CHANGES IN *PINUS RADIATA* STEM FORM IN RESPONSE TO NITROGEN AND PHOSPHORUS FERTILISER

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ABSTRACT

The change in tree form of **Pinus radiata** D. Don after application of nitrogen and/or phosphorus fertiliser was examined through analysis of bark thickness, relative taper curves, and tree volume equations. Based on some 1300 sectionally measured trees, the results indicate that the application of phosphorus leads to thinner bark and a small improvement in form, while nitrogen alone results in a slight deterioration in form. A weak negative relationship between the change in form and the basal area response to fertiliser suggests that only when basal area response exceeds 35% will average form improve by more than 2.5%.

Keywords: stem form; fertiliser; nitrogen; phosphorus; **Pinus radiata**.

INTRODUCTION

It has been believed that part of the response to fertiliser occurs through a beneficial change in tree form (Woollons & Will 1975; Mead & Gadgil 1978). This change appeared to occur through increased diameter growth at the base of the green crown leading to a reduction in taper over the lower stem. As standard volume estimation is based largely on functions of total tree height and over-bark diameter at breast height, the addition of fertiliser could lead to bias in the volume estimate if such a form change occurred.

Evidence in the literature is conflicting and suggests that changes in form result from many complex interactions.

Whyte & Mead (1976) recorded a 12% basal area response in a 40-year-old *Pinus radiata* stand, whereas volume response ranged from 36% to 64%, depending on the method of volume calculation, thus indicating a change in stem form. However, Hunter & Hoy (1983) detected no significant effect of fertiliser on 11-year-old *P. radiata* form factor either with or without breast height diameter as a covariate. Barker (1980) found that fertiliser did not influence allocation of growth in the bole to any sustained degree when he examined 5 years' growth after fertiliser application at age 14.

In other *Pinus* species, various results have been reported. Groot *et al.* (1984) found no significant fertiliser effect on the 10-year change in form factor of *P. banksiana* Lamb., but described a number of "subtle indications" that fertiliser had improved form. Also in *P. banksiana* Camire & Bernier (1981) noted a decrease in form due to greater area growth response to fertiliser in the lower portions of the stem than in the upper. Pegg (1966) found the Girard form class significantly increased by fertiliser in *P. taeda* L., whereas in *P. nigra* subsp. *laricio* (Poir.) Maire, Miller & Cooper (1973) and Cochran (1978) found no effect of fertiliser on form factor.

Mitchell & Kellogg (1972) noted a decrease in form in dominant *Pseudotsuga menziesii* (Mirb.) Franco which had received fertiliser. Sterba (1978) found a similar result in *Picea abies* (L.) Karst., and calculated that the additional volume increment due to fertiliser was over-estimated by 50% if a standard volume function was used. Richard & Veilleux (1980) reported a small but non-significant increase in the form factor of *Abies balsamea* (L.) Miller 10 years after fertiliser application.

In order to test the hypothesis of general form change, we have based this paper on sectional measurements that have been performed on some 1300 *Pinus radiata* trees from fertiliser trials throughout New Zealand (Fig. 1).

