branch clusters and essentially represents defect free timber. Internode distribution can be expressed as an index, the one used in SILMOD is calculated as the sum of internodes 600 mm or longer for a 5.5 m log (Whiteside et al., 1986). However, internodes less than 600 mm may also be of value and the internode index does not estimate these. Mean internode length (MIL) can be used to derive distributions of internodes within a tree.

Multinodal trees produce more branch clusters a year than do long internode trees and correspondingly the average MIL is shorter, (0.39 m compared to 0.70 m for the latter in this study). "Climbing Select" average MIL was 0.54 (Table 9). These differences are significant at the 0.001 level. There is more variation in MIL between trees for the long internode type, (with a coefficient of variation of 40%) compared to the multinodal and climbing select trees (Figure 4). MIL ranged from 0.34 m to 1.8 m for the long internode trees with 2/3 (one standard deviation) of the internode lengths within 0.28 m of the mean. The multinodal trees ranged from 0.20 m to 0.75 m with a standard deviation of $\pm$ 0.09 m. This represents a considerable reduction in the mean and variance of internode length from the climbing select trees, for which the coefficient of variation was 35% and standard deviation $\pm$ 0.19 m.

TABLE 9 - Mean internode length (MIL) values for all seedlots

	Climbing Select	"268"	"875"	"870"
Mean internode length[1] (m)	0.54	0.39	0.39	0.70
- coefficient of variation	37.74	25.24	22.15	40.28
Mean internode[2] (m)	0.58	0.39	0.39	0.65

[1] Mean internode length calculated for branched whorls only, 2.2 - 5.7 m = mean of the mean internodes of each tree by seedlot.

[2] Mean internode length calculated for all whorls 0.2 - 5.7 m, = mean of all internodes by seedlot.

Internode index, expressed as the sum of internodes greater than or equal to 600 mm was calculated for the first 5.5 m log. The distribution of indices (Figure 5) is very similar to what Inglis (unpublished results) found in work with genetically improved stock. Multinodal trees have a high frequency of trees with an index of 1 m while for long internode trees the mean index is around 2.6 m.

The main use of clearwood is in furniture, componentry, joinery and mouldings. Lengths much shorter than 600 mm and even less than 300 m can be utilised (G.P. Horgan, pers. comm.). An index expressed as the sum of internodes not less than 300 mm for a 5.5 m log can be used to predict the clearcuttings (given that a market exists for such short lengths). Multinodal trees had 48% of the 5.5 m log length in internodes 300 mm or longer while long internode trees had 64%. The difference between the two tree types is less than for the 600 mm index for which 18% of the 5.5 m log of multinodal trees is in internodes 600 mm or longer and 46% for long internode trees. Thus, even multinodal trees with a mean internode length of 0.39 m can provide a potential source of short clearcuttings.

The results of sawing studies on eight locations throughout New Zealand have been collated and the mean sawn volume of clearcuttings by SED class tabulated by internode class (T. Gosnell, pers. comm). Internode classes were for the percentage of log length in internodes 300 mm or more. These results indicate that for the same SED class, multinodal trees will yield a slightly lower percentage of sawn volume in clearcuttings 300 mm or longer than long internode trees. There will be differences in the size distribution of the pieces, and long internode trees will yield more longer clears. It is also likely that some long clears can be cut from multinodal trees from between the branches in a whorl, since these trees have smaller and fewer branches per whorl than long internode trees.

While the sum of internodes within a tree is similar for both tree types, a greater number of crosscuts will be needed to realise these clearcuttings for the multinodal tree type and this will increase costs. For the first log, a multinodal tree requires one and a half more crosscuts on average per unit of index than does the long internode tree (Table 10). Additional costs of cutting clears from multinodal compared to long internode trees will probably be more apparent in the second log where the differences in branching habit are more pronounced.

TABLE 10 - Clear cuttings greater than 300 mm on improved seedlots of radiata pine

	"268"	"875"	"870"
Index of internodes			
> 300 mm (m)	2.7	2.6	3.5
crosscuts required (number)	11.4	11.2	10.0
crosscuts per unit of index (number)	4.2	4.3	2.9

The frequency distribution of internodes (Figure 6) represents the within tree variation of internode length distributions. The use of mean internode length as a predictor of clearcuttings relies on the ability to predict this internode distribution from a given mean internode length value. The shape of the distribution supports the hypothesis that frequency distributions can be estimated from mean internode length for a given breed and site by using the "gamma" distribution, (C.S. Inglis, pers. comm.). The Weibull distribution is an alternative as it is more flexible and could be used to estimate both probability density functions and cumulative distributions.

Mean internode length is a useful measure but it is very laborious to measure directly as it requires climbing the tree and measuring the height of all whorls. A more convenient measure would be to use branch clusters counted from the ground to a predetermined height. The validity of using branch cluster counts as a predictive method for mean internode length was checked using students t-test. The number of branch clusters per tree in the first log were summed and with an allowance for whorl depth, the mean internode length was calculated using equation 5.

$$MIL = \frac{\text{log length (m)} - \text{number whorls} \times \text{whorl depth (m)}}{\text{number internodes}} \qquad \text{equation 5}$$

Number of whorls was calculated as the number of whorls up to but not at 5.7 m and the number of internodes = 1 - number of whorls unless the first whorl was at stump height. Whorl depth was calculated for all whorls in the 5.5 m log. The average whorl depth was 0.13 m, with no difference between seedlots. The hypothesis that there is no difference between actual mean internode and that predicted using cluster counts was accepted; predicted mean internode is slightly larger than the actual mean internode but not significantly so, the mean internode was 0.50 m compared to the mean predicted internode of 0.53 m.

Since 45% of the internodes of the long internode trees are longer than 600 mm and 75% are longer than 300 mm the yield of clear cuttings from between whorls will be high and there is no apparent need to prune. While stem form and percent acceptable stems for the long internode trees are not as favourable as for multinodal trees (Carson, 1987), there is a clear case to support their planting on sites where pruning is not possible, or where pruning costs are considered prohibitive. (Initial stockings should be relatively high for selection of acceptable stems.) By not pruning, diameter growth of long internode trees will be favoured relative to pruned multinodal trees. Maximum expression of the long internode trait is found on moderately fertile and high latitude sites. Trees on Kaingaroa, Nelson and Southland sites express some of the longest internodes in New Zealand (M.J. Carson, pers comm.) but on other sites (for example, sand sites) the internode distribution may not be so favourable. Unfortunately, tree form problems may limit the use of long internode trees to more sheltered and less fertile sites.

5.2 Stem Cones

Cones are the source of seeds, and their abundance is vital for seed production, and for genetic crossing purposes. However, stem cones form continuous holes as they grow outwards with increasing stem diameter and they can constitute a serious defect in sawn timber. Cone holes are small enough not to be a problem in structural timber but they will have a serious degrading effect in board grades. However, stem cones occur just below whorls and for the production of clear cuttings they would be cut out with the branch defect, with no real loss in timber conversion.

The total number of stem cones recorded on all 300 trees was only 82 with almost half of these on the "875" seedlot trees (Table 11). Considering the relative infrequency of stem cones in the "268" and "870" seedlots there is not likely to be a significant effect on timber outturn.

TABLE 11 - Number and proportion of stem cones on all seedlots of radiata pine

	n[1]	Climbing select	"268"	875"	"870"
Total number cones	75	16	21	36	9
Total number whorls with cones	75	11	14	20	5
Mean number cone whorls per tree		0.03	0.03	0.04	0.02

[1]n = number of trees

5.3 Pulp Quality

The production of kraft pulp is mainly from top logs, thinnings, mill residue and specific pulpwood regimes. This material usually has a high proportion of knotwood which is difficult to chip and can cause problems in pulping. Knotwood is composed of compression wood fibres which are shorter, rounder, more thickwalled and more lignified than normal softwood tracheids (R.J. Allison, pers. comm.). Most reject material can be screened out but smaller particles such as shives (fibre bundles) will persist and be visible in the resultant pulp and paper.

