

SOME SILVICULTURAL EFFECTS OF FERTILISATION

J. E. BARKER

School of Forestry, University of Canterbury, Christchurch

ABSTRACT

Several silvicultural aspects of forest fertilisation other than volume responses, are reviewed with respect to the present New Zealand situation.

Fertilisation to increase flowering in New Zealand seed orchards has not been successful. However, continued use at reduced levels may be justified in terms of orchard health and vigour.

Substantial increases in tree form factor can occur in *Pinus radiata* following N fertilisation and thinning. These increases are correlated with crown growth pattern.

Increased crown growth rates in fertilised, thinned stands suggest optimal thinning regimes will be different for fertilised stands.

Fertilisation at establishment increases the probability of frost damage.

Weed control should accompany fertilisation at establishment for best, most reliable, results.

Wood density is generally reduced by fertilisation but is more than compensated for by increased volume growth. Density reductions measured at 1.4 m may overestimate the importance of such reductions.

Fertilisation has been shown to influence susceptibility to insects and disease in several overseas countries. In New Zealand, such effects have not been demonstrated.

INTRODUCTION

The application of fertilisers to a forest crop not only results in increased yields of wood but also causes numerous other changes which may be of considerable silvicultural and economic importance. It is the purpose of this paper to review several of these other effects emphasising, when possible, the situation existing in New Zealand and the implications for intensive silvicultural practices.

PRODUCTION OF SEED

In order to obtain maximum benefit from intensive silviculture, it is desirable to use improved genetic strains. If this goal is to be realised, then production of *Pinus radiata* seed from New Zealand seed orchards must be increased drastically to meet a 2000 kg/yr shortfall in supply predicted for 1980 (Anon, 1974). Intensive seed orchard cultural treatments such as fertilisation, ripping, irrigation and thinning offer means of increasing production.

Improved seed yields from intensive culture have been reported for the southern pines (Kellison, 1974; Shoulders, 1968; Schmidtling, 1973) and for Douglas fir (Ebell, 1972; Griffith, 1968). Such responses have yet to be demonstrated for *P. radiata* in New Zealand (Sweet and Hong, 1978).

The complexity of the flowering process makes it unlikely that fertilisation alone will prove successful in stimulating seed yields. Trees having no past history of seed production do not appear to respond to cultural treatments such as fertilisation (Griffith, 1968; Barnes and Bengtson, 1968; Ebell, 1972) as do trees which have produced seed previously. However, Pharis (1976) suggests that application of large, continuing dosages of gibberellins in conjunction with cultivation and fertilisation can be expected to stimulate non-productive trees to flower.

It is likely that stimulatory treatments must be applied with careful regard to the stage of tree development and the form of fertiliser used. For instance, Ebell (1972; 1972a) has shown that application of nitrate fertiliser just prior to vegetative bud burst is far more effective in stimulating a flowering response in Douglas fir than use of urea, or even nitrate applied at a different time. Timing of imposition of water stress is an important factor in stimulating flowering (Matthews, 1963) with best results appearing when the stress coincides with the time of flower initiation.

Consistent responses to large applications of various forms of N applied at different times have not been obtained, so that these practices are being scaled down in *P. radiata* seed orchards (Sweet, pers. comm.) in New Zealand. Continued fertilisation on a less-intensive scale could be justified however, in maintaining healthy, vigorous clones with large crowns capable of bearing large seed crops, perhaps in response to other stimulating treatments.

ESTABLISHMENT PRACTICE

At establishment fertiliser may have a favourable effect on survival and growth, but maximum benefit is likely to result when it is applied in conjunction with other cultural treatments (Ballard and Mead, 1976; N.Z.F.P., 1974; Sutton, 1975; Waring, 1973; Will, 1970a).

Seedling Growth and Survival

Applications of N fertilisers either before lifting in the nursery (Benzian *et al.*, 1974) or at time of planting (Brunsdon, 1976; Malcolm and Freezaillah, 1975) have been associated with increased amounts of frost damage. Alden and Hermann (1971) suggest that such increased damage occurs because N fertilisation extends the period of active growth further into the cold season increasing the probability of frost occurring before hardiness has fully developed. Christersson (1975) has shown that fertilisation may not influence the degree of hardiness developed, since his fertilised and control Norway spruce suffered similar damage after undergoing similar hardening regimes.

Fertilisation at planting may stimulate growth of competing weeds to such an extent that tree growth and survival are poor. This may be of particular importance if moisture is limited. Control of competition by use of herbicide, large planting stock or intensive cultivation generally results in a synergistic response to fertiliser by the trees (Sutton, 1975; Waring, 1973; Will, 1970a). According to Waring (1970) such responses are of great importance to the subsequent stand development since growth advantages tend to be compounded, at least up to crown closure.

Seedlings of *P. radiata* have been shown to produce disproportionately large tops under high N supply (Will, 1974a; Knight, 1973) in common with many agricultural crops (Black, 1968). In addition, where fertiliser is applied in a localised dose such as in a spade slit, particularly on deficient soils, localised root proliferation in this zone

may result at the expense of development in other parts of the root system (Coutts and Philipson, 1976). Either one or both of these factors could be expected to reduce wind stability and increase the amount of toppling. Ballard and Mead (1976) report that wind damage was increased in an NP uniform establishment trial with *P. radiata* on deficient soils in the Auckland area. In a 6-year-old trial with *P. radiata* near Pigeon Valley, Nelson, fertilised trees on one block have been observed to be more severely damaged by wind than controls (D. J. Mead, pers. comm.).

THINNING

Thinning acts to redistribute the growth potential of a site on to selected stems and, in addition, leads to a redistribution of growth within individual trees. Recent evidence shows that nitrogen fertilisation, when accompanying thinning, can influence both of these redistribution processes (Woollons and Will, 1975; Whyte and Mead, 1976).

Change in Form

The response to fertilisation accompanied by thinning may result in a change of tree form in some cases, yet not in others. Gessel *et al.* (1969) report no change in tree form following N fertilisation and light thinning of Douglas fir. However, Flewelling and Yang (1976) concluded that the volume estimation techniques used were probably not sufficiently sensitive to detect the changes that their later analyses suggest occurred. Mitchell and Kellogg (1972) found that N fertilisation (but no thinning) caused rather complex changes in the form of Douglas fir, and that the changes appeared to vary with the social class of the tree. Dominant, and to a lesser extent codominant, trees, showed reduced cross-sectional increment in the mid-bole region but had increased increment in the lower and mid- to upper-crown regions relative to controls. Brix and Ebell (1969) found that fertilised Douglas fir had relatively lower radial increment in the upper parts of the bole than at or below 1.4 m as compared with controls. Miller and Cooper (1973) investigating an N fertilised 36-year-old *Pinus nigra* stand, found no change in form factor following addition of up to 504 kg/ha year of ammonium sulphate for 3 years followed by a thinning removing 25 percent of basal area. A slight change in taper was noted which suggested some redistribution occurred.