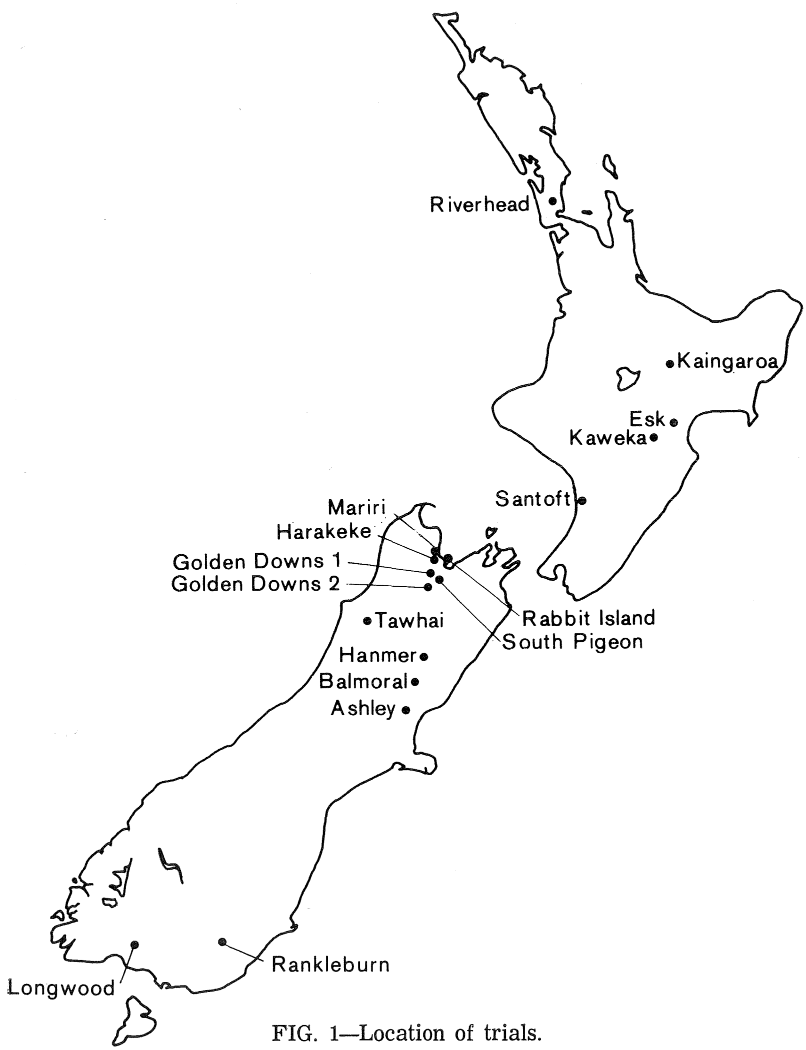

FIG. 1—Location of trials.

NOTATION

h	=	level above ground (m)
D_h	=	Over-bark diameter (cm) at level h above ground
d_h	=	Under-bark diameter (cm) at level h above ground
B	=	Double bark thickness (cm) (B = D − d)
H	=	Total tree height (m) (or total stem length when measured after felling)
V	=	Total stem volume under bark (m^3)
Vob	=	Total stem volume over bark (m^3)
PMAI	=	Periodic mean annual increment

In this paper form factor is considered to be the ratio of V to the volume of a cylinder of length H, diameter $D_{1.4}$. The size of V, for a given $D_{1.4}$ and H, determines a tree's form. Tree taper is a description of the rate of change of under-bark diameter from tree tip to ground-level relative to a reference diameter on that tree.

METHODS

The Trials

The fertiliser trials from which these data were collected were of several types – namely, nitrogen rates trials (e.g., as described by Hunter & Hoy 1983), phosphorus rates trials (e.g., as described by Hunter & Graham 1982), and nitrogen × phosphorus trials (e.g., as described by Mead & Gadgil 1978).

Each of the 18 trials contained at least two but normally four replicates in a randomised complete block design. Each fertiliser plot was at least 0.04 ha in area and contained at least 15 trees. In this investigation six distinct treatments were selected:

Without fertiliser	—	control
100 kg N/ha	—	N100
200 kg N/ha	—	N200
300 kg N/ha	—	N300
100 kg P/ha	—	P100
200 kg N/ha plus 100 kg P/ha	—	N200+P100

General information on the trials is presented in Table 1, and their growth rates are detailed in Table 2.

Sectional Measurements

Of the 18 trials considered, sectional measurements in nine were based on the taper steps of Whyte's (1971) method – that is, taper steps of 25 mm, 50 mm, or 75 mm depending on the large-end diameter (l.e.d.) of the stem. Of the remaining trials, four were measured at approximately fixed lengths, two by a taper step of 10% of the stem l.e.d., two by a taper step of 10% of the section l.e.d. (to about 100 mm diameter), and one showed no obvious pattern. All the latter methods gave a measurement intensity at least equal to and usually greater than the method of Whyte. If measurements were not done at about 0.7 m and 1.4 m, then there were at least two measurement points at less than 2.0 m. Measurements were taken at mid-internode or at least away from stem swellings.

TABLE 1—Information on trials

Trial	Age at fert. (yr)	Mean dbhob at fert. (cm)	Mean ht at fert. (m)	Growth period (yr)	No. measurement points per tree
Hanmer	8	13.0	–	4	9–20
Ashley	11	21.3	–	4	9–22
Longwood	9	9.4	–	4	5–12
Esk	9	22.6	–	4	6–10
Kaweka	9	15.8	–	4	5–9
Balmoral 1	7	8.3	6.3	4	8–14
Balmoral 2	12	17.0	10.5	4	7–18
Golden Downs 1	7	12.5	9.0	4	5–11
Golden Downs 2	8	10.4	6.8	4	5–9
South Pigeon	10	19.1	–	4	5–8
Rabbit Island	8	13.8	15.6	4	6–10
Santoft	11	16.2	12.6	5	7–12
Mariri	40	42.9	36.0	5	12–22
Tawhai	24	38.9	–	5	6–11
Harakeke	20	29.5	27.4	5	6–10
Kaingaroa	16	32.7	24.1	2	6–9
Rankleburn	8	10.3	–	4	4–8
Riverhead	6	4.2	3.3	6	4–9

TABLE 2—Periodic mean annual increment of basal area (m^2/ha/yr)