The formation of reject material during kraft pulping depends on the proportion of knotwood. Considering the two tree types, long internode trees have fewer whorls per length of log, 23% of the log length is in whorls compared to 31% for the multinodal tree. Within a whorl, however, the long internode trees have more numerous and larger branches. It is possible that these two factors counteract each other and there may be no real difference in the proportion of knotwood between tree types. Differences in branching characteristics are most apparent in the lower half of a mature tree. If there were any differences between tree types in the proportion of knotwood with current practices, this would mainly effect thinning material which usually only makes up a quarter of the total mill input (R.J. Allison, pers. comm.), the remainder coming from the more multinodal top logs. However, the effect of such differences on pulp quality could be larger if lower logs are pulped, rather than being sold for solid wood processing.

CONCLUSIONS

* Gains in tree heights have been made in the improved seedlots at age seven. Diameter gains were moderate, but not statistically significant.

* Selection for multinodality reduces average branch size while also yielding genetic gains in growth rate and improved stem form.

* The costs to prune a tree depend on the number of whorls removed and the size of the branches. For the second and third lifts, multinodal trees may take longer to prune than long internode trees because there are more whorls to prune. In the first lift the effect of smaller branches outweighs the effect of additional whorls and multinodal trees can be pruned more quickly.

* Diameter over stubs (DOS) was best predicted using a two variable model using diameter at breast height and the diameter of the maximum branch in the DOS whorl.

* There is little difference between multinodal and long internode trees in the proportion of clearcuttings in lengths greater than 300 mm. However, long internode trees require fewer crosscuts to produce this clearwood and average lengths are longer.

* Internode distributions (used to predict clearcuttings) can be accurately predicted from mean internode length, using appropriate statistical distributions.

* Mean internode length can be predicted from counts of branch clusters.

* Almost half of the internodes in the long internode trees are longer than 600 mm, which suggests that (on suitable sites) a high proportion of clearwood can be produced without the need to prune.

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APPENDIX I - Analysis of variance

Dependent Variable : height

Source	DF[1]	Sums of squares	Mean square	F[2]	PR > F
Seedlot	3	50.81	16.94	10.36	0.0012
Rep	4	4.48	1.12	0.69	0.6157
Seed x Rep	12	19.63	1.64	2.28	
Error	280	202.92	0.72		
Total	299	277.84			

Dependent Variable : diameter at breast height

Source	DF[1]	Sums of squares	Mean square	F[2]	PR > F
Seedlot	3	65.55	21.85	2.04	0.1617
Rep	4	48.40	12.10	1.13	0.3878
Seed x Rep	12	128.41	10.70	2.86	
Error	280	1045.97	3.74		
Total	299	1287.32			

APPENDIX II - Definition of 'whorl class' classification of branch size

	Whorl Class	Diameter of largest branch
1	very light	19 mm or less
2	light	20 - 39 mm
3	medium	40 - 55 mm
4	heavy	1 or 2 greater than 55 mm
5	very heavy	3 or more greater than 55 mm

Prune times are based on five whorl classes

APPENDIX III - Epicormic Growth Classification

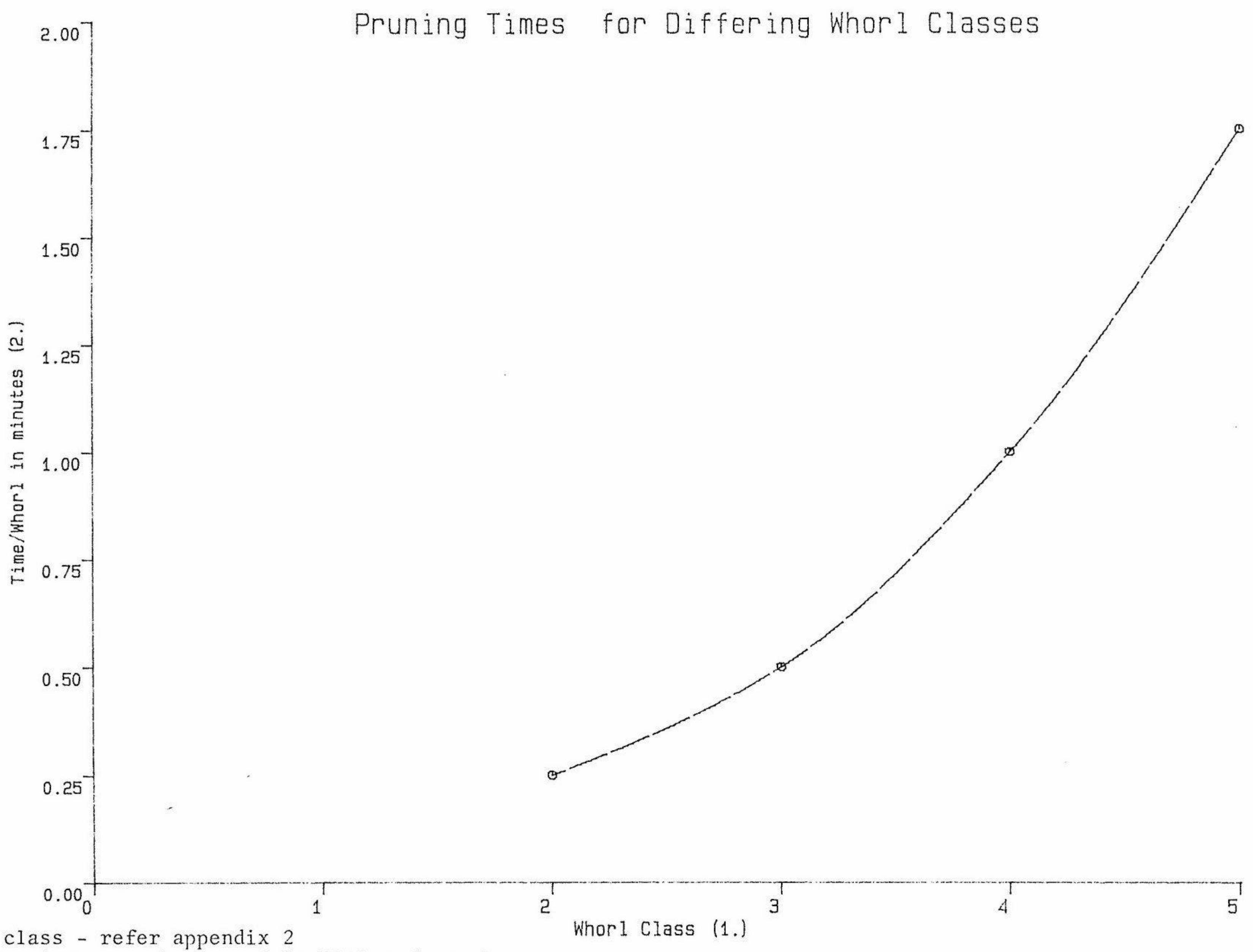
Description	Class	Standard Time Allowed for removal
Small numbers of Epicormic shoots or needles removed easily Does not interfere greatly with the prune operation	Included in prune time. Not recorded as epicormic removal	0
Small numbers of Epicormic shoots or needles removed A definite delay to pruning is caused	Light	0.14 min
A significant delay of up to half the pruning time can be experienced due to numbers of shoots or needles removed or the difficulty of removal	Medium	0.41 min
Large amounts of Epicormic shoots and/or needles removed Can take as long as the pruning operation	Heavy	0.94 min

TABLE 1 - Growth rate and branching measurements of improved and unimproved radiata pine