In these experiments a height growth response accompanied the fertilisation. In New Zealand, *P. radiata*, when fertilised with N and thinned, shows no such response in height growth despite substantial volume responses. Where such responses occur, a marked change in form factor can be expected (Woollons and Will, 1975). An analysis of two comparably-aged N trials in *P. radiata* in New Zealand, one near Tokoroa (N.Z. Forest Products Limited, Owen Road trial) in the central North Island and the other at Harakeke (N.Z.F.S. trial N191, Mead, 1976) near Nelson in the South Island shows that the amount of change in form factor resulting from fertilisation is in a direction opposite to that caused by thinning and depends upon the competitive situation existing prior to and at the time of treatment. Prior to treatment (14 years old, 210 to 240 kg/ha N, thinned to approximately 500 stems/ha although Harakeke was variable in this respect) form factor was declining at Harakeke (Fig. 1) indicating low between-tree crown competition relative to the Tokoroa situation where tree form factor was increasing (Fig. 2). At Tokoroa, fertilisation offset the effect of thinning on form factor. That is, a reduction in form factor due to thinning was not evident in the fertilised

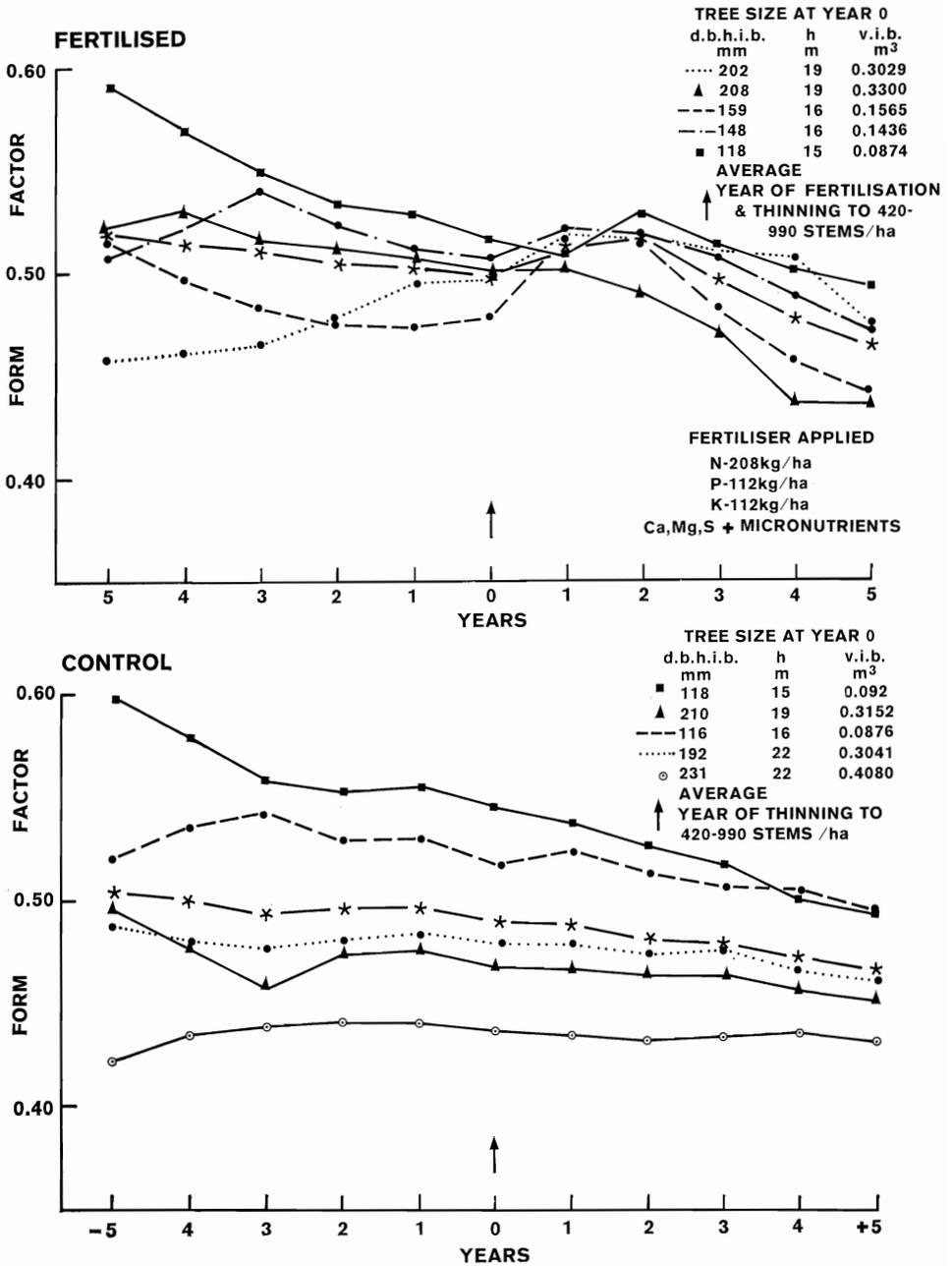


FIG. 1—Effect of fertilisation on form factor: *Pinus radiata*, 14 years old at fertilisation, at Harakeke, Nelson.

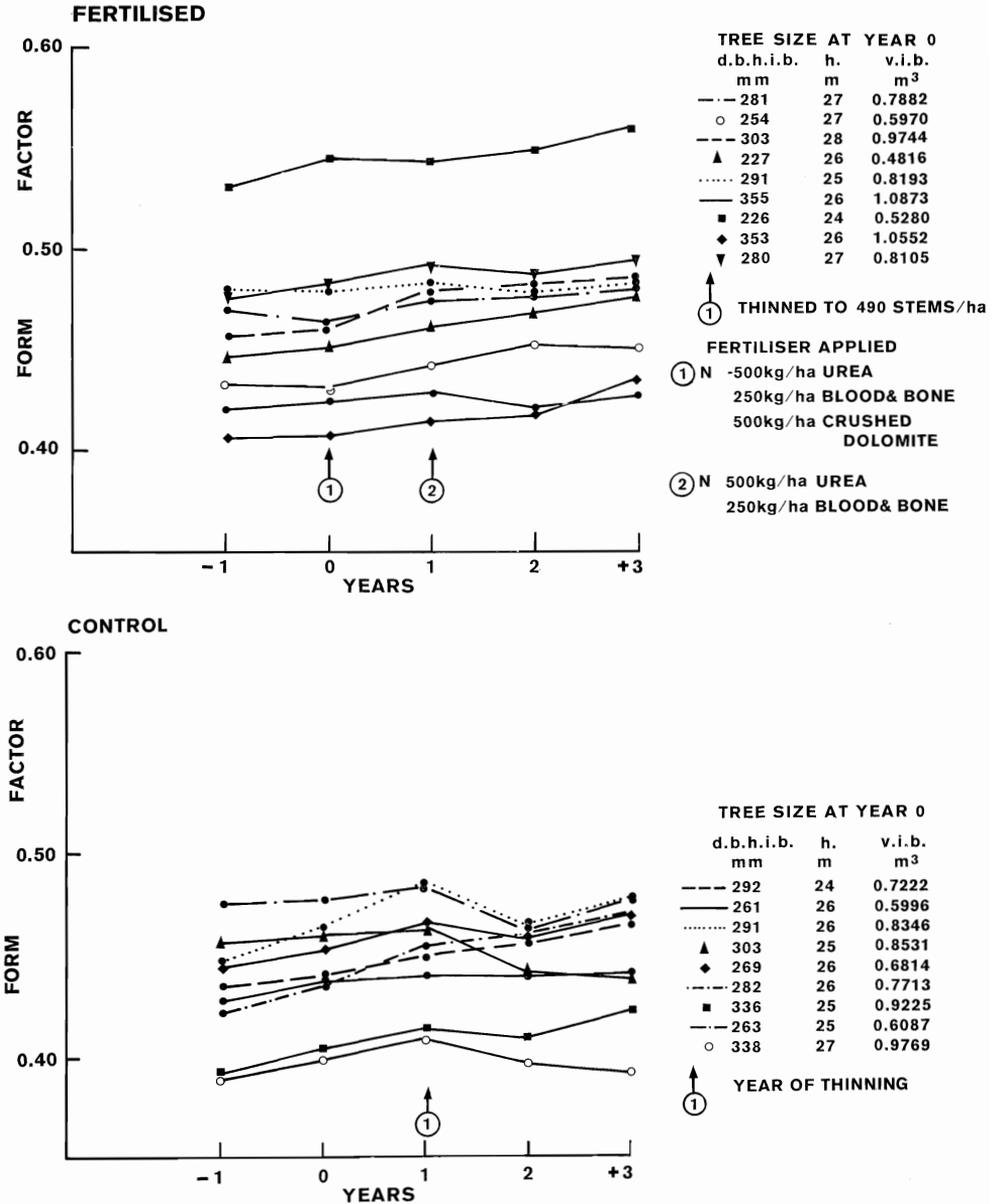


FIG. 2—Effect of fertilisation on form factor: *Pinus radiata*, 14 years old at fertilisation, at Owen Road, Tokoroa. Control stand was thinned at year 0, not year 1 as indicated.

