Establishing radiata pine on the North Auckland podzols

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ABSTRACT

Early attempts at afforestation with radiata pine on the severely podsolized soils of Northland failed because of the soils' restricted volume, impeded drainage, and low natural fertility. The past decade has seen steady improvements in fertilizer regimes and techniques of soil cultivation, and so nowadays young stands of radiata pine comparable to those in Kaingaroa State Forest can be routinely achieved. The forest manager, in seeking high productivity on these degraded soils, must be aware not only of the nutritional demands of the establishing tree crop, but also of the need to satisfy these demands with a balanced fertilizer programme.

There are approximately 110,000 hectares of land north of Auckland which possess soils mapped as "podzols". Prior to 1972, whenever these soils were included within land to be afforested, they were left unplanted. However, since 1972 a large number of trials have been carried out by the Auckland Conservancy, the Forest Research Institute (FRI), and the private sector to examine the role of site preparation and fertilizer treatment in the successful establishment of radiata pine on these soils. Progress in this area of research has been possible because of consultation and cooperation between the forestry groups; many people have contributed and their work is acknowledged. Although some aspects of this progress have been published (Hunter 1980; Williamson 1985), and others exist in unpublished reports, the whole story has yet to be presented. This paper continues that story with a special emphasis on the FRI contribution.

THE TRIALS

All the trials discussed in this paper were split plot factorials, some of which were Uniform Establishment Trials (Mead, unpubl.) In each trial the main plots tested either cultivation practices or broadcast fertilizer treatments. Each main plot consisted of a number of ten-tree row plots which tested a range of fertilizer treatments applied in a spade slit shortly after tree planting. Only treatments that were shown to have a statistically significant effect on tree growth are discussed in this paper.
THE PROBLEM WITH PODZOLS

Although there is considerable variability within the family of soils mapped as podzols in parent material, soil texture, depth, and development and continuity of the silica-, iron-, and humus pans, all podzols tend to occur on relatively shallow slopes and tend to have infiltration rates incapable of dealing with high winter rainfall. Furthermore, although rainfall in the lowlands of the far north averages 1200-1400 mm/yr, in the hills it reaches 2500 mm/yr, with 60% falling in the six months from April to September (Anon. 1973). This rainfall makes the hills of North Auckland wetter than comparable regions of the West Coast of the South Island (Totara Flats-Reefton), where the average rainfall is 2000 mm/yr.

Consequently, these podzol soils tend to be waterlogged in winter and have a peaty topsoil. In the most developed of the podzols (Te Kopuru on silicious sands) the silica pan can be extremely compact, up to half a metre thick, and underlain by often fragile iron humus pans. The loamy podzols (typified by the Wharakohe suite of soils from sedimentary materials) have clay constituents and variable development of the silica layers and iron-humus pans, all of which contribute to their poor drainage. In winter there is a perched water table above the pan and in summer often a complete drought as the shallow soil dries out. In addition, kauri peg roots and kauri gum are found on many of these sites, remnants of kauri forests of long ago.

DEVELOPMENT OF CULTIVATION PRACTICES

The vegetation on the areas that come into afforestation is often pink-flowered manuka and hakea, less than a metre in height. The usual practice is to crush and burn the scrub before site cultivation, although attempts have been made to rotary slash the native scrub to conserve its nutrients and make use of the organic matter to help keep the soil more open. However, the slashed material tended to clog during later cultivation, particularly where wiwi rush was present.

First attempts at ripping

In 1973 FRI, in conjunction with local foresters, set up several trials near Parengarenga (Aupouri Peninsula) to assess the value of ripping as a soil conditioning technique for radiata pine plantations. These trials followed earlier work by the Forest Service (see Williamson 1986) at Waitangi, which showed ripping to be a promising technique. The Parengarenga trials were established on Te Kopuru, Te Hapua, and Ohia Sands, and on Rangiuru Clay. The cultivated plots at all sites were ripped between 30 and 60 cm with an unmodified rock tine ripper (Fig. 1), and then rotary hoed. Because of perceived difficulties in the use of herbicides on native vegetation, there was no attempt at weed control.