Seedlot	n[1]	HT[3]	C.V.[2]	Diam[4]	C.V.	B.A.[5]	C.V.	No. whorl[6]	C.V.	Brandi[7]	C.V.
Climbing select	75	11.11[a8]	7.4	17.21	11.2	7.07	22.5	4.99	23.0	4.31	28.7
"268"	75	11.96[b]	6.8	17.81	11.7	7.57	23.2	6.65	20.6	3.18	28.0
"875"	75	11.91[b]	6.7	17.67	10.4	7.43	21.2	6.59	18.2	3.24	26.4
"870"	75	11.12[a]	9.5	16.61	13.6	6.62	26.9	4.27	30.4	4.45	27.3
Overall	300	11.52	8.4	17.32	12.0	7.17	23.8	5.62	28.8	3.78	31.9

1 n = number of trees
2 C.V. = coefficient of variation
3 HT = total tree height (m)
4 Diam = diameter at breast height (cm)
5 B.A. = basal area (m^2/ha)
6 No. whorl = number of branched whorls, on average 2.3 - 5.7 m
7 Brandi = diameter (cm) of the largest branch in the DOS whorl
8 tested using linear contrasts: means followed by a different letter are significantly different ($p > 0.01$)

Figure 1



(1) Whorl class - refer appendix 2
(2) Pruning times are those used in NZFS work study

Figure 2

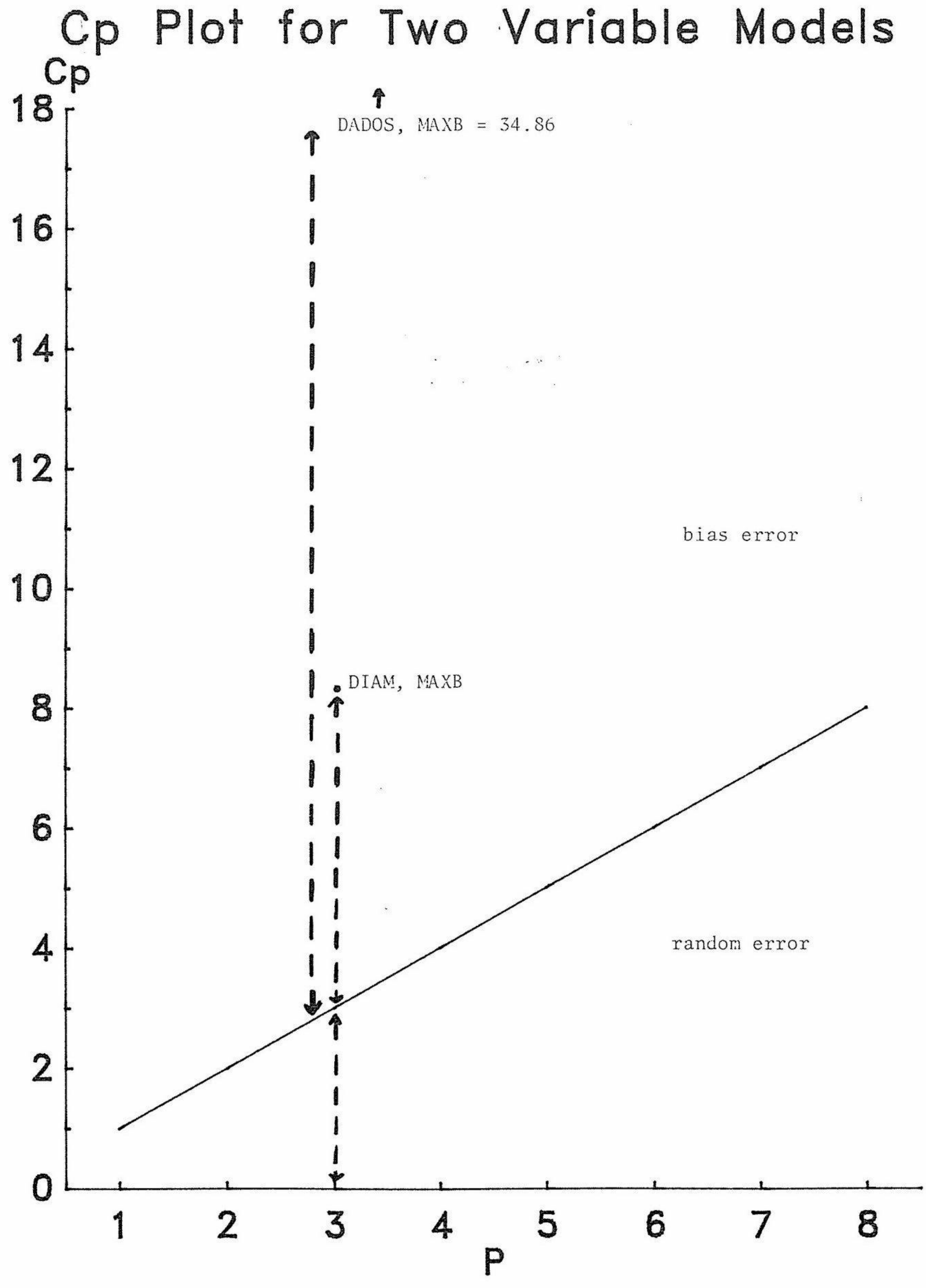
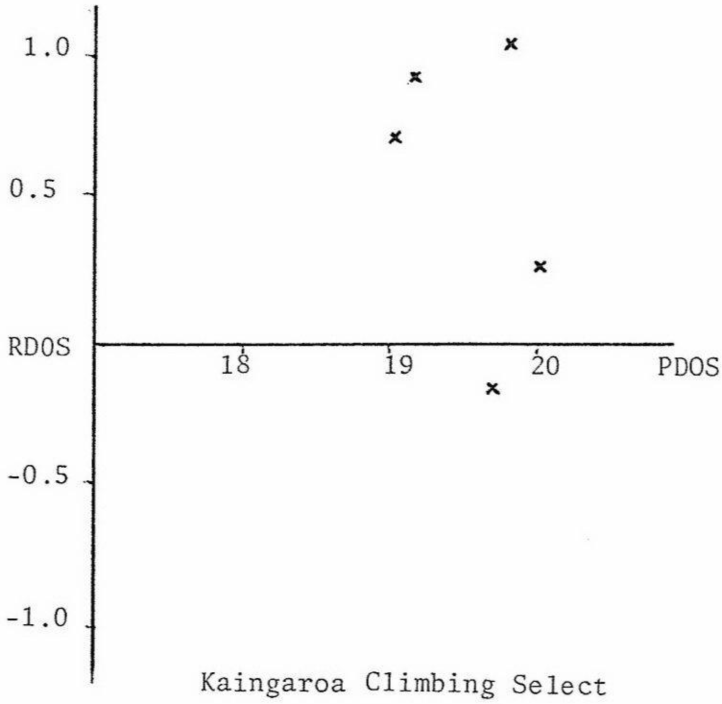
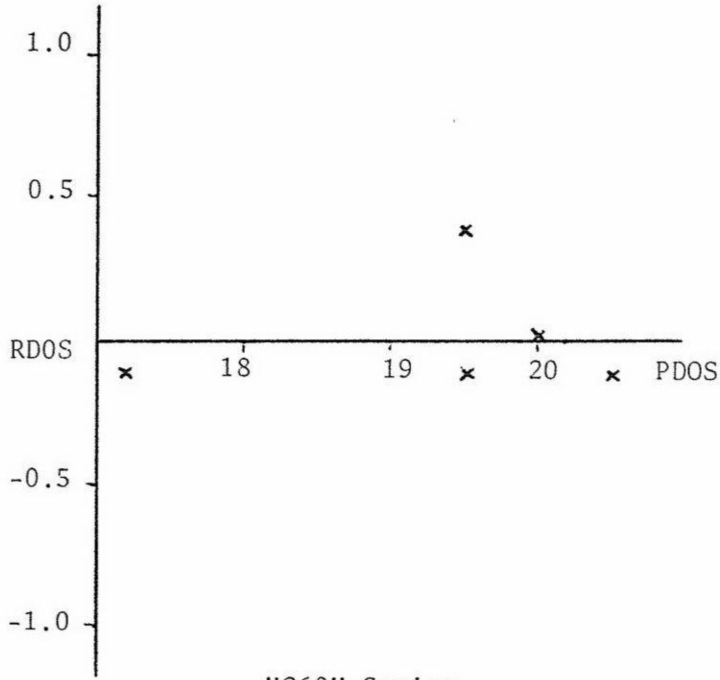