Trial	Control	N100	N200	N300	P100	N+P
Hanmer	2.65		3.00		2.47	3.47
Ashley	1.84		2.51		2.74	2.61
Longwood	3.15		3.30		3.49	4.05
Esk	3.36		3.88		3.67	3.90
Kaweka	2.70		2.44		3.00	2.68
Balmoral 1	1.90	2.19	2.25	2.26		
Balmoral 2	1.63	1.91	2.01	1.98		
Golden Downs 1	2.22	2.53	2.66	2.81		
Golden Downs 2	1.88	2.24	2.42	2.41		
South Pigeon	2.14	2.52	2.61	2.88		
Rabbit Island	3.68	3.23	3.55	3.13		
Santoft	2.08	2.57	3.20	3.27		
Mariri	1.41					1.74
Tawhai	1.01					1.92
Harakeke	1.82		2.88			
Kaingaroa	2.08		2.40			
Rankleburn	5.58		5.45			5.64
Riverhead	1.54				3.22	4.09

Usually five sample trees were chosen from each fertiliser plot to span the diameter range of the treatment, yielding around 70 trees per trial.

At each measurement point over-bark diameter and four equiangular bark thicknesses were taken. The height of each point and total stem length were also recorded.

Data validation involved computer checks that height increased and diameter decreased along the stem and that no single bark thickness was more than 2.5 times the mean bark thickness at that point.

Where diameters were required at fixed points on the stem, an interpolation routine was used. This routine returned the average of two diameter estimates, made using quadratic curves derived from two measured points above and two below the stem section of interest. Several checks ensured that the interpolated value was reasonable and fell between the two spanning measurements.

Analysis of Bark Thickness

Bark thicknesses were found (either as directly measured or interpolated) at the points on the stem 10, 20, . . . 90% of tree height on all trees. The ratio of bark thickness to over-bark diameter (B/D) was calculated at all these points on the stem of each tree.

For each trial

(a) The mean ratio (R) over all trees in each treatment was calculated for each point on the stem;

(b) The difference ($R_i - R_{control}$) was calculated for each point on the stem (for $i =$ N100, N200, N300, P100, N200+P100).

The resulting differences were analysed across the trials where corresponding treatments existed.

Analysis of Taper Curves

Trees with little taper over the lower bole show better form than those of similar size but with rapid taper over the lower bole. Taper curves can show the rate of taper in a manner that is independent of tree size, which allows groups of trees with different mean tree sizes to be compared. To test whether fertiliser leads to changes in form as a result of changes in the rate of stem taper, the following analysis was performed.

The under-bark diameter at one-fifth height ($d_{0.2H}$) was found on each tree. If not directly measured, this diameter was interpolated. $D_{1.4}$ was not used as a reference point as its relative position on the stem alters with tree height which confuses taper curve comparisons between trees of different height. One-fifth height was chosen because the taper at this point is usually changing slowly (Gray 1956) and the over-bark diameter can be measured with less error above the butt portion and below the green crown.

Under-bark rather than over-bark diameter was used at the reference point to exclude the effect fertiliser may have on bark thickness, even though the bark measurement error (Loetsch & Haller 1973) was thus introduced.

All under-bark diameters were then expressed as a ratio of $d_{0.2H}$ for every tree. The corresponding levels above ground were expressed as a proportion of tree height from the tip. Thus the sectional measurements were reduced to two variables:

$$d/d_{0.2H} \qquad \text{and} \qquad 1 - h/H$$

Taper curves were then constructed by fitting a polynomial in $(1 - h/H)$ using powers 1,2,3, and 4 to $(d/d_{0.2H})$ as the dependent variable. This polynomial was chosen as a flexible curve which could adequately model stem taper from tip to ground-level.

The data used for fitting the curves were subsets generated by selecting one observation per tree on a random basis. This process removes the effect of correlation between measurements within trees which can cause considerable under-estimates of the residual error and so over-estimates of the significance.

In each trial taper curves were fitted by least squares to the combined subset and then separately to the portion of the subset in each treatment. Analysis of variance of the residual sum of squares was then calculated as in Table 3. This general procedure tests whether there is a significant reduction in residual variation of $(d/d_{0.2H})$ when separate curves are fitted for each treatment, compared with a single curve.

TABLE 3—Analysis of variance of residual sum of squares for South Pigeon trial (total Df = 72; total SS = 60.1016)

Source	Residual SS	Df	Mean Square	F	Approx. prob.
Single curve	0.1799	68	0.002646		
Treatment curves	0.1136	56	0.002029		
Difference	0.0663	12	0.005528	2.73	0.006

$$\text{where } F = \frac{\text{Difference mean square}}{\text{Treatment curves mean square}}$$

For those trials where significantly different taper curves were found the fitting procedure was repeated using all the data. This re-fitting was performed to obtain more accurate coefficient estimates (coefficient estimates are not affected by the measurement correlation within trees). The resulting taper curves were plotted for graphical interpretation.