One of the podzolised sand sites, mapped as Te Hapua soil, had a well-developed, compact silica pan 60 cm from the surface. The rip had scarcely penetrated the pan and the soil reset when wetted. At age four, the soil in both the cultivated and uncultivated plots of this site was equally firm and it was impossible to detect any residual effect of cultivation. The marginal difference in tree growth attributable to cultivation was not significant. The trees had a mean height and diameter of 1.9 m and 54 mm, respectively. At the Te Kopuru site, the trial was abandoned: the ripper had failed to break through the silica pan, the rotary hoeing contributed to making soil conditions very boggy, and tree survival was extremely poor. At the third podzolised sand site (mapped as Ohia sand) the pan was about 1 m deep, discontinuous, and disturbed. During digging, blocks of the pan were encountered that were tilted sideways, possibly a result of the previous kauri gum diggings. Growth on this site reached 2.5 m in height and 55 mm in diameter at age four without cultivation. Cultivation significantly improved growth such that trees reached 3.2 m tall and 77 mm in diameter. Cultivation also improved height growth at the Rangiuru clay site (from 1.6 m to 2.3 m at age four), but at the cost of considerable (over 80%) socketing and toppling of the trees. Tree survival (58% cultivated, 50% uncultivated) was poor.

These experiments were a first step. They showed that, although it was possible to establish radiata pine on these soils, generally survival was poor and growth slow. The exception was the Ohia sand site, where the best row had 100% survival, a mean height of 4.5 m, and a diameter of 90 mm, doubtless all results of cultivation and treatment with 15 g nitrogen (N) and 15 g phosphorus (P). The challenge was to achieve similar success in the more typical podzol sites.

Ripping gets supplemented with bedding

Cultivation and its effect on soil drainage and aeration was seen as one of the ways of meeting this challenge. Overseas work had shown soil ridging or bedding to form raised mounds could be used to improve drainage (Pruitt 1947; Haines and Pritchett 1965; Derr and Mann 1970). In 1974, Kaikohe District staff used Sweetwater Nursery’s swamp plough (twin discs) to ridge soil from either side of a rip line. The raised bed was expected to have improved drainage. Because of the encouraging results, a bedding plough (Fig. 2) — six discs, three each side and offset — was built and several trials established.

One such trial for the FRI was at Waipoua State Forest. A similar trial was established at Utakura by the Whitecliffs...
Sawmilling Co using the twin discs, double pass technique, followed by rotary hoeing over the bed to consolidate the soil. The Utakura site, on a Wharekohe silt loam with pan, was a podzol as strongly developed as at the Te Hapua site (see earlier). However unlike the Te Hapua site, the silica pan had not reset within four years of ripping and the soil in the cultivated plots was noticeably softer at age four. Perhaps the major cause of this result was the plough’s mixing of the topsoil with the silica pan, as evidenced by the humus often found in the lower parts of the rip line. Growth with neither cultivation nor fertilizer application at the Utakura site was worse than at the other FRI sites (i.e. Parengarenga and Waipoua) — at age four, mean height: 0.5 m, and survival: 60%. At the Utakura and Waipoua sites, cultivation alone improved growth, but there was a large and significant interaction between cultivation and fertilizer application. Trees receiving both achieved 4.7 m in height and 100 mm in diameter at age four, with survival in excess of 90%. This very satisfactory height growth was close to that achieved in a comparable trial in Kaingaroa (Hunter 1980). Clearly, cultivation had a significant effect on improving soil drainage and aeration on podzols and therefore is a valuable tool for improving tree growth.

Advances in ripping and bedding

While the Utakura and Waipoua experiments were running, Ian Page and John Cullen from FRI, and Graham Manson, a contractor, were developing the winged tine ripper (Fig. 1), which heaves and shatters the soil rather than creating a slot in it (Page 1977, 1979). In addition, by trailing sets of large discs behind the ripper, bedding could be done in a single pass. Beds so formed were as large but perhaps not as finely cultivated as those formed by earlier equipment. In 1978 FRI established several experiments to test a range of cultivation treatments, including the techniques described above. At two sites, Shenstone Forest (on Te Kopuru sand just south of Cape Reinga) and Takau Bay (on a Wharakohe podzol in the Bay of Islands), fertilizer treatments were imposed on some of the cultivation treatments. In the latter experiments the advantage of bedding was confirmed by gains of over 1 m in height from ripping and bedding compared with ripping alone.