Cp Plot for Two Variable Models
Cp
18
16
14
12
10
8
6
4
2
0
DADOS, MAXB = 34.86
DIAM, MAXB
bias error
random error
1
2
3
4
5
6
7
8
P

Figure 3

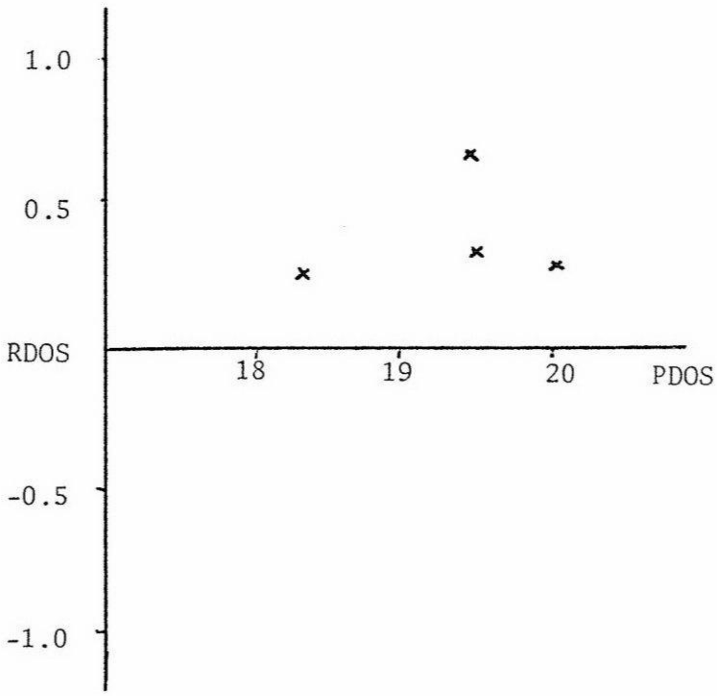


Kaingaroa Climbing Select

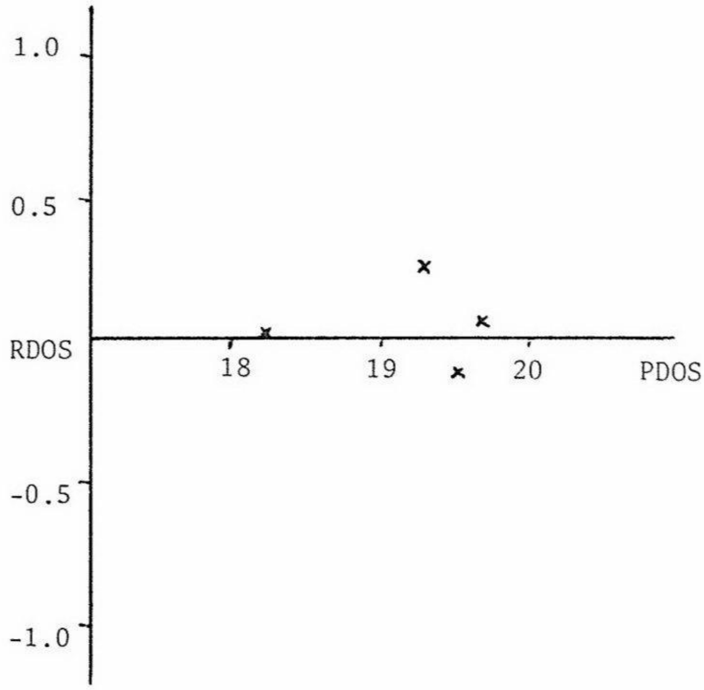


"268" Series

PDOS - predicted DOS
RDOS - actual DOS - predicted DOS

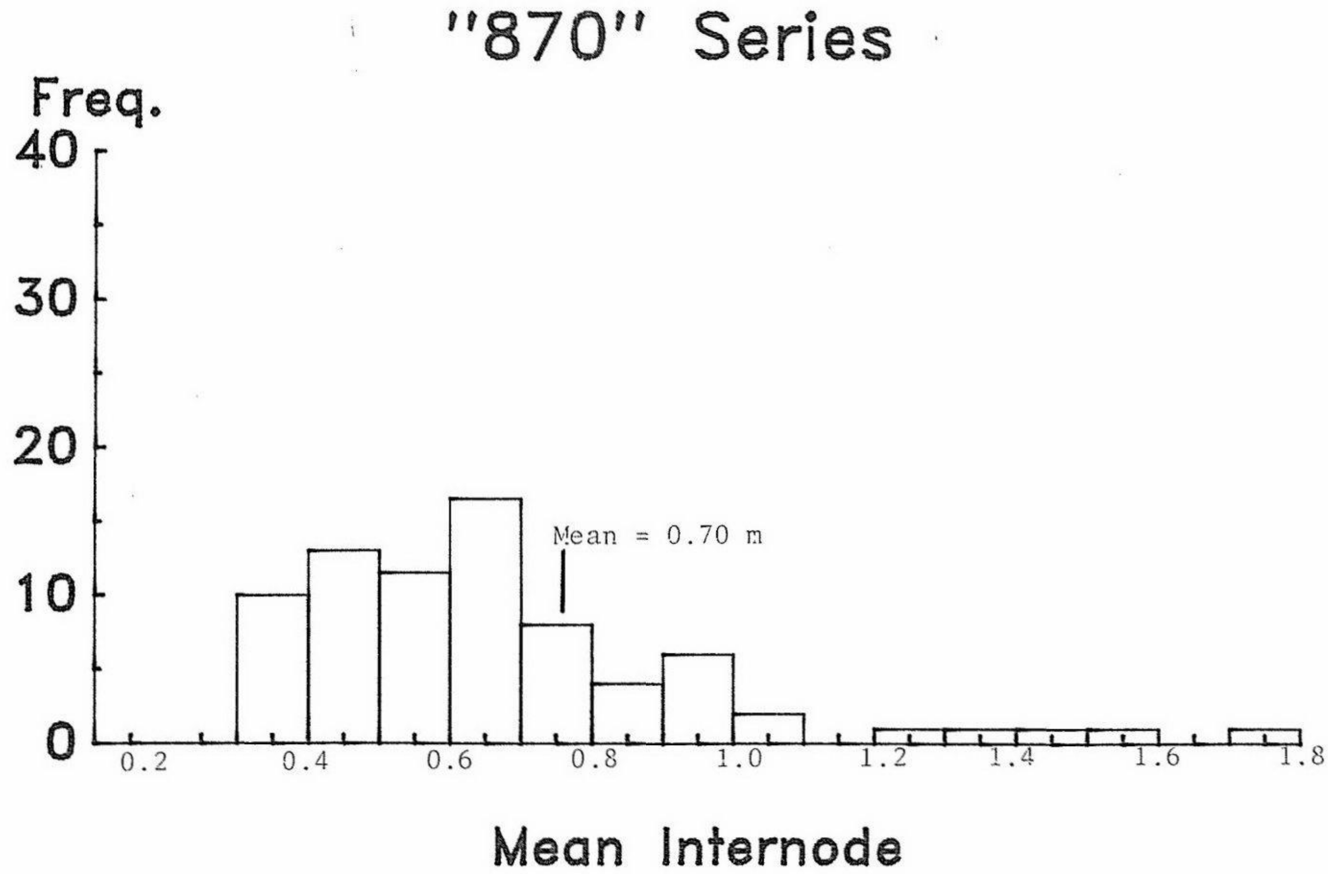


"870" Series



"875" Series

Figure 4a


"870" Series
Freq.
40
30
20
10
0
Mean = 0.70 m
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Mean Internode