Analysis of Sectional Volumes

Volume equations are normally derived by relating tree volume to efficiently measured tree variables such as $D_{1.4}$ and H. Tree volume is usually determined by sectionally measuring the stem and summing the volumes of the sections. To compare volume and tree form (derived from sectional measurements) between treatments on a practical basis, the following steps were taken.

Total stem volumes under-bark were calculated from the sectional measurements. Sections below breast-height were assumed to approximate truncated cones. Those between breast-height and the last measured diameter were assumed to approximate truncated paraboloids (Smalian's formula), while the volume of the tip of the stem was calculated as a cone.

For each trial a volume equation was fitted using only those trees from control (no fertiliser) plots. The form of the equation was:

$$\hat{V} = b1 \ (D_{1.4})^{b2} \left\{ \frac{H^2}{H - 1.4} \right\}^{b3} \qquad (1)$$

Fitting was accomplished using logarithmic transformations and adjusting the coefficient b1 for bias (Finney 1941). Equation (1) is a form of the current N.Z. Forest Service standard equation for estimating total volume of coniferous stems.

Estimates of stem volume were then calculated (from $D_{1.4}$ and H) for all non-control trees in each trial using the equation derived from the control trees. Checks were made to ensure that any non-control trees which fell more than 10% outside the $D_{1.4}$ range of the volume equation were excluded from the analysis at this point. Although less than two trees per trial, on average, were excluded (30% too small, 70% too large), without this trap a control-based volume equation may have been extrapolated beyond reasonable limits.

Finally, the percentage bias in the total volume estimate was calculated for every treatment in every trial. This value is defined as

$$\text{BIAS} = 100 \left\{ 1 - \frac{\sum^{m} \text{Sectional Stem Volume}}{\sum^{m} \text{Estimated Stem Volume}} \right\}$$

(where m = number of trees)

and indicates improved (negative values) or degraded (positive values) tree form relative to the control.

The percentage bias values were then plotted against the percentage response in basal area periodic mean annual increment (PMAI), and the age at time of fertiliser application, in an attempt to relate the change in form to the response to fertiliser or stand age.

RESULTS

Bark Thicknesses Analysis

Both the N200+P100 (Fig. 2) and the P100 treatments showed very similar results, with a fairly consistent decrease of approximately 0.007 in the mean bark ratios at all points on the stem. In contrast the N100, N200, and N300 treatments showed little pattern (on average the bark ratios increased slightly in the upper 60% of the stem) and none of the mean differences approached significance.

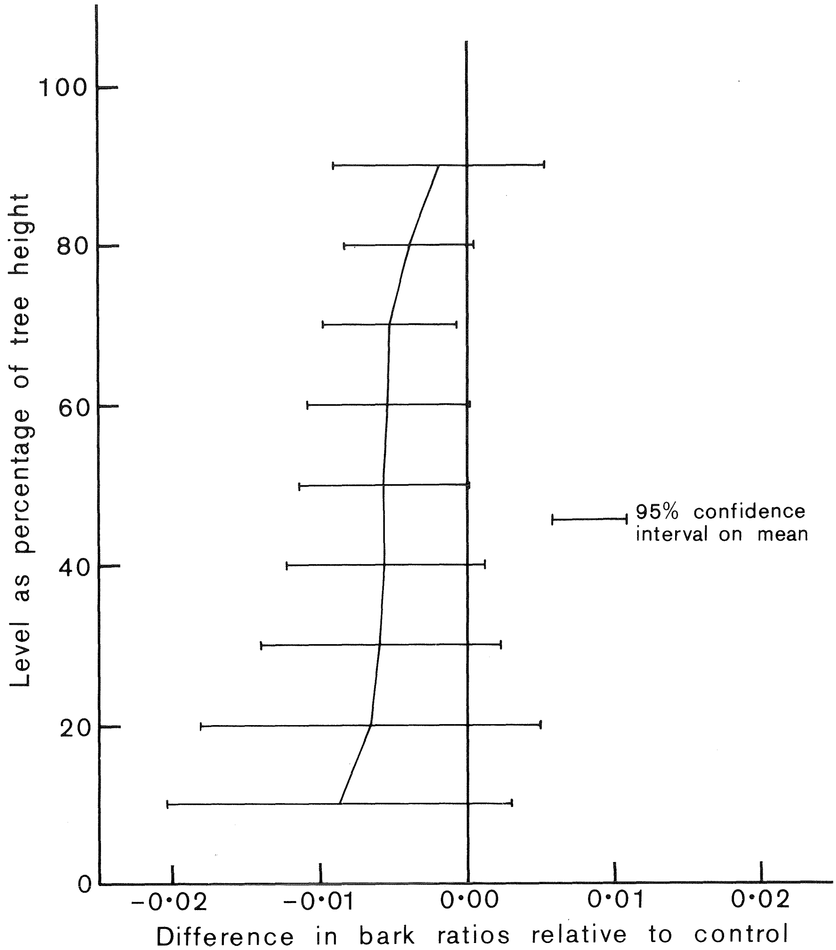

FIG. 2—Mean difference in bark ratios over the nine N200+P100 treatments. (The mean values at each point are connected.)