trees but did appear in the controls. However, at Harakeke, thinning had no noticeable effect on the controls but fertilisation markedly increased the form factor of the fertilised trees. In another N.Z. Forest Products trial (190 kg/ha N, complete fertiliser, thinning to 540 and 320 stems/ha in 13-year-old *P. radiata* near Tokoroa) the amount of form change was minor at 540 stems/ha but more pronounced at the 320 stems/ha level

(Woollons, pers. comm.). In yet another trial (13-year-old *P. radiata* unthinned at 1100, 740 and 440 stems/ha, 250 kg/ha N) no form change or volumetric increase was found (N.Z. Forest Products Limited, 1974). Nonetheless, crowns would be expected to fully occupy the site at this age at all density levels.

It can be concluded from these cases, that the form change accompanying N fertilisation and thinning in *P. radiata* will depend upon the competitive situation existing at the time of treatment and the degree of thinning. In a stand, closed at time of treatment, N fertilisation plus thinning can be expected to offset the decline in form factor caused by the thinning. Furthermore, the intensity of the thinning can be expected to interact with the fertiliser effect, heavier thinnings causing larger changes in form.

Crown Growth Responses

Fertilisation, in cases where responses are obtained, influences both the size of and physiological processes in the tree crowns. Understanding these two aspects of the response is important since it will play a part in defining optimal thinning and fertilisation combinations. For example, stands with below optimum foliage mass could be expected to respond to N fertilisation without thinning whereas denser stands would require thinning if crown size was the major constraint. Thinning however would be less critical if increased physiological efficiency was the dominant factor.

(a) *Dimensional changes*

Madgwick *et al.* (1970) found that yearly foliage production in *Pinus resinosa* was not influenced by K fertilisation but that needle retention time was increased leading to substantial increases in crown size. Other workers have found fertilisation, in particular with N and P, increases the rate of foliage production and branch growth (Brix and Ebell, 1969; Weston, 1956). In New Zealand, dramatic improvements in crown colour, density and growth occur when P is added to *P. radiata* growing on deficient gumland soils near Auckland (Weston, 1956). Overseas, Gessel *et al.* (1965), and Turner and Olson (1976), found N fertilisation increased increments in branch length and foliage weight in Douglas fir, particularly in the middle to upper crown. Leaf size, number of leaves per shoot and number of lateral shoots were also increased (Brix and Ebell, 1969; Crossin *et al.*, 1966). Baker *et al.* (1974) report N fertilisation of 3- to 4-year-old *Pinus taeda* increased branch and foliage biomass by 25 percent. While such responses usually continue for several years following treatment, Calvert and Armson (1975) have reported NP fertilisation to increase needle production in *Pinus banksiana* only for needles produced during the year of fertilisation.

Analysis of branch growth patterns of *P. radiata* following N fertilisation and thinning in the 14-year-old Owen Road trial mentioned above, suggests a possible temporal component in the response under those conditions (Fig. 3). The more rapid branch growth response evident in the fertilised trees, indicates a more rapid utilisation of the growing space made available by thinning. That is, the volume growth of fertilised trees may be superior, at least in part, because of the speed of the response of the crown. As the controls take up their available space and their crown size approaches that of the fertilised trees, the difference may be expected to decline. This would also suggest that ultimate branch development may be similar in both fertilised and unfertilised trees of similar size and at similar spacings.

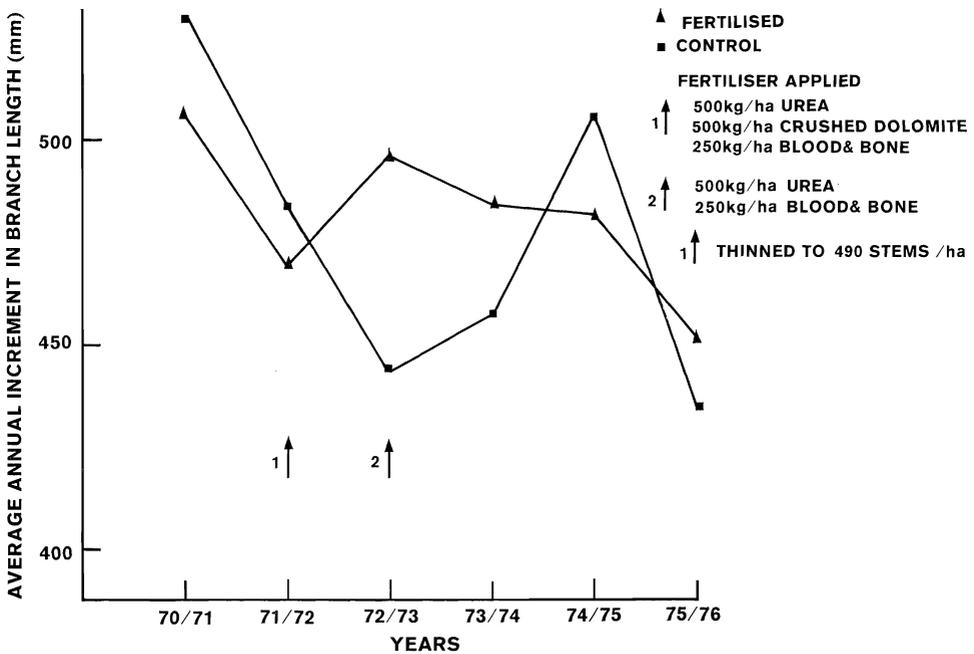


FIG. 3—Effect of fertilisation on branch length increments: *Pinus radiata* planted 1957, Owen Road, Tokoroa.

Analysis of the differences between fertilised and control trees shows a good correlation between crown increment patterns and differences in volume increment during the subsequent year (Fig. 4). The differences in branch growth were also closely associated with the differences in the way form factor changed in any year (Fig. 5). These findings are consistent with the current branch growth activity influencing the distribution of growth along the bole in that year whereas the added mass of foliage has its main effect on volume increment during the subsequent year.

(b) *Physiological functioning*

In addition to increasing the size and growth rate of crowns, fertilisation may also improve the physiological status of the crown. Various indices can be used to assess this improvement.

The foliar content of several nutrient elements, particularly P and B, has been shown to be an important index of growth potential of *P. radiata* in New Zealand. With respect to N however, foliage nutrient concentrations are not always well correlated with growth, particularly if the N deficiency is not marked. For example, Burdon (1976) has found foliar concentrations of N (and P, K, Mg, Ca) in several *P. radiata* clones on four New Zealand sites of differing fertility, to be independent of growth rate. Correlations (when significant) between growth and foliar nutrient concentration vary from poor to good. Raupach *et al.* (1975) could only account for between 19 and 65 percent of growth variation in *P. caribaea* and *P. radiata* using N and P concentrations.