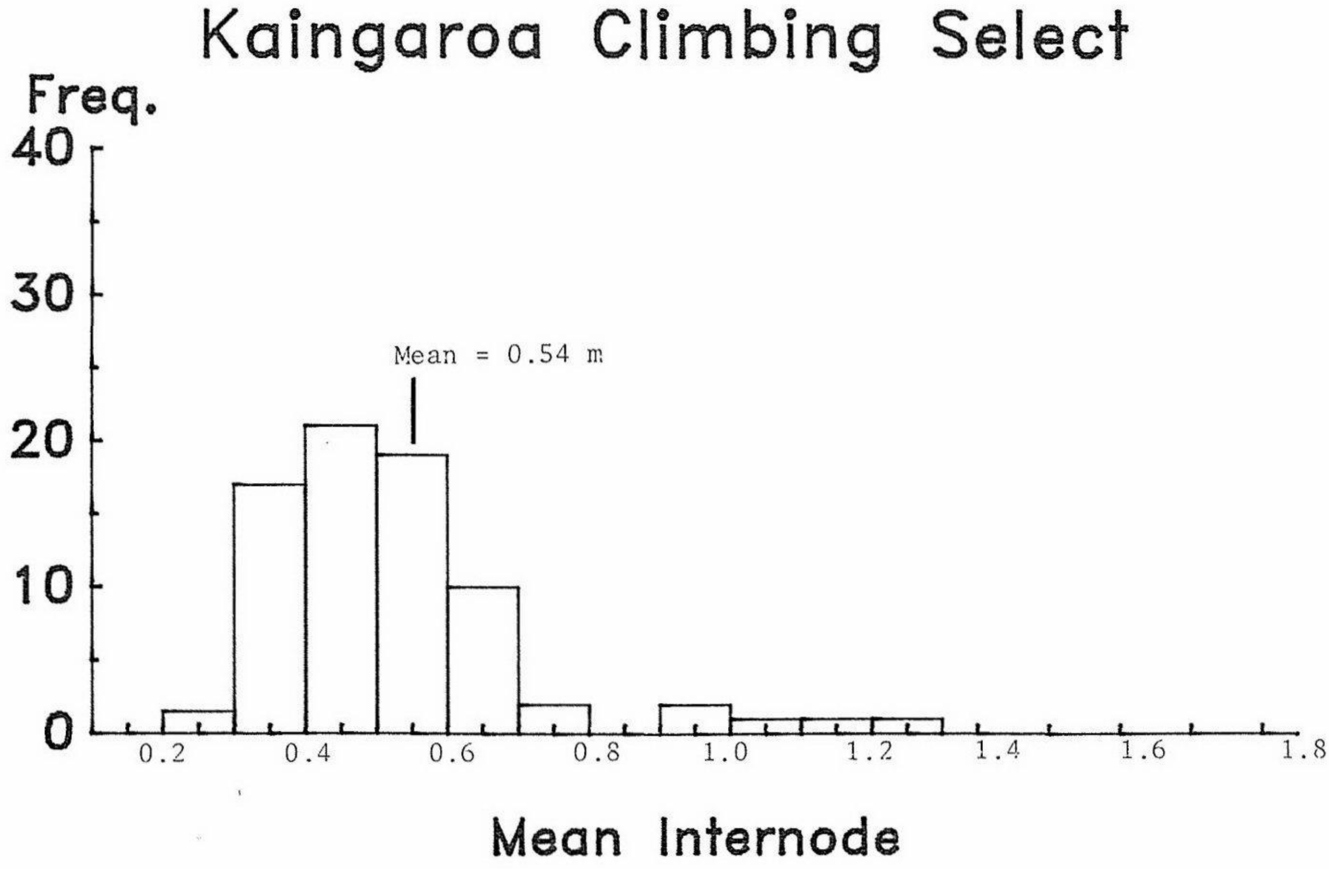
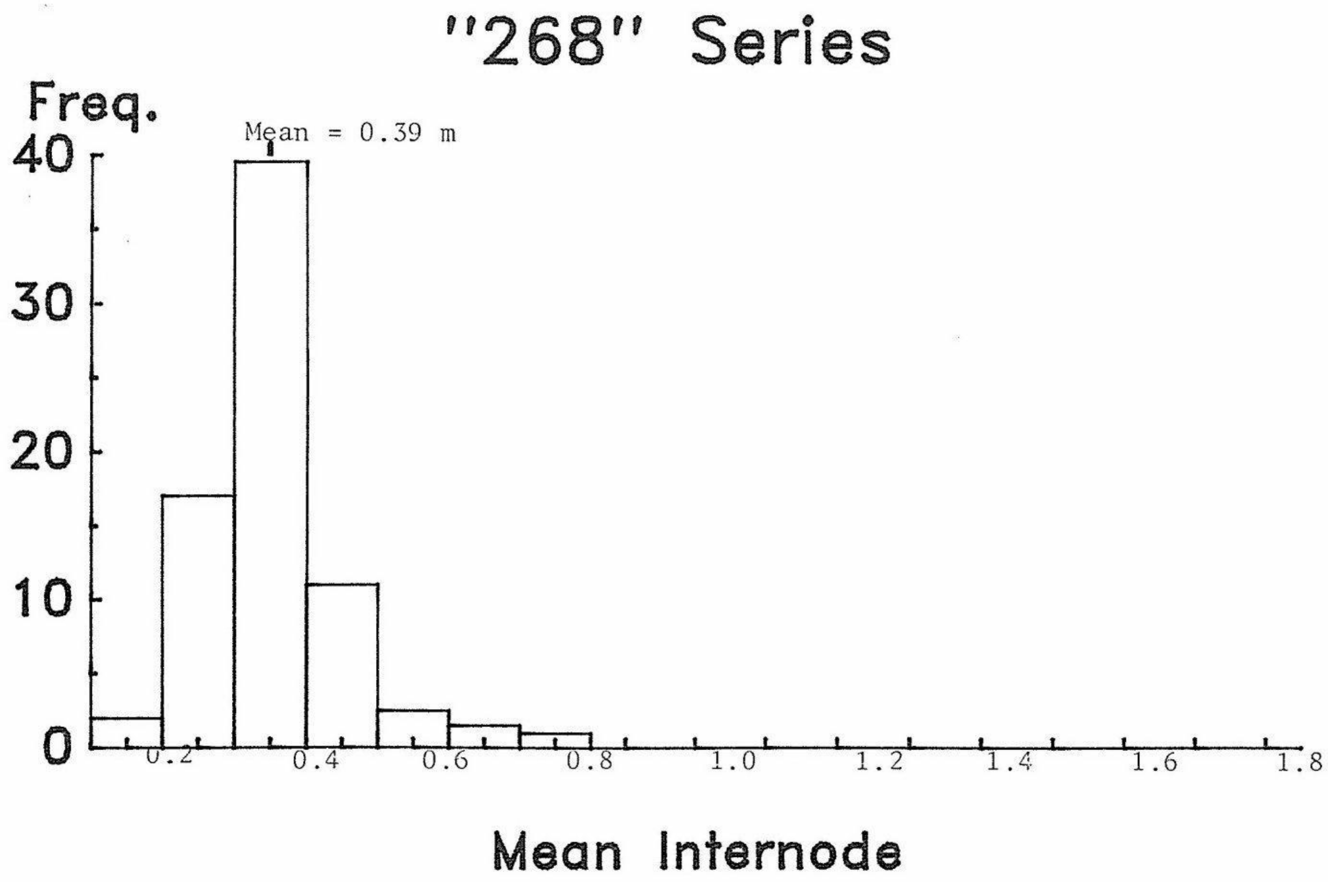
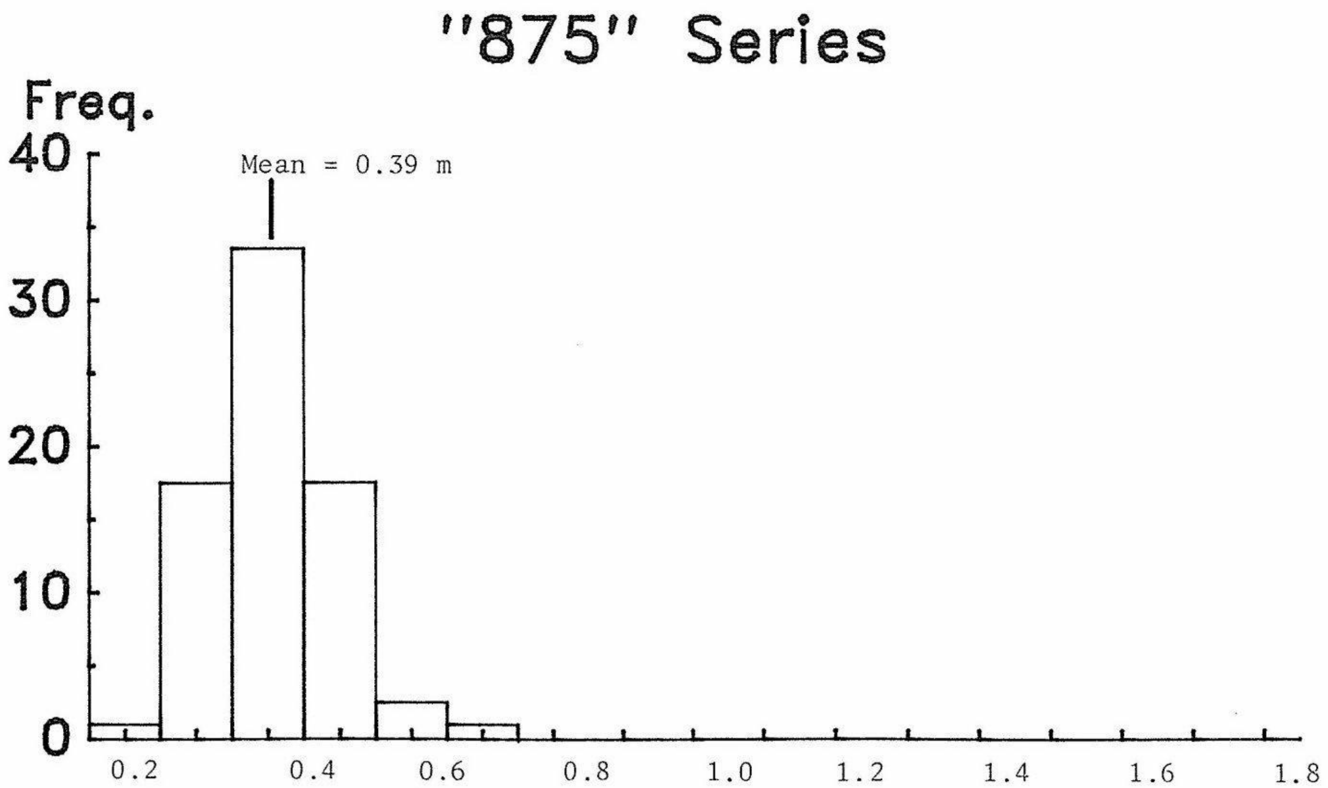