Taper Curve Analysis

Only two of the 18 trials emerged with significantly ($p < 0.05$) different taper curves by treatment. These were Ashley and South Pigeon with F ratios of 2.14 and 2.73, degrees of freedom of 12,64 and 12,56, and probabilities of 0.03 and 0.006 respectively. The plotted taper curves for South Pigeon are shown in Fig. 3.

Sectional Volume Analysis

All 18 volume equations fitted to control trees were highly significant, the percentage variance of ln(V) accounted for averaging over 97%. Detailed plots of residuals were made for all trials where less than 96% of the variance was accounted for. These checks revealed no error trends or outliers and the volume equations were used unaltered.

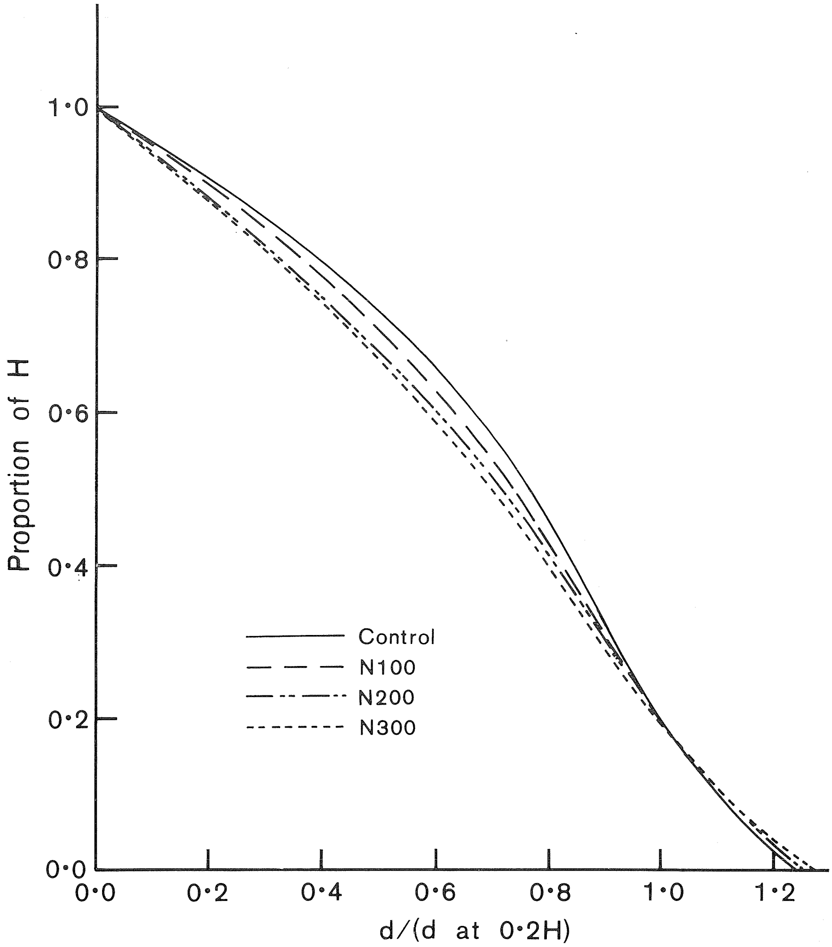

FIG. 3—Treatment taper curves at South Pigeon.

The percentage bias values are presented in Table 4. Analysis of percentage bias values, in relation to percentage response in basal area PMAI, revealed a significant but weak linear relationship (Fig. 4). The same trend was observed on each of the fertiliser treatments when analysed separately – that is, the over-estimate of volume decreased and became an under-estimate (improvement in form) with increasing basal area PMAI response. This is similar to the trend observed in the older Nelson trial results presented by Mead & Gadgil (1978).

No relationship was found between percentage bias and age at time of fertiliser application.