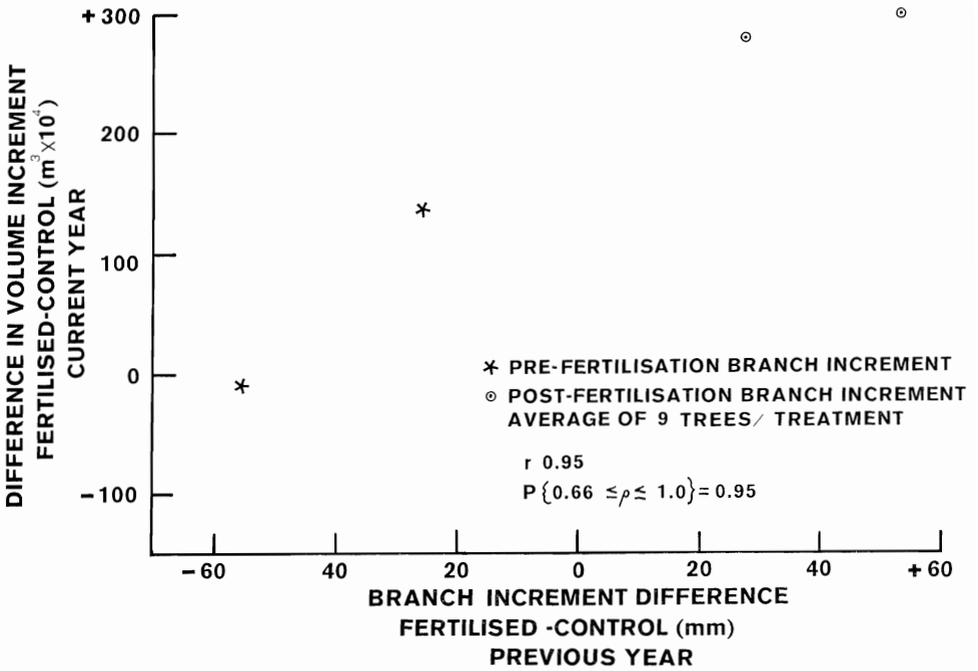


FIG. 4—Relationship between branch growth in preceding year and bole volume increment of current year: *Pinus radiata* planted 1957, Owen Road, Tokoroa.

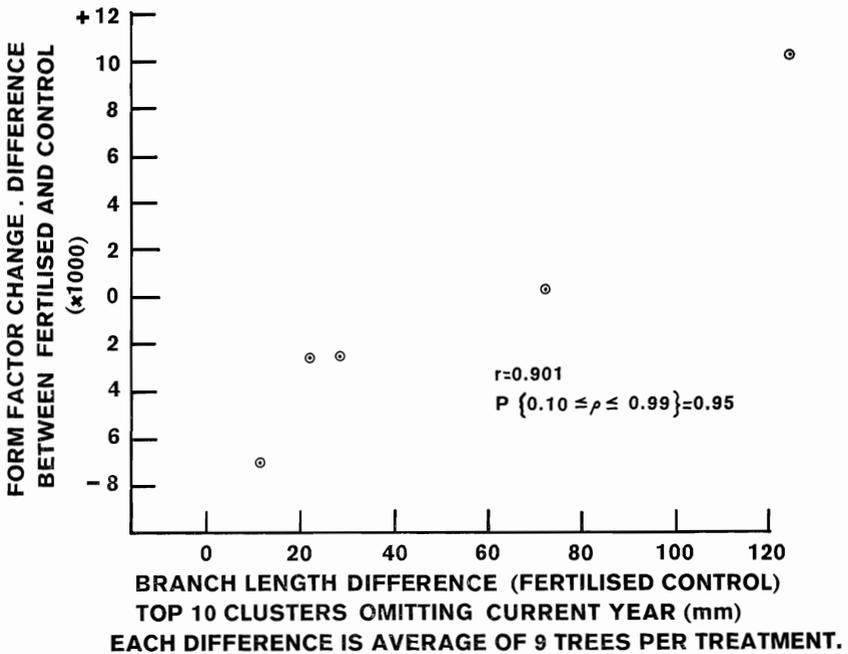


FIG. 5—Effect of fertilisation on form factor, in relation to difference in crown size: *Pinus radiata* planted 1957, Owen Road, Tokoroa.

Adams and Walker (1975) were able to account for about 74 percent of tree size variation using a multiple correlation technique with Mn, P and N foliage concentrations. This variability suggests that careful interpretation of foliar nutrient concentration is necessary when using it as a guide for management decisions.

Keay *et al.* (1968) has reported increased $^{14}\text{CO}_2$ incorporation following N fertilisation of *Pinus pinaster*. Both Keay *et al.* (1968) and Brix (1971) found increased amounts of chlorophyll a and b as a result of fertilisation. Brix (1972) also has published evidence that N fertilisation leads to improved internal water relations.

There is evidence for Douglas fir (Gessel *et al.*, 1965) that foliage from fertilised trees produces more wood per unit weight than that from unfertilised trees. Helms (1964) studied CO_2 exchange on these same trees but could detect no differences in photosynthetic efficiency. Brix and Ebell (1969) were unable to detect any increase in photosynthetic efficiency in N-fertilised Douglas fir grown in optimum conditions. However, Brix (1971) was able to detect markedly higher net photosynthetic rates in Douglas fir foliage formed during the year following N fertilisation, but only at light intensities markedly higher than used in the earlier study. Previously formed foliage was not affected. The effect was reduced in subsequent years as well. These results suggest an interaction between thinning intensity as it affects light penetration patterns and the photosynthetic efficiency of the crown. That thinning is required for fertilisation responses in some New Zealand situations, but not in others, suggests that both crown expansion and physiological efficiency factors are operative in *P. radiata*.

Roots

Data on root response to fertiliser are scant, particularly with reference to field trials. Core sampling by Farrell and Leaf (1974) in K-fertilised *P. resinosa* found more root tips present in the control than in the fertilised plots. Hagg (1975) on the other hand, reports a proportional stimulation of roots and tops by fertilisation. In seedling studies, Will (1974a) has reported a shift from roots to shoots in biomass production following N and P fertilisation. However, until more data become available, field responses of roots to fertilisation will remain obscure.

EFFECT ON CROP QUALITY

Fertilisation may lead to undesirable changes in wood quality, particularly with respect to knot size, malformation frequency and wood density.

Will (1965, 1971, 1974a) and Knight (1973) have shown that in *P. radiata*, increased levels of N and P lead to a marked shift in dry matter production to the branches. In N and P deficient trees, branch dry matter was about 50-80 percent of the stem dry matter whereas under higher fertility conditions, branch dry matter rose to 110 percent that of the stem. Whether these results apply to a field fertilisation situation where inter-tree competition becomes active is not clear however. Manley (1975), in an analysis of a *P. radiata* NPK trial with irrigation carried out on Eyrewell Forest, was unable to detect a change in allocation pattern after adjustment for tree size differences was made.

Baker *et al.* (1974) found fertilisation caused no change in pattern of biomass allocation in 3- to 4-year-old *P. taeda* either. Unpublished data of the author on over 2000 branches in the Owen Road trial near Tokoroa showed that fertilisation has had

no effect on average branch diameters four years after fertilisation. The branch growth response pattern in Fig. 3 suggests that a temporary increase in branch diameter may have occurred but this disappeared as stand closure occurred. Thus, bigger trees, whether larger because of fertiliser (or for other reasons) probably will have bigger branches in the active crown than similarly-aged but smaller trees under well-stocked forest conditions. The lysimeter trees and seedlings used by Will and Knight likely reflect development under conditions approaching free growth. If this is the case, then branch diameters may become even more undesirably large under wide spacing regimes where fertiliser is used.

Deficiencies of B and Cu have been found to occur in *P. radiata* in some parts of New Zealand (Will *et al.*, 1963; Will, 1970b) which cause severe malformation due to dieback and twisting of the branches and leaders.

Malformation caused by such things as retarded leader may be increased by increased soil fertility (Will, 1971; Hodgkiss, 1974). There appears to be reasonably strong genetic control over this factor however (Shelbourne *et al.*, 1972) so that use of genetically improved seed should help reduce the impact of this undesirable effect.