Although ripping and bedding have become the standard methods of ground preparation on these soils, variations on the theme are still being studied. For example, Northern Pulp has used multiple ripping (see Fig. 3), and hour-glass rollers (Fig. 4) have been used extensively to recompact coarsely-formed soil beds. V-blading is used on the very shallow slopes of North Auckland to provide drainage, a technique used on the west coast of the South Island on gley-podzol “pakihi” soils (Fig. 5).

Long-term effects of early cultivation

A question often asked is whether the growth gains associated with early cultivation will persist. Such concern is understandable and difficult to answer from available data. Recently Squire (1983) and others discussed this question regarding the early growth gains observed in South Australia. They concluded that moisture would ultimately limit annual growth in a low rainfall climate regardless of treatment, and therefore that the early percentage gain in height would eventually be eroded. However, the earliest cultivation trials in North Auckland are now ten years old and there has been no improvement in the growth rate of trees on the uncultivated soils. Projected site indices now range from 16 m on the Te Hapua sand to 20 m on the Ohia sand, similar to projections made at age four. Moreover, the uncultivated plots at Waipoua and Utakura have shown no improvement in growth rate. At this stage it seems clear that growth on uncultivated or unsatisfactorily cultivated sites will not improve with time to achieve a reasonable growth rate, and
there is no evidence that growth on well cultivated sites will slow down. Current indications are that cultivation gains will persist and, at Utakura and Waipoua, it is likely that the projected site indices, 33 m, are achievable.

Concern is expressed about the effects of cultivation on toppling, windthrow, and root configuration. Cultivation admittedly often increases rootable depth by only 60 cm. Limited and constrained root development and rapid top growth could predispose trees to toppling at an early age, and windthrow at a later age. Equally, stock with poorly trimmed roots and therefore poor root regeneration potential may produce inherently unstable young trees. However, in later trials there has been only a low level of toppling in the first four to six years. Furthermore, at Utakura toppling was of the same low intensity in the large trees of the cultivated plots as in the small trees of the uncultivated plots. Our excavations on site have shown that fine feeder roots leave the confines of the bed at the latest by age five and begin to explore the interbed areas. The reduction in winter waterlogging associated with increased evapotranspiration and rainfall interception by the foliage and the beginnings of a litter layer may be important in allowing this root egress to occur, and thus increase tree stability.

In podzolized soils the total rooting depth at 60-80 cm in cultivated areas is as great, if not greater, than that in many other forests such as Southern Kaingaroa and Balmoral. Interestingly, for the forests on soils derived from tertiary rocks (e.g. Gwavas), later age windthrow is not an inevitable feature of those forests. However, no cultivation practice can protect against either the effects of the decaying tropical cyclone to which North Auckland is perhaps more exposed than other areas of the country, or the problem of poor, badly planted nursery stock.

DEVELOPMENT OF FERTILIZER APPLICATION PRACTICES
Phosphorus and Nitrogen

Trials with soluble fertilizers

From foliar nutrient analyses it was obvious that phosphorus was the major element limiting growth on podzolized sites and without it there was little improvement in growth by the addition of any other nutrient. Even in the earliest trials there were gains of 40 cm in height and 10 mm in root collar diameter when 150 g of superphosphate were applied in a spade slit beside the tree. There was no growth improvement by the addition of nitrogen (as urea) alone and in fact nitrogen applications in a spade slit caused, on average, a 10% increase in mortality. A small growth increment (20 cm in height and 5 mm in diameter) occurred when urea (30 g) was applied with the superphosphate. However, 70% of the total response to 150 g of superphosphate and 30 g of urea was due to the phosphorus and 30% to the nitrogen. Thus, the basic pattern was established: phosphorus was essential; nitrogen beneficial only when applied with phosphorus.