TABLE 4—Percentage bias in total volume estimate by control-based volume equation

Trial	Treatment					
	Control	N100	N200	N300	P100	N200+P100
Hanmer	-0.02		3.10		1.14	-0.34
Ashley	0.08		-0.23		-1.66	-2.40
Longwood	-0.42		3.18		0.74	0.11
Esk	0.03		1.58		0.32	-1.39
Kaweka	0.05		2.23		-2.16	-0.43
Balmoral 1	0.03	0.34	0.58	1.10		
Balmoral 2	-0.04	0.64	-4.68	-3.97		
Golden Downs 1	0.00	4.29	0.87	4.38		
Golden Downs 2	0.09	2.08	-4.45	-1.60		
South Pigeon	-0.01	-4.73	-1.19	1.60		
Rabbit Island	-0.01	3.05	6.21	1.56		
Santoft	-0.42	5.74	-0.04	-3.37		
Mariri	-0.58					-5.59
Tawhai	-0.04					-2.31
Harakeke	-0.19		3.15			
Kaingaroa	0.16		-0.21			
Rankleburn	0.17		0.94			-1.80
Riverhead	0.01				-10.93	-13.29

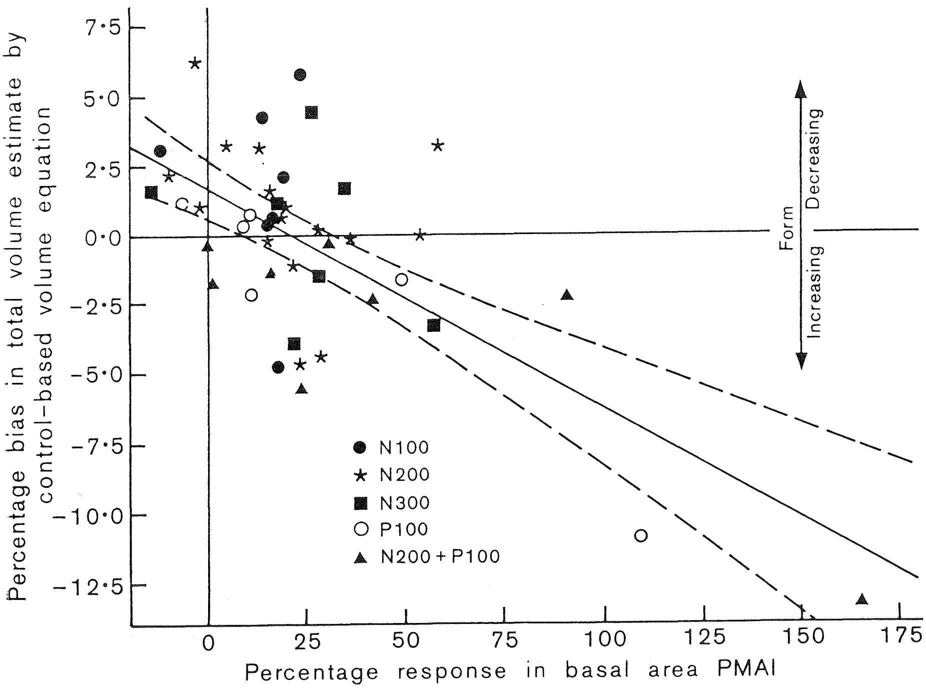

FIG. 4—Change in form with fertiliser response. (Broken lines show 95% confidence limits on the mean bias in total volume estimate.)

DISCUSSION

Bark Thickness

Assuming a constant bark ratio (R = B/D) at all points on the stem, volume under bark can be expressed as a proportion of volume over bark –

$$V/Vob = (1 - R)^2$$

An average value for *P. radiata* of R = 0.074 (Gordon 1983) implies a proportion of 85.7%. If R decreased by 0.007, as indicated by the P100 and N200+P100 treatments (Fig. 2), the proportion would rise to 87.0%, an increase of 1.3%.

The median bias values of the control-based volume equation when applied to the P100 and N200+P100 treatments were –0.67% and –1.80% respectively (Fig. 5, Table 4). These under-estimates are in reasonable agreement with the increase in actual under-bark volume expected from a 0.007 drop in average bark ratio relative to the control. This suggests that the improvement in form in the P100 and N200+P100 treatments, indicated by the sectional volume analysis, can be partially attributed to the change in bark ratio.