Volumetric responses to fertilisation are frequently offset to some degree by a reduction in wood density. A summary of 25 papers (Table 1) gives 17 cases where a density reduction accompanied fertilisation and 10 where no change or an increase was found. Bamber (1971) reported 10 cases of fertiliser-induced density reduction and 3 with no change. Significant density responses appear to occur when:

- (a) a substantial increase in growth occurs;
- (b) samples are taken below the green crown region.

Elliott (1970) concluded that a positive growth response appears necessary before a density reduction occurs. Erickson and Harrison (1974) found a fertiliser-induced density reduction in *Pinus elliotii* trees showing increased ring widths, while uniformly fast-growing trees showed little density change following fertilisation. Other stand treatments to encourage wide growth rings such as heavy, early, thinning done before ring widths are reduced by competition, appear to have no deleterious effect on density (Sutton and Harris, 1974). In New Zealand, Harris (1966) and Cown (1972, 1972a, 1974) have shown that fertilisation of very slowly growing *P. radiata* causes substantial volume growth increases and reductions in density towards more normal values for the species.

Fertilisation influences wood density both by influencing timing of shoot growth patterns and by modification of internal water relations. Fertilisation of deficient *P. radiata* stimulates the otherwise-reduced tendency towards a second height growth flush (Will, 1974b). A similar fertiliser stimulus of lammas growth occurs in Douglas fir (Walters and Kozak, 1967). Such an effect would likely lead to an extension of early wood production and a reduction in density according to Larson (1964) and Kennedy (1961).

In addition, N fertilisation reduces internal water stress in Douglas fir (Brix, 1972). Smith and Wilsie (1961) found water stress had a substantial influence on the vertical patterns of ring density in *P. taeda*, with drought causing maximum percentage of latewood to occur higher in the stem than usual. Timing of rainfall deficits have been related to relative amounts of early- and latewood (Kennedy, 1961; McKinnell, 1971).

TABLE 1—Density responses to fertiliser application

DENSITY REDUCED			
Species	Age	Treatment	Author
<i>Pinus radiata</i>	1-20	NPK	McKinnell, 1971
<i>P. radiata</i>	11	N	Cown, 1972a
<i>P. radiata</i>	11	N,N(P),N(PB)	Cown, 1972
<i>Pseudotsuga menziesii</i>	45-52	N	Siddiqui <i>et al.</i> , 1971
<i>Populus tremuloides</i>	6	NPK + Irrigation; CaMg	Einspahr <i>et al.</i> , 1971
<i>Pinus ponderosa</i>	46	N	Echols, 1971
<i>P. taeda</i>	12-16	N,NP	Posey, 1964
<i>P. menziesii</i>	21	N	Erickson and Harrison, 1974
<i>P. radiata</i>	6-12	K	McKinnell and Rudman, 1972
<i>Eucalyptus regnans</i>	27-34	NPK	Higgs and Rudman, 1973
<i>P. radiata</i>	7	NPS Micro	Rudman and McKinnell, 1970
<i>Picea abies</i>	Various ages on medium to good sites	N	Klem, 1968
<i>Pinus sylvestris</i>	good sites	N	Klem, 1968
<i>P. taeda</i>	16	N(P,K)	Zobel <i>et al.</i> , 1961
<i>P. menziesii</i>	30	N	Erickson and Lambert, 1958
<i>P. elliotii</i>	8	N(P)	Williams and Hamilton, 1961
<i>P. radiata</i>	22	P	Harris, 1966
<i>Abies balsamifera</i>	60	N(K)	Gagnon and Hunt, 1975
NO DENSITY REDUCTION			
Species	Age	Treatment	Author
<i>P. radiata</i>	5	NPK	Cown, 1972b
<i>Populus tremuloides</i>	6	NPK CaMg	Einspahr <i>et al.</i> , 1971
<i>P. elliotii</i>	15	P	Gooding and Smith, 1971
<i>Platanus americana</i>	10	N	Saucier and Ike, 1971
<i>P. elliotii</i>	6	NPK	Smith <i>et al.</i> , 1971*
<i>P. taeda</i>	1	NPK	Schmidting, 1973†
<i>P. palustris</i>	1	NPK	Schmidting, 1973†
<i>Picea abies</i>	various ages	N	Klem, 1968†
<i>Pinus sylvestris</i>	on poor sites	N	Klem, 1968†
<i>P. menziesii</i>	16-18	N	Megraw and Nearn, 1971
<i>P. radiata</i>		P	Gentle <i>et al.</i> , 1968
<i>P. resinosa</i>	(37)	K	Gladstone and Gray, 1973

† had higher density than controls

* slight reduction in upper bole in one year.

Smith *et al.* (1971), and Paul and Marts (1954) found fertilisation alone lowered the amount of latewood but when combined with irrigation it had little effect on the proportion of latewood. However, use of within-ring densitometric methods show that the fertilisation effect involves more than a simple influence on percentage latewood (Cown, 1972; Gladstone and Gray, 1973; Harris, 1966; Megraw and Nearn, 1971; Siddiqui *et al.*, 1971). These authors all report a trend to more uniform within-ring densities whereas Echols (1971) reported less uniform within-ring density following fertilisation. The extent to which such redistribution occurs reduces the correlation between density and the percentage latewood.

Burdon and Harris (1973), Cown (1974), Elliott (1970), and McKinnell (1971), all state that wood formed within the live-crown region of the bole is not influenced by fertilisation to the same degree as wood taken from below this region. Data from the Owen Road trial near Tokoroa support this (Leonard, pers. comm.). At 1.4 m and 12 m height, density reductions were 5.39 and 1.37% relative to controls. At 20-30 m height, within the green crown region, only a 0.97% reduction occurred. If generally true, an accurate appraisal of fertiliser-induced density changes will necessitate a weighting of density by volume along a gradient of tree height. Use of breast height density alone would, in this case, substantially over-estimate the density effect on wood yield.

Despite density reductions from fertilisation, the additional volume increment more than compensates for the loss of wood substance. There is some scattered evidence that although fast-grown wood has lower density, the pulp yield per unit weight of wood is actually increased (Gagnon and Hunt, 1975; Siddiqui *et al.*, 1971; Stairs *et al.*, 1966). This aspect needs further investigation.

Fertilisation has been shown to reduce tracheid (or fibre) length (Cown, 1972a; Erickson and Harrison, 1974; Higgs and Rudman, 1973; Klem, 1968; Zobel *et al.*, 1961). There is, however, a rapid return to normal (Cown, 1972a). Other workers reporting no effect of fertilisation on fibre length (Einspahr *et al.*, 1971; Gentle *et al.*, 1968; Saucier and Ike, 1971; Schmidting, 1973) were, in most cases, dealing with young trees and in one case, a P response as opposed to N responses in the others. The magnitudes and duration of any reductions appear to have minor practical significance.

Other wood quality parameters such as cellulose yield, lignin content and amount of extractives, do not appear to be influenced to any significant extent by fertilisation (Erickson and Lambert, 1950; Klem, 1968; Schmidting, 1973; Siddiqui *et al.*, 1971).

DISEASE AND INSECT SUSCEPTIBILITY

While it is desirable to apply fertiliser to improve or to maintain the productive capacity of a site, it should be done in a way calculated to maintain a well-balanced nutrient supply or possible management complications with disease and insects are likely to arise.

Insects

Much evidence regarding the effects of fertiliser application on susceptibility of trees to insects particularly in European situations is given by Baule (1973). Use of nitrogen fertilisation tends to reduce the amount of attack by leaf-eating insects. For example Smirnoff and Bernier (1973) found jack pine sawfly larva mortality was increased 20-30 percent following urea fertilisation. They also found control sprays with a viral agent proved more effective on fertilised trees. Goyer and Benjamin (1972) found a correlation between high soil N levels and pine root weevil resistance in jack pine. Pritchett and Smith (1972) showed phosphorus and potassium fertilisers reduced tip moth attack on *P. elliotii*. Baule (1973) lists 8 insect pests including sawflies, loopers and bark beetles which are affected similarly.