At the more successfully cultivated Utakura (Fig. 6) and Waipoua sites, the addition of phosphorus (as 150 g
Superphosphate resulted in a much larger growth increment by age four — at Utakura saraie 2.8 m in height and 60 mm in root collar diameter — at Waipoua about 1 m in height and 40 mm in diameter. Where phosphate was supplemented with nitrogen (as 30 g urea), there was a useful gain of 60 cm in height and 9 mm in diameter. However, with the more rapid overall growth a previously unencountered problem arose at these sites: foliar concentrations of phosphorus, nitrogen, and potassium (K) declined between ages two and four to deficient levels like those of the unfertilized trees, even where applications of up to 450 g of superphosphate and 60 g of urea had been used. The corresponding height increment on trials receiving fertilizer was only slightly lower than in a comparable trial in Kaingaroa, but the increment in root collar diameter was markedly less; the Utakura and Waipoua trees grew only 40 mm in two years, while the Kaingaroa trees grew 80 mm, despite being almost the same size at age two. Thus the decrease in foliar nutrients appeared to be accompanied by the loss of one year’s increment in two years.

The problem is illustrated in Figure 7. The young crop’s need for nutrients increased rapidly in the early establishment years. In Kaingaroa, the rapid increase in nutrient demand was accompanied by a small decrease in foliar nutrient concentrations (during this period of transient nutrient deficiency, small gains caused by added fertilizers have been observed). However, for radiata pine on the northern podzols the decline into nutrient deficiency was marked. To determine whether this decline was the result of a nutritional shortage, half of each of the trials at

**FIGURE 7** — Relationship between foliar nutrient uptake (+) and the changes in foliar nutrient concentrations for radiata at Kaingaroa (+) compared with Northland (--). Data after Madgwick et al. 1977. *Nutrient: for one-year-old foliage, mean values for N, P, K.

**FIGURE 8** — Contrast between control trees (no fertilizer) on left, trees treated with soluble fertilizer (15 g N, 15 g P per tree) in centre, and trees treated with insoluble phosphate rock (56 g P/ha) on right.

**FIGURE 9** — An example of the widespread nature of potassium deficiencies in certain areas of Northland (pale areas are trees deficient in potassium).

**FIGURE 10** — Extreme copper deficiency brought about by an unbalanced application of soluble fertilizers.
Shenstone Forest and Takau Bay established in 1978 were retreated with fertilizer when they were two years old, receiving half a tonne of DAP and 200 kg of muriate of potash per hectare (a 9:10:10 mix giving 90 kg of N, 100 kg of P, and 100 kg of K). By age four, the trees which had received a second application of fertilizer showed a 35 cm height gain and a 24 mm diameter gain over those trees that had not been retreated. At one site the re-application of fertilizer lifted total height to 4.9 m and mean diameter to 150 mm (values achieved in Kaingaroa). Apparently the trees on the northern podzols did suffer from nutrient shortages, necessitating additional fertilizer applications between ages two and four, but fewer between age four and six.

In summary, past research by FRJ has shown that although it is possible to establish radiata pine on the North Auckland podzols and to grow them as fast initially as in the better parts of Kaingaroa, there is a cost involved in terms of fertilizer application. It could be inferred that the spade slit method application used was sub-optimal, giving only a short-term protection against nutrient deficiency. It seems likely that this method placed the fertilizer in such a way that the roots of two-year-old trees were unable to continue to exploit it and the remaining phosphate had probably reverted to less soluble and therefore less usable forms. Ideally trees should receive an appropriate amount of fertilizer, that becomes slowly available and meets their long-term nutritional requirements. For phosphorus at least a source of fertilizer was potentially available, as cheap insoluble phosphate rock (Christmas and Nauru A grade).

**Trials with phosphate rock**

The first two trials with phosphate rock at the time of planting were established in 1980; one on a sand podzol near Te Kao, the other on a clay podzol south of Kaikohe. In each trial there were three main broadcast fertilizer treatments: control, phosphate rock (Christmas A/Nauru A blend, 15% P) at 1 tonne/ha, and a mix of superphosphate with phosphate rock (1:1 w/w) at 1 tonne/ha. Within each broadcast treatment varying combinations of soluble N, P, and K fertilizer (at 5 g elemental each) were applied as a "starter dose" in a spade slit beside the trees. At each site the soils were ripped and bedded.