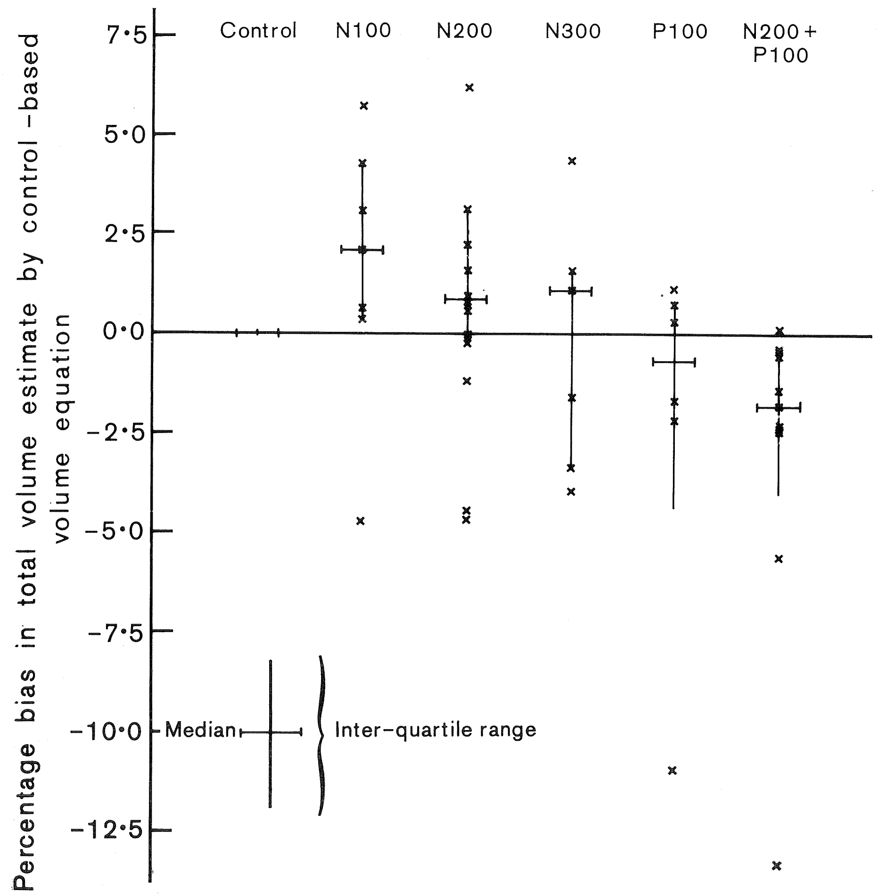

FIG. 5—Distribution of form change within treatments.

Taper Curves

The results of the taper curve analysis imply that there is little measurable difference in tree taper induced by fertiliser treatment with nitrogen and/or phosphorus. However, the method used has certain limitations. By randomly selecting one measurement from each tree in order to remove the within-tree correlation between measurements, further sampling error is introduced. The resulting drop in sample size (by a factor of 8 to 10 times) increases the probability that the null hypothesis (a single taper curve describes all treatments in any trial) is accepted in error.

The taper curves for South Pigeon (Fig. 3) indicate increasing taper in the lower stem with increasing level of nitrogen fertiliser. The same progression within this trial is evidenced in Table 4, which shows an improvement in form diminishing, then a decrease in form, with increasing level of nitrogen fertiliser.

Sectional Volume Analysis

Volume equation bias

The distribution of the percentage bias in the control-based volume equation estimates from the sectional volume analysis is shown in Fig. 5. The median and the inter-quartile range are marked for each treatment. Positive values represent over-estimates by the control-based volume equation and imply a decrease in volume (V) for a given $D_{1.4}$ and H pair. Negative values imply an improvement in form.

It is noteworthy that all three N-alone treatments tended to result in a degradation of stem form, while P-alone produced little change, and the nutrients in combination tended to improve form. However, all changes were small, the majority being within $\pm$ 3% bias, with considerable variation.

The phosphorus rates trial at Riverhead is an extreme example, the control representing growth under marked nutrient deficiency. The results of this trial are obvious in both treatments containing phosphorus (Table 4, Fig. 4 and 5). The large improvement in form is partially due to a drop in the bark ratio in the P100 and N200+P100 treatments, representing approximately 4% increase in volume. However, the very small tree size and the large response to fertiliser (around 140% in basal area PMAI) make this trial atypical.

To interpret Fig. 5 clearly it should be noted that Equation (1) can be rearranged to predict form factor as a function of $D_{1.4}$ and H. Thus the control-based volume equations estimated the form of treated trees as equivalent to an untreated tree of the same $D_{1.4}$ and H. As $D_{1.4}$ increment increases in response to nitrogen and phosphorus fertiliser and H in response to phosphorus (H response to nitrogen is not often detected – Woollons & Will 1975) the comparable untreated tree (same $D_{1.4}$ and H) will represent a higher element in the dominance hierarchy of the stand. With N-alone treatment the comparable trees will be those with higher total taper ($D_{1.4}$/H) than the average.

So the trend to positive volume estimate bias in response to N-alone fertiliser (Fig. 5) means that these trees with fertiliser tend to have poorer form than untreated ones of the same $D_{1.4}$ and H which are higher in the dominance hierarchy and have higher total taper. As form usually decreases with increasing $D_{1.4}$ and increasing total taper (Larson 1963), the values in Table 4 will tend to be conservative estimates. In other words, a control-based volume equation derived from data which included older trees of similar mean size to the nitrogen-treated trees may give slightly larger over-estimates of volume than those in Table 4.

The combined N200+P100 treatment appears to have the opposite effect as trees with this treatment tended to show better form than untreated trees of the same $D_{1.4}$ and H. The drop in bark ratio, mentioned above, may be one cause for this improvement.