On the other hand, attack by sucking insects is encouraged by high concentrations of nitrogenous materials. In many European cases, application of potassium appears to counteract this tendency. Baule (1973) presents a graphic case of how increases in K content inhibit development of oak scale insect.

Changes in susceptibility may be related to factors other than nutritional content of foliage. Bud and leaf size, as well as the influence of fertilisation on the timing of relative stages of development of the host relative to those of the pest, can also be involved (e.g., Thalenhorst, 1972).

Disease

Several reviews have appeared recently on this topic (Schoenweiss, 1975; Baule, 1973; Hesterberg and Jurgensen, 1972). Perhaps the best example of the influence of fertilisers on disease susceptibility is that of *Pinus elliottii* and *Cronartium fusiforme*. Boggess and Stahelin (1948) reported N, P fertilised plots of slash pine exhibited higher rust infections. These findings were still in evidence some 10 years later (Gilmore and Livingston, 1958) and have been substantiated by others (Pritchett and Smith, 1972). Dinus and Schmidting (1971) found a similar, but less marked effect in *P. taeda*. Hesterberg and Jurgensen (1972) suggest that earlier breaking of dormancy in fertilised trees places them in a succulent, highly susceptible state which coincides better with the time of maximum spore production. Baule (1973) gives evidence that susceptibility to *Melampsora* rust in poplar is related to K content of the foliage and Hesterberg and Jurgensen (1972) note that *Fomes annosus* root rot infection levels are reduced at high levels of soil K and Mg. Nitrogen effects were less clear although they do state that *Phytophthora* effects are reduced by application of N, the higher N levels offsetting the reduced absorptive area of the damaged roots.

In New Zealand, these effects have not been reported for *P. radiata*, although Gilmour and Noordenhaven (1966) mention a minor depression of *Dothistroma pini* development following fertilisation with N, P, K, Mg. Sievwright (1968) found that increased Mn, Fe and Ni levels in foliage had no influence on resistance of *P. radiata* to *D. pini*.

ACKNOWLEDGMENT

The author wishes to thank N.Z. Forest Products Limited for the support received while carrying out the measurements of tree characteristics on the Owen Road trial.

REFERENCES

- ADAMS, J. A. and WALKER, T. W. 1975: Nutrient relationships of radiata pine in Tasman Forest, Nelson. **N.Z. J. For. Sci.** **5(1)**: 18-32.
- ALDEN, J. and HERMANN, R. K. 1971: Aspects of the cold-hardiness mechanism in plants. **Bot. Rev.** **37(1)**: 37-142.
- ANON, 1974: Radiata pine seed orchards. **N.Z. For. Serv., For. Res. Inst., What's New In For. Res.** **16**.
- BAKER, J. B., SWITZER, G. L. and NELSON, L. E. 1974: Biomass production and nitrogen recovery after fertilisation of young loblolly pine. **Proc. Soil Sci. Soc. Amer.** **33**: 958-61.
- BALLARD, R. and MEAD, D. J. 1976: Uniform fertiliser — site preparation trials in the Auckland Conservancy. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rpt.** **73** (unpubl.).
- BAMBER, R. K. 1971: Some studies of the effects of fertilisers on the wood properties of *Pinus* species. **Proc. Aust. Forest Tree Nutrition Conf.**: 366-79.
- BARNES, R. L. and BENGTON, G. W. 1968: Effects of fertilisation, irrigation and cover cropping on flowering and on nitrogen and soluble sugar composition of slash pine. **For. Sci.** **14(2)**: 172-80.
- BAULE, H. 1973: Effect of fertilisers on resistance to adverse agencies, In 'International Symposium of Forest Fertilisation'. IUFRO. pp. 181-214.

- BENZIAN, B., BROWN, R. M. and FREEMAN, S. C. R. 1974: Effect of late season top dressings of N (and K) applied to conifer transplants in the nursery on their survival and growth on British forest sites. **Forestry** **47**: 153-84.
- BLACK, C. A. 1968: "Soil-Plant Relationships". John Wiley and Sons, New York. 792 pp.
- BOGGESE, W. R. and STAHELIN, R. 1948: The incidence of fusiform rust in slash pine plantations receiving cultural treatments. **J. For.** **46(9)**: 683-5.
- BRIX, H. 1971: Effects of nitrogen fertilisation on photosynthesis and respiration in Douglas fir. **For. Sci.** **17(4)**: 407-14.
- 1972: Nitrogen fertilisation and water effects on photosynthesis and earlywood and latewood production in Douglas fir. **Can. J. For. Res.** **2(4)**: 467-78.
- BRIX, H. and EBELL, L. F. 1969: Effects of nitrogen fertilisation on growth, leaf area, and photosynthesis rate in Douglas fir. **For. Sci.** **15(2)**: 189-96.
- BRUNSDEN, G. J. 1976: Hard site establishment: the effect of fertiliser on the survival and growth of 1½/0 radiata pine. **N.Z. For. Serv., For. Res. Inst., Forest Establishment Rep. 79** (unpubl.).
- BURDON, R. D. 1976: Foliar macronutrient concentrations and foliage retention in radiata pine clones on four sites. **N.Z. J. For. Sci.** **5(3)**: 250-9.
- BURDON, R. D. and HARRIS, J. M. 1973: Wood density in radiata pine clones on four different sites. **N.Z. J. For. Sci.** **3(3)**: 286-303.
- CALVERT, R. F. and ARMSON, K. A. 1975: The growth response of young jack pine to nitrogen and phosphorus. **Can. J. For. Res.** **5(4)**: 529-38.
- CHRISTERSSON, L. 1975: Frost hardiness development in rapid- and slow-growing Norway spruce seedlings. **Can. J. For. Res.** **5(2)**: 340-3.
- COUTTS, M. P. and PHILIPSON, J. J. 1976: Plasticity of the growth of tree root systems in response to changes in the nutrient environment. Proc. XVI IUFRO World Congress. pp. 70-7.
- COWN, D. J. 1972: The influence of fertiliser applications on wood quality. 2. Trials N.225 and N.191, Nelson Conservancy. **N.Z. For. Serv., For. Res. Inst., Forest Products Rep. 431** (unpubl.).
- 1972a: The influence of fertiliser applications on wood quality. 1. The effects of thinning and nitrogen fertiliser in dense natural regeneration. **N.Z. For. Serv., For. Res. Inst., Forest Products Rep. 411** (unpubl.).
- 1972b: The influence of fertiliser applications on wood quality. 3. Trial R.246, Kaingaroa Forest. **N.Z. For. Serv., For. Res. Inst., Forest Products Lab. Rep. WQ 12** (unpubl.).
- 1974: Wood density of radiata pine: its variation and manipulation. **N.Z. J. For.** **19(1)**: 84-92.
- CROSSIN, E. C., MARLOW, J. A. and AINSCOUGH, G. L. 1966: A progress report on forest nutrition studies on Vancouver Island. **Forestry Chronicle** **42(3)**: 265-84.
- DINUS, R. J. and SCHMIDTLING, R. C. 1971: Fusiform rust in loblolly and slash pines after cultivation and fertilisation. **USDA For. Serv., Southern Forest Exp. Sta., Res. Pap. No. 50-68**.
- EBELL, L. F. 1972: Cone production and stem growth response of Douglas fir to rate and frequency of nitrogen fertilisation. **Can. J. For. Res.** **2(3)**: 327-8.
- 1972a: Cone induction response of Douglas fir to form of nitrogen fertiliser and time of treatment. **Can. J. For. Res.** **2(3)**: 317-26.
- ECHOLS, R. M. 1971: Patterns of wood density distribution and growth rate in ponderosa pine. In "Effects of Growth Acceleration on the Properties of Wood". Univ. Wisconsin M1-18.
- EINSPAHR, D. W., BENSON, M. K. and HARDER, M. L. 1971: Influence of irrigation and fertilisation on growth and wood properties of quaking aspen. In "Effects of Growth Acceleration on the Properties of Wood". Univ. Wisconsin I1-9.
- ELLIOTT, G. K. 1970: Wood density in conifers. **Comm. For. Bur., Tech. Comm. 8**.
- ERICKSON, H. D. and HARRISON, A. Th. 1974: Douglas fir wood quality studies. Part I,