Kaingaroa Climbing Select
Freq.
40
30
20
10
0
Mean = 0.54 m
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Mean Internode

Figure 4b

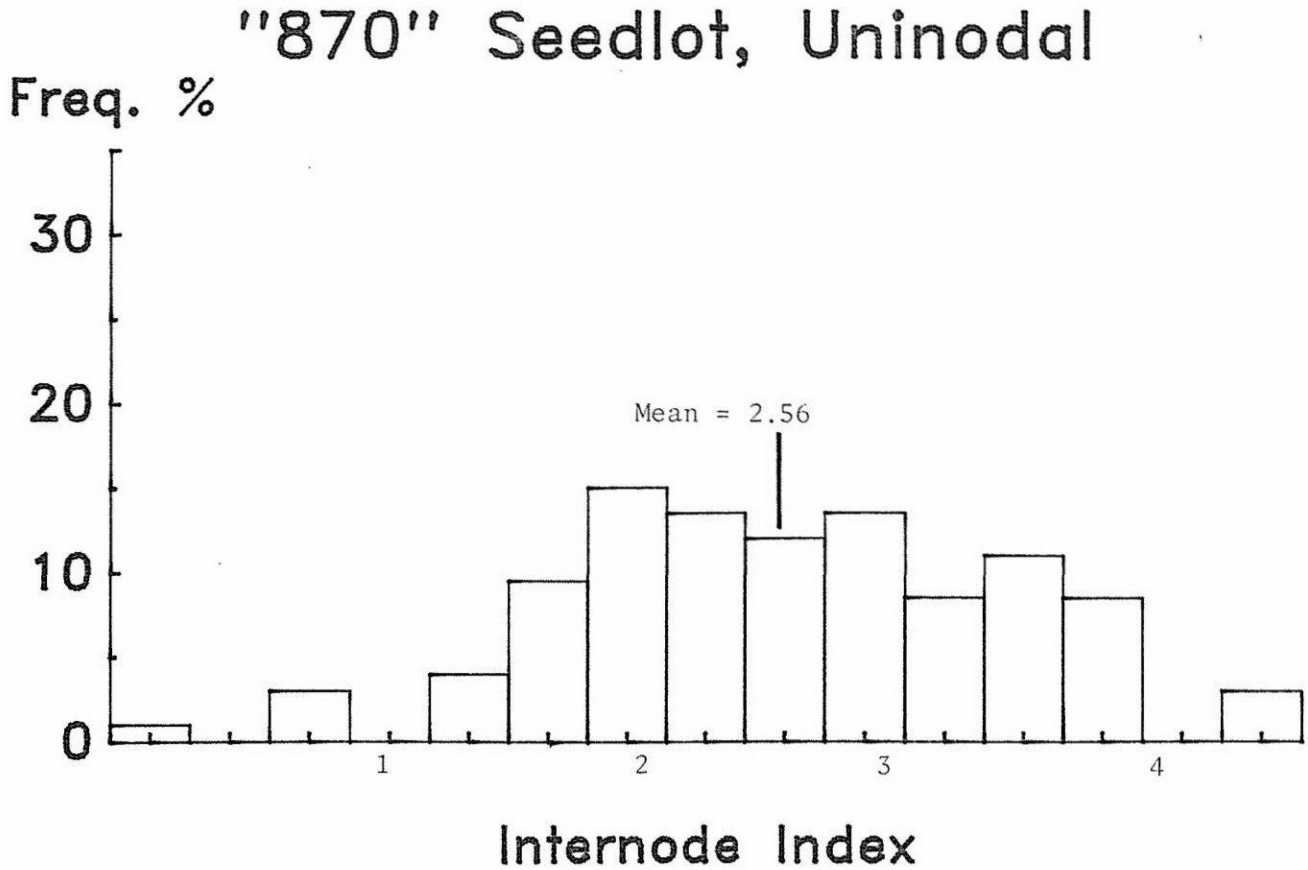


"268" Series
Freq.
Mean = 0.39 m
40
30
20
10
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Mean Internode



"875" Series
Freq.
Mean = 0.39 m
40
30
20
10
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
Mean Internode