Relationship to basal area response

The trend observed between the bias in control-based volume equation estimate and basal area PMAI response (Fig. 4) can be partially interpreted for large basal area responses. If fertiliser treatment is considered as a simple acceleration of tree growth and there is a concomitant large increase in crown size (Barker 1978), site occupancy will increase. A decrease in relative crown length is commonly observed with increasing site occupancy and this is invariably associated with a decrease in taper (Larson 1963) which is an improvement in form.

CONCLUSION

The application of phosphorus tends to decrease the bark ratio (B/D) and so leads to a small (of the order of 1%) improvement in form – that is, larger V relative to $D_{1.4}$ and H.

Where fertiliser has a pronounced effect on basal area growth, form change is to be expected and should be quantified.

If the response to nitrogen and/or phosphorus fertiliser is less than 35% in basal area PMAI, the absolute error in a volume estimate, by an equation derived from untreated trees, will probably average less than 2.5%. It is unlikely that the cost of adjusting for errors of this size by intensive measurement of changes in tree form can be justified.

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REFERENCES

BARKER, J. E. 1978: Some silvicultural effects of fertilisation. **New Zealand Journal of Forestry Science 8:** 160–77.

——— 1980: Bole growth patterns of **Pinus radiata** D. Don in relation to fertilisation, bending stress, and crown growth. **New Zealand Journal of Forestry Science 10:** 445–53.

CAMIRE, C.; BERNIER, B. 1981: Fertilisation azotée en forêt de pin gris (**Pinus banksiana**). III. Croissance du pin gris. **Canadian Journal of Forest Research 11:** 432–40.

COCHRAN, P. H. 1978: Response of a pole-size Ponderosa pine stand to nitrogen, phosphorus, and sulfur. **U.S. Department of Agriculture, Forest Service, Research Note PNW-319.**

FINNEY, D. J. 1941: On the distribution of a variate whose logarithm is normally distributed. **Journal of the Royal Statistical Society (supplement) 7:** 155–61.

GORDON, A. 1983: Estimating bark thickness of **Pinus radiata. New Zealand Journal of Forestry Science 13:** 340–53.

GRAY, H. R. 1956: The form and taper of forest-tree stems. **Imperial Forestry Institute, University of Oxford, Paper Number 32.**

GROOT, A.; BROWN, K. M.; MORRISON, I. K.; BARKER, J. E. 1984: A 10-year tree and stand response of jack pine to urea fertilization and low thinning. **Canadian Journal of Forest Research 14:** 44–50.

HUNTER, I. R.; GRAHAM, J. D. 1982: Growth response of phosphorus-deficient **Pinus radiata** to various rates of superphosphate fertiliser. **New Zealand Journal of Forestry Science 12:** 49–61.

HUNTER, I. R.; HOY, G. F. 1983: Growth and nutrition of **Pinus radiata** on a recent coastal sand as affected by nitrogen fertiliser. **New Zealand Journal of Forestry Science 13:** 3–13.

LARSON, PHILIP R. 1963: Stem form development of forest trees. **Forest Science – Monograph 5.**

LOETSCH, F.; HALLER, K. E. 1973: "Forest Inventory". BLV Verlagsgesellschaft, München.

MEAD, D. J.; GADGIL, R. L. 1978: Fertiliser use in established radiata pine stands in New Zealand. **New Zealand Journal of Forestry Science 8:** 105–34.

MILLER, H. G.; COOPER, J. M. 1973: Changes in amount and distribution of stem growth in pole-stage Corsican pine following application of nitrogen fertiliser. **Forestry 46:** 173–90.

MITCHELL, K. J.; KELLOGG, R. M. 1972: Distribution of area increment over the bole of fertilized Douglas-fir. **Canadian Journal of Forest Research 2:** 95–7.

PEGG, R. E. 1966: Stem form of fertilized loblolly pine. **Journal of Forestry 64:** 19–20.

RICHARD, Yvon; VEILLEUX, Jean-Marc 1980: Effets de la fertilisation sur la forme du tronc du Sapin Baumier en Gaspesie. **Gouvernement du Quebec, Ministère de l'Energie et des Ressources, Service de la Recherche Forestière, Note 12.**

STERBA, H. Von 1978: Methodische Erfahrungen bei Einzelstammdungungsversuchen. **Allgemeine Forst- und Jagdzeitung 149:** 35–40.

WHYTE, A. G. D. 1971: Sectional measurement of trees: a rationalised method. **New Zealand Journal of Forestry Science 1:** 74–9.

WHYTE, A. G. D.; MEAD, D. J. 1976: Quantifying responses to fertiliser in the growth of radiata pine. **New Zealand Journal of Forestry Science 6:** 431–42.

WOOLLONS, R. C.; WILL, G. M. 1975: Increasing growth in high production radiata pine stands by nitrogen fertilisers. **New Zealand Journal of Forestry 20:** 243–53.