Up to age two there was little difference in growth between the trees that had received a starter dose alone, and those growing on the broadcast fertilizer treatments, regard-less of starter dose. Between ages two and four the growth of the trees with the starter dose alone slowed, while those that had received broadcast fertilizer continued to grow well, maintaining foliar P concentrations at a satisfactory level (Skinner, unpubl. data). Subsequent trials demonstrated that the first year's growth of trees that had received an application of phosphate rock alone was slower than that of commercially-grown trees on comparable soils receiving soluble fertilizers as starter doses, equivalent to 15 g P (and N) (Fig. 8). From the second year, however, phosphate rock-treated trees began to accelerate in growth, whereas the trees that had received only the small starter dose (equivalent to about one-fifth of the rate on a per hectare basis) showed early signs of nutrient deficiency.

In contrast to trials with starter doses of superphosphate fertilizer, nitrogen concentrations in the foliage of trees in broadcast plots declined to a lesser extent between ages two and four. This may have resulted from greater root vigour, through a high P status, or an improved carbon to phosphorus ratio in the topsoil leading to more rapid mineralization and/or the spontaneous invasion of N fixers such as lotus and acacia. Directing and managing the N fixers may be a way to permanently improve the N nutrition of these soils.

**Potassium**

As mentioned above, the foliar potassium concentrations at Utakura fell dramatically from 1.0% at age two to 0.3% at age four. A lesser decline was observed at Waipoua. In the fifth spring the bright yellow tips diagnostic of potassium deficiency (set at 0.4% from overseas work) appeared on needles in the lower crown. However, three years after applying a range of fertilizer options at age four there was a potassium gain of 6 m²/ha basal area at Utakura and 2.5 m²/ha at Waipoua (Hunter 1984).

In trials where potassium had been included in the NP starter dose, foliar concentrations have been 0.1-0.2% higher at ages one and two than in other trials. However, since potassium concentrations were always well above deficiency levels at those ages, there was no increase in growth when potassium was added. The decline in foliar potassium between ages two and four is such that this small increase between age one and two appears to have no effect on the onset of deficiency or on the typical minimum concentration in trees on the site.

To date, of all sites studied the Utakura site slumped into the deepest potassium deficiency. The Waipoua site went less deficient and recent analyses from the Parengarenga trials showed an adequate concentration of potassium (0.7%) at the clay site and only a satisfactory concentration (0.5%) at both podzolized sand sites. Thus some but not all sites (see Fig. 9) will require potassium fertilizer from the air at approximately age four. These sites can best be identified by foliage analysis. Recommended applications of fertilizer are 80 kg/ha of K (160 kg ha of muriate of potash). Fortunately, potassium is one of the cheapest elements to apply, costing only $100 per tonne of element, as against $1000 for N and $1500 for P.

**Minor Elements**

**COPPER**

Copper (Cu) deficiency can cause twisting of the main stem and branches (Fig. 10), but it is important to note that not all twisting is attributable to this factor (Will 1981). Fortunately the twisting induced by wind and rain often assumes a similar pattern among trees of one stand.

Copper concentrations tend to be low in radiata pine foliage over much of North Auckland. Experience in FRJ trials has shown that the insensitive use of high application rates of pure NP fertilizers, either at the time of planting or later, can induce the branch and stem twisting indicative of a copper deficiency. This malformation is likely to affect only a small proportion of trees at normal rates of pure NP fertilizer application, so managers can either ignore the twisting and remove affected stems in silviculture, or else use fertilizers containing copper such as the forestry mix offered by some Northland fertilizer companies. Copper oxychloride (7-10 kg Cu/ha) as a foliar spray is a satisfactory treatment remedy.

**ZINC**

Recent re-analysis of foliage collected in 1980 at Utakura...
showed zinc concentrations between 3 and 11 ppm (parts per million) — i.e. below the deficiency level of 10-15 ppm. Affected trees have dead buds surrounded by many small lime-green-coloured shoots and tree height growth is markedly affected. This belatedly-revealed zinc deficiency may explain why height growth in trees treated with NP fertilizer alone was actually less than in the untreated control trees (Hunter 1984).

In 1984 zinc deficiency was discovered in one- and two-year-old trees on Cape Karikari (Fig. 11). There is, moreover, a fairly high level of multi-leadering in crops on the podzolized soils which may be a symptom of transient zinc deficiency. Thus, like copper, zinc is low to marginal on most soils but, unlike copper, the likelihood of zinc deficiency cannot yet be accurately predicted for every site.

REFERENCES