THE ESTABLISHMENT OF SECOND-ROTATION RADIATA PINE IN RIVERHEAD FOREST

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SYNOPSIS

It is suggested that there are four principal factors which ensure successful establishment of young trees and form the first stage in the production of sawlogs and pulpwood in greater quantities and of better quality than have been grown in many first-rotation stands in Riverhead Forest. These factors are summarized as: (1) The necessity of having a clean or weed-free site; (2) The use of well hardened nursery stock which is well planted; (3) Adequate early hand topdressing with a phosphatic fertilizer; and (4) Where necessary, timely releasing of the crops from competing regrowth vegetation.

Planting trees which show a marked tolerance of low soil phosphate concentrations yet remain healthy and vigorous and/or demonstrate superior responses to topdressing is a further factor in achieving these production objectives.

Natural regeneration is too sparse and irregularly distributed to be relied upon for successful establishment of second-rotation crops.

In the paper, the techniques of achieving clean sites, tree-planting methods, planting costs, spacing and treestock survivals are discussed. Excellent results from manual topdressing young trees are indicated, while some aspects of fertilizer trials in Riverhead are outlined. Techniques for controlling competing regrowth vegetation are discussed.

INTRODUCTION

Riverhead Forest was planted some 40 years ago and is situated at the head of Waitemata Harbour, where the forest occupies nearly 12,000 acres of rolling hill country left in a barren, wilderness-like state following several decades of scrub burning and digging of the soil for kauri gum by early settlers. Nowadays, Riverhead strongly complements the intensive and varied agricultural uses of surrounding land and also a rapid urban expansion of metropolitan Auckland. Indeed, Riverhead is within sight of much of Auckland and in the not too distant future will provide a backdrop to many more homes than it does today.

The forest was established largely in radiata pine between 1926 and 1933. Smaller areas were planted with Corsican pine and a number of minor species. The physical features of Riverhead Forest are described by Weston (1956) who continues with an account of the unthrifty growth of radiata pine, which became evident at an early stage especially in stands growing upon hill crests and upper valley slopes. This very poor growth

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was shown to be caused by poorly structured, low fertility soils and in particular to a severe deficiency of soil phosphate. Early experimental work demonstrated that the decline in health and vigour of trees could not only be arrested but strongly reversed by application of superphosphate, and Conway (1962) gives an account of a large-scale management programme of aerial topdressing many of the debilitated stands.

Some effects of topdressing on phosphorus content of foliage, wood and bark are given by Will (1965) while Mead (1968a) describes quantitatively the excellent growth of radiata pine over a 10-year period following early aerial topdressing. Recent inventory data have also shown that outstanding improvements have taken place in the forest following this treatment.

It is perhaps something of a paradox that parts of the forest, often overlooked by one's preoccupation with the extent and severity of phosphate deficient tree growth, are located on utropic, valley bottom soils and display superlative growth, yet these same stands are in close proximity to their strikingly less productive neighbours.

For several years, only small volumes of timber had been cut from radiata pine stands, a proportion of it as thinnings, but in 1965 the output from the forest was increased to more than 1 million cubic feet annually. All of the yield is taken from clearfelled crops, the majority of it being radiata pine. The removal of these resources, extends across more than 500 acres annually. In consequence, the establishment of second-rotation crops has, locally, become a management operation of some magnitude.

Natural Regeneration. Early in the reafforestation programme it became evident that natural regeneration of radiata pine was too sparse and too irregularly distributed to be relied upon for successful establishment of second-rotation crops. Very limited areas of acceptable regeneration do develop but its distribution bears little relation to soil type, topography or merchantability class of forest. The occurrence of regeneration does, however, have some affinity with early summer logging. In contrast with experience at Maramarua Forest following aerial topdressing (Conway, 1962), many topdressed stands do not bear an increased number of branch or stem cones and this feature may be one explanation for the paucity of regeneration. Other reasons suggested for the absence of regeneration are, firstly, the presence of seed-eating birds which probably consume some of the seed shed from cones, and, secondly, the unfavourable seed germination conditions especially during dry weather on indurated, generally infertile and poorly structured clay and clay loam soils.

Establishment by Planting. In the absence of satisfactory natural regeneration, the establishment of second-rotation crops is achieved by hand planting of nursery raised stock. From observations on the early growth of young stands, it is evident that there are four principal factors which when applied together ensure successful establishment of young trees. These may be summarized as follows:

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The necessity of having a clean or weed-free site.

The use of well-hardened nursery stock which is well planted.

Adequate early hand topdressing with a phosphatic fertiliser.

Where necessary, timely releasing of the crops from competing regrowth vegetation.

These factors are necessary, not only to successfully re-establish the forest upon a series of impoverished soil types, but as the first stage in the production of sawlogs and pulpwood in greater quantities, and of better quality than have been grown in many first-rotation stands.

As a further step in achieving these objectives, it is intended shortly to plant tree stocks grown from seed collected from trees which show a marked tolerance of low soil phosphate concentrations yet remain healthy and vigorous and/or demonstrate superior responses to topdressing while retaining such desirable characteristics as stem straightness and light branching. Going one stage further, the extensive use of cutting stock in the not too distant future for the afforestation of at least the most impoverished sites will usefully complement the topdressing programmes and together will lead to the development of more highly productive radiata pine stands in Riverhead.

Weed Growth. Although the success of re-establishment is dependent upon many factors, perhaps the most important single contribution in this direction can be made by replanting cutover land while it is predominantly free of regrowth vegetation. Where replanting follows summer, autumn and early winter logging, the land at the time of planting and for several months afterwards is largely weed-free and only minimal competition for light, water and nutrients (especially added phosphate) is offered to trees. The most troublesome species of competing regrowth