Figure 5a


"870" Seedlot, Uninodal
Freq. %
30
20
10
0
Mean = 2.56
1
2
3
4
Internode Index

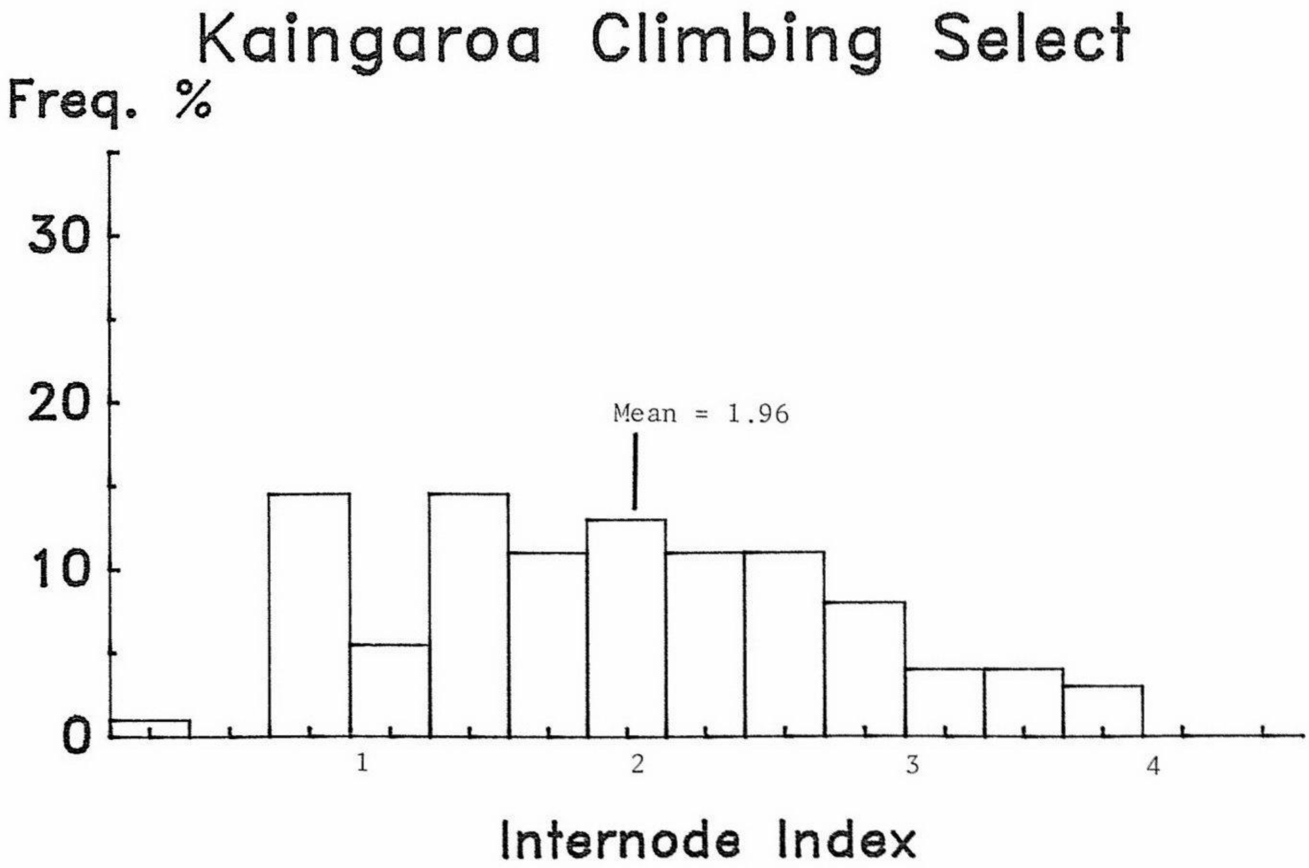
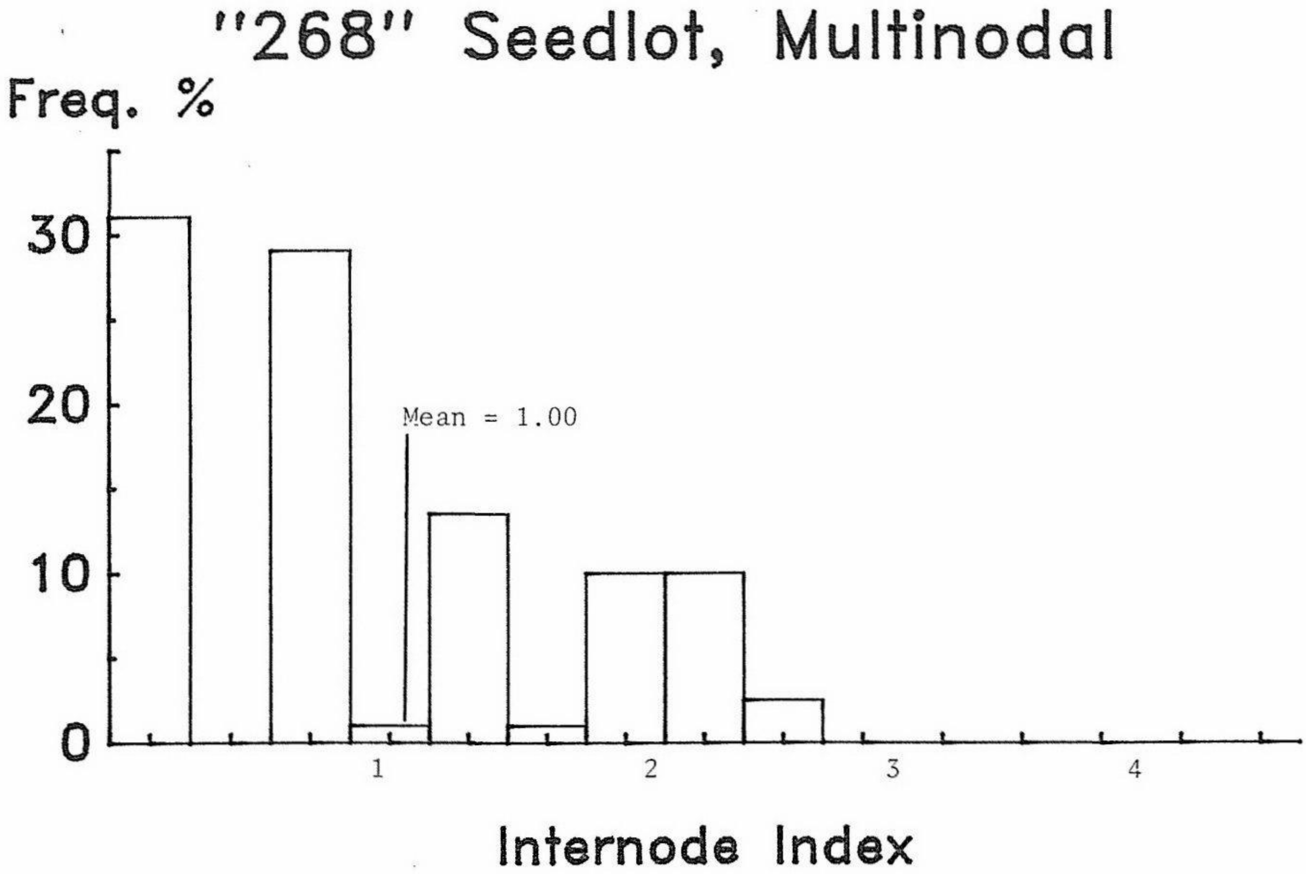