- Effects of age and stimulated growth on wood density and anatomy. **Wood Sci. Technol.** **8**: 207-26.
- ERICKSON, H. D. and LAMBERT, G. M. G. 1958: Effects of fertilisation and thinning on chemical composition, growth and specific gravity of young Douglas fir. **For. Sci.** **4**: 307-15.
- FARRELL, E. P. and LEAF, A. L. 1974: Effects of fertilisation and irrigation on root numbers in a red pine plantation. **Can. J. For. Res.** **4**(3): 366-71.
- FLEWELLING, J. W. and YANG, Y. C. 1976: Tree volume growth relationships possibly affected by fertilisation. **For. Sci.** **22**(1): 58-60.
- GAGNON, J. D. and HUNT, K. 1975: Kraft pulping and specific gravity in the uppermost stem of fertilised Balsam fir. **Can. J. For. Res.** **5**(3): 399-402.
- GENTLE, S. W., BAMBER, R. K. and HUMPHREYS, F. R. 1968: Effect of two phosphate fertilisers on yield, financial yield and wood quality of radiata pine. **For. Sci.** **14**: 282-6.
- GESSEL, S. P., STOATE, T. N. and TURNBULL, K. J. 1965: The growth behaviour of Douglas fir with nitrogenous fertiliser in western Washington. College of Forestry, Institute of Forest Products, University of Washington. First and Second Reports.
- GILMORE, A. R. LIVINGSTONE, K. W. 1958: Cultivating and fertilising a slash pine plantation. Effects on volume and fusiform rust. **J. For.** **56**: 481-3.
- GILMOUR, J. W. and NOORDENHAVEN, A. 1966: Progress report on *Dothistroma pini* research. **N.Z. For. Serv., For. Res. Inst., Forest Pathology Rep.** **16** (unpubl.).
- GLADSTONE, W. T. and GRAY, RICHARD, L. 1973: Effects of forest fertilisation on wood quality. In Proc. Sympos. Forest Fertilisation, USDA, Forest Service General Tech. Rpt. NE3: 167-73.
- GOODING, J. W. and SMITH, W. H. 1971: Effects of fertilisation on stem, wood properties, and pulping characteristics of slash pine (*Pinus elliottii* var. *elliottii* Engelm.). Proc. Symp. on the Effects of Growth Acceleration on the Properties of Wood. Univ. Wisconsin, E1-18.
- GOYER, R. A. and BENJAMIN, D. M. 1972: Influence of soil fertility on infestation of jack pine plantations by the pine root weevil. **For. Sci.** **18**(2): 139-47.
- GRIFFITH, B. G. 1968: Phenology, growth, and flower and cone production of 154 Douglas fir trees on the University Research Forest as influenced by climate and fertiliser. **Univ. of British Columbia, Fac. of Forestry, Bull.** **6**. 70 pp.
- HAGG, S. 1975: Bestämning av rot biomassa på prov trad av gran. Determination of root biomass of spruce sample trees. **Research Note 19, Dept. Forest Ecology and Forest Soils, Royal Coll. For., Stockholm.**
- HARRIS, J. M. 1966: Phosphate deficiency and wood density in radiata pine: Examination with a beta ray densitometer. **N.Z. For. Res. Inst., Forest Products Rep.** **187** (unpubl.).
- HELMS, J. A. 1964: Apparent photosynthesis of Douglas fir in relation to silvicultural treatment. **For. Sci.** **19**(4): 432-42.
- HESTERBERG, G. A. and JURGENSEN, M. F. 1972: The relation of forest fertilisation to disease incidence. **Forestry Chronicle** **48**(2): 92-6.
- HIGGS, M. L. and RUDMAN, P. 1973: The effects of fertilising and thinning on wood properties of *Eucalyptus regnans*. **Appita** **27**: 51-55.
- HODGKISS, P. D. 1974: Stem and crown growth and form in radiata pine as influenced by nitrogen and phosphorus supply. Part II. Growth assessment of components of whole trees by destructive sampling at age 6 years. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep.** **52** (unpubl.).
- KEAY, J., TURTON, A. G. and CAMPBELL, N. A. 1968: Some effects of nitrogen and phosphorus fertilisation of *Pinus pinaster* in western Australia. **For. Sci.** **14**(4): 408-17.
- KELLISON, R. C. 1974: Status and plans for the radiata seed orchards of the New Zealand Forest Service. **N.Z. For. Serv., For. Res. Inst., Genetics and Tree Improvement Rep.** **66**.

- KENNEDY, R. W. 1961: Variation and periodicity of summerwood in some second-growth Douglas fir. **Tappi** **44(3)**: 161-6.
- KLEM, G. S. 1968: Quality of wood from fertilised forests. **Tappi** **51(11)**: 99A-103A, FA 30, No. 4692.
- KNIGHT, P. J. 1973: Influence of nitrogen supply on the growth and branching habit of *Pinus radiata* seedlings. **N.Z. J. For.** **18(2)**: 273-8.
- LARSON, P. R. 1964: Some indirect effects of environment on wood formation. Pp. 345-61 in "The Formation of Wood in Forest Trees", M. H. Zimmerman, Ed. Academic Press.
- McKINNELL, F. H. 1971: Fertiliser and the wood density of radiata pine. Proc. Australian Forest-Tree Nutrition Conf. pp. 381-3.
- McKINNELL, F. H. and RUDMAN, P. 1972: Potassium fertiliser and wood density in *Pinus radiata*. **Appita** **26**: 283-6.
- MADGWICK, H. A. I., WHITE, E. H., XYDIAS, G. K. and LEAF, A. L. 1970: Biomass in *Pinus resinosa* in relation to potassium nutrition. **For. Sci.** **16**: 154-9.
- MALCOLM, D. C. and FREEZAILLAH, B. C. Y. 1975: Early frost damage on Sitka spruce seedlings and the influence of phosphorus nutrition. **Forestry** **48(2)**: 139-45.
- MANLEY, B. R. 1975: Study of the effect of fertilising and ripping on the branch growth of young radiata pine at Eyrewell Forest. B. For. Sci. Dissertation, University of Canterbury.
- MATTHEWS, J. D. 1963: Factors affecting the production of seed by forest trees. **For Abstr.** **24**: i-xiii.
- MEAD, D. J. 1976: Fertiliser response in 14-year-old radiata pine at Harakeke, Nelson (N191). **N.Z. For. Serv., For. Res. Inst., Soils & Site Productivity Rep.** **69** (unpubl.).
- MEGRAW, R. A. and NEARN, W. T. 1971: Detailed dbh-density profiles of several trees from Douglas fir fertiliser/thinning plots. In "Symposium on the Effect of Growth Acceleration on the Properties of Wood." Univ. of Wisconsin.
- MILLER, H. G. and COOPER, J. M. 1973: Changes in amount of distribution of stem growth in pole-stage Corsican pine following application of nitrogen fertiliser. **Forestry** **46(2)**: 157-90.
- MITCHELL, K. J. and KELLOGG, R. M. 1972: Distribution of area increment over the bole of fertilised Douglas fir. **Can. J. For. Res.** **2(2)**: 95-7.
- N.Z. FOREST PRODUCTS LIMITED. 1974: Report on *Pinus radiata* fertiliser investigations 1973 and 1974 (unpubl.).
- PAUL, B. H. and MARTS, R. O. 1954: Controlling the proportion of summerwood in longleaf Pine. USDA, Forest Products Laboratory, Rep. 1988. Madison, Wisconsin, U.S.A.
- PHARIS, R. P. 1976: Manipulation of flowering in conifers through the use of plant hormones. In "Modern Methods in Forest Genetics", J. P. Miksche, Ed. Springer-Verlag, Berlin.
- PRITCHETT, W. L. and SMITH, W. H. 1972: Fertiliser responses in young pine plantations. **Soil Sci. Soc. Amer. Proc.** **36(4)**: 660-63.
- POSEY, C. E. 1964: The effects of fertilisation upon wood properties of loblolly pine (*Pinus taeda* L.). **School of Forestry, N.C. State Univ., Rep.** **22**.
- RAUPACH, M., CLARKE, A. R. P., GIBSON, B. F. and CELLIER, K. M. 1975: Cultivation and fertilisation effects on the growth and foliage nutrient concentrations of *P. radiata*, *P. pinaster* and *P. caribaea* on three soil types at Anglesea (Victoria). **C.S.I.R.O. (Austral.) Div. Soils, Tech. Paper** **25**.
- RUDMAN, P. and McKINNELL, F. H. 1970: Effect of fertilisers on wood density of young radiata pine. **Austral. For.** **34(3)**: 170-8.
- SAUCIER, J. R. and IKE, A. F. 1971: Response in growth and wood properties of American sycamore to fertilisation and thinning. In "Effect of Growth Acceleration on the Properties of Wood". Univ. of Wisconsin p. F1-11.
- SCHMIDTLING, R. C. 1973: Intensive culture increases growth without affecting wood quality of young southern pines. **Can. J. For. Res.** **3(4)**: 565-73.