Kaingaroa Climbing Select
Freq. %
30
20
10
0
Mean = 1.96
1
2
3
4
Internode Index

Figure 5b


"268" Seedlot, Multinodal
Freq. %
30
20
10
0
Mean = 1.00
1
2
3
4
Internode Index

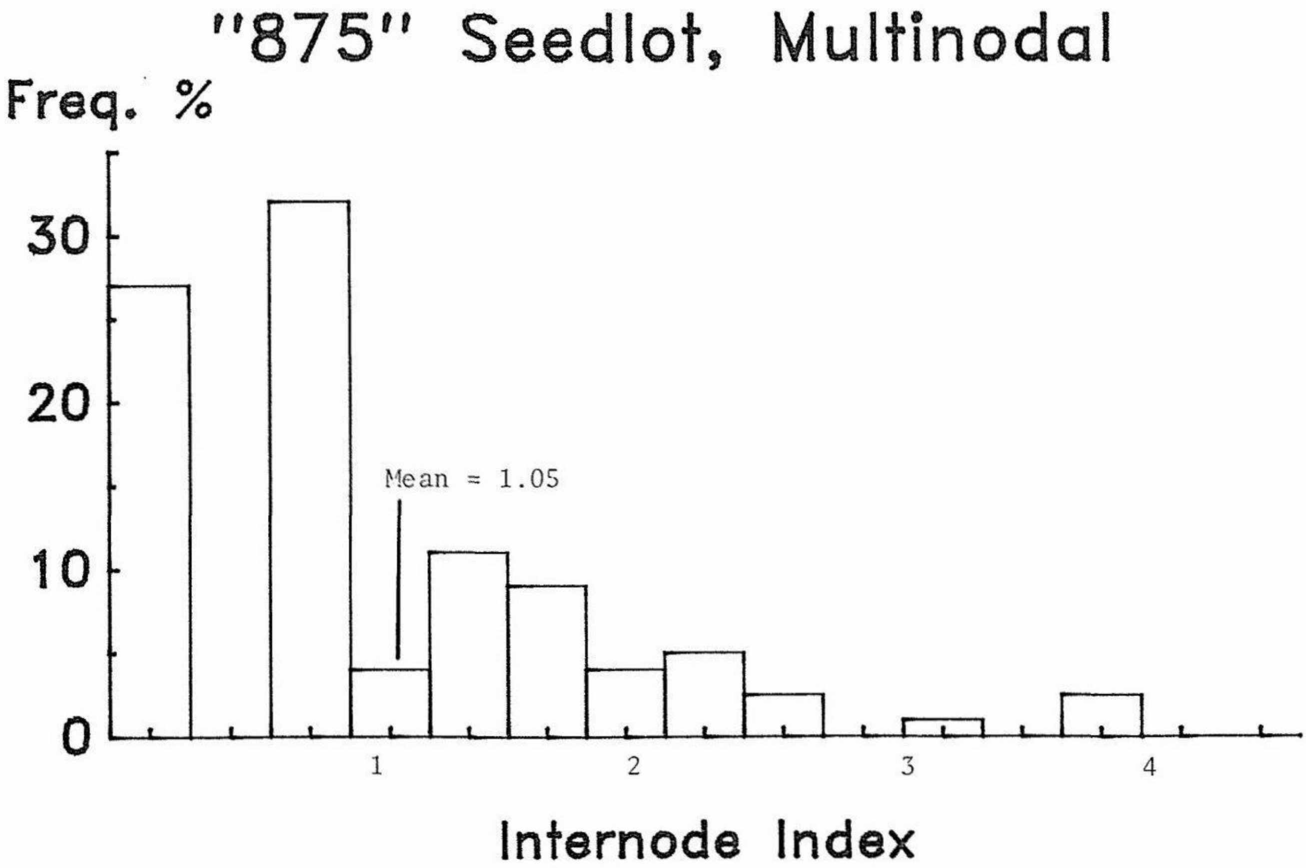
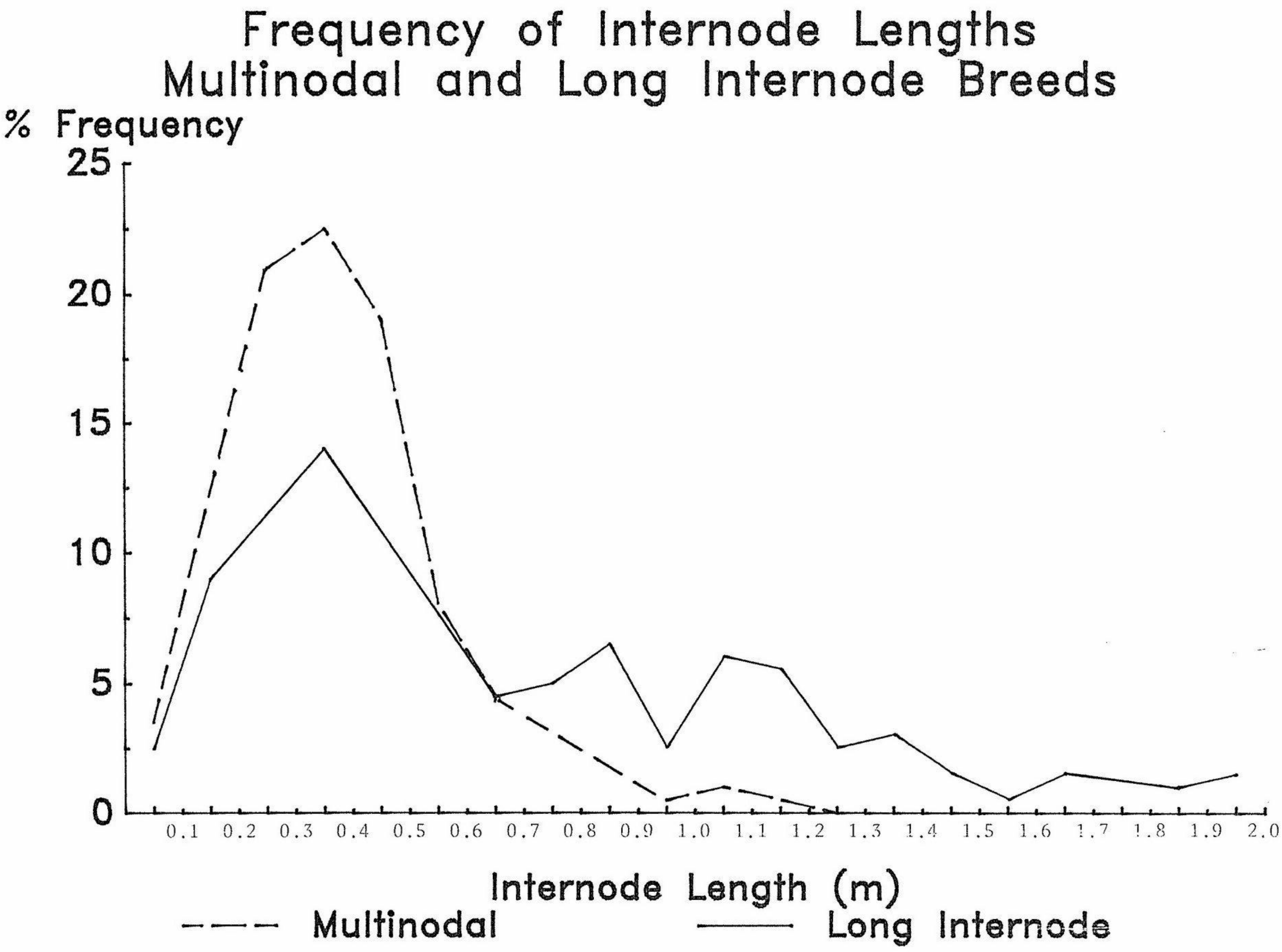

"875" Seedlot, Multinodal
Freq. %
30
20
10
0
Mean = 1.05
1
2
3
4
Internode Index

Figure 6


Frequency of Internode Lengths
Multinodal and Long Internode Breeds
% Frequency
25
20
15
10
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
Internode Length (m)
Multinodal
Long Internode