- SCHOENWEISS, D. F. 1975: Predisposition, stress and plant disease. **Ann. Rev. Phytopath.** **13**: 193-211.
- SHELBOURNE, C. J. A., THULIN, I. J. and SCOTT, R. M. H. C. 1972: Variation, inheritance and correlation amongst growth, morphological and wood characters in radiata pine. **N.Z. For. Serv., For. Res. Inst., Genetics and Tree Improvement Rep. 61** (unpubl.).
- SHOULDERS, E. 1968: Fertilisation increases longleaf and slash pine flower and cone crops in Louisiana. **J. For.** **66(3)**: 193-7.
- SIDDIQUI, K. H., GLADSTONE, W. T. and MARTON, R. 1971: Influence of fertilisation on wood and pulp properties of Douglas fir. In "Effect of Growth Acceleration on the Properties of Wood." Univ. Wisconsin C1-16.
- SIEVWRIGHT, R. A. 1968: The effect of raising the level of some elements in young *Pinus radiata* on their resistance to *Dothistroma pini*. **N.Z. For. Serv., For. Res. Inst., Forest Pathology Rep. 25** (unpubl.).
- SMIRNOFF, W. A. and BERNIER, B. 1973: Increased mortality of the swaine jackpine sawfly, and foliar nitrogen concentration after urea fertilisation. **Can. J. For. Res.** **3(1)**: 112-21.
- SMITH, D., WAHLGREN, H. and BENGTON, G. W. 1971: Effect of irrigation and fertilisation on wood quality of young slash pine. In "Effects of Growth Acceleration on the Properties of Wood". Univ. of Wisconsin D1.
- SMITH, D. M. and WILSIE, M. C. 1961: Some anatomical responses of loblolly pine to soil-water deficiencies. **Tappi** **44(3)**: 179-85.
- STAIRS, G. R., MARTON, R., BROWN, A. F., RIZZIO, M. and PETRIK, A. 1966: Anatomical and pulping properties of fast- and slow-grown Norway spruce. **Tappi** **49(7)**: 296-300.
- SUTTON, R. F. 1975: Nutrition and growth of white spruce outplants: enhancement by herbicidal site preparation. **Can. J. For. Res.** **5(2)**: 217-23.
- SUTTON, W. R. J. and HARRIS, J. MADDERN. 1974: Effect of heavy thinning on wood density in radiata pine. **N.Z. J. For. Sci.** **4(1)**: 112-5.
- SWEET, G. B. and HONG, S. O. 1978: The role of nitrogen in relation to cone production in *Pinus radiata*. **N.Z. J. For. Sci.** **8(2)**: in press.
- THALENHORST, W. 1972: Fertilising, growth characteristics and arthropod infestation of Norway spruce. *Aus dem Walde* 18, 248 pps. **FA** **34(2)**: 962.
- TURNER, J. and OLSON, P. R. 1976: Nitrogen relations in a Douglas fir plantation. **Ann. Bot.** **40**: 1185-93.
- WALTERS, J. and KOZAK, A. 1967: The effect of chemical fertilisation on the formation of lammas shoots in Douglas fir. **University of British Columbia, Faculty of Forestry, Res. Pap. 76**.
- WARING, H. D. 1970: Some soil relationships of *Pinus radiata*. In "*Pinus radiata*". Australian National University, Canberra.
- 1973: Early fertilisation for maximum production. In International Symposium on Forest Fertilisation. IUFRO, pp. 215-41.
- WESTON, G. C. 1956: Fertiliser trials in unthrifty pine plantations at Riverhead Forest. **N.Z. J. For.** **7(3)**: 35-46.
- WHYTE, A. G. D. and MEAD, D. J. 1976: Quantifying responses to fertiliser in the growth of radiata pine. **N.Z. J. For. Sci.** **6(3)**: 431-42.
- WILL, G. M. 1965: The effects of N deficiency on tree form in radiata pine. **N.Z. For. Serv., For. Res. Inst., Silviculture Rep. 43** (unpubl.).
- 1970a: Effects of size of planting stock, use of fertilisers, and weed competition on tree growth in initial years. **N.Z. For. Serv., For. Res. Inst., Soils and Nutrition Rep. 11** (unpubl.).
- 1970b: Copper deficiency the cause of distorted shoot growth in *Pinus radiata* at Mangawhai Forest. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 13** (unpubl.).
- 1971: Nitrogen supply, apical dominance and branch growth in *Pinus radiata*. **Plant & Soil** **34(2)**: 515-7.

- 1974a: Growth form and growth rate of *Pinus radiata* seedlings as influenced by nitrogen supply. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 53** (unpubl.).
- 1974b: Stem and crown growth and form in radiata pine as influenced by nitrogen and phosphorus supply. I. Growth of cuttings of two clones during six years prior to harvest. **N.Z. For. Serv., For. Res. Inst., Soils and Site Productivity Rep. 51** (unpubl.).
- WILL, G. M., APPLETON, E. J., SLOW, L. J. and STONE, E. L. 1963: Boron deficiency — cause of dieback in pines in the Nelson district. **N.Z. For. Serv., For. Res. Inst., Res. Leaf. No. 1.**
- WILLIAMS, R. F. and HAMILTON, J. R. 1961: The effects of fertilisation on four wood properties of slash pine. **J. For. 59:** 662-5.
- WOOLLONS, R. C. and WILL, G. M. 1975: Increasing growth in high production radiata pine stands by nitrogen fertilisers. **N.Z. J. For. 20(2):** 243-53.
- ZOBEL, B. J., GOGGANS, J. F., MAKI, T. F. and HENSON, F. 1961: Some effects of fertilisers on wood properties of loblolly pine. **Tappi 44:** 186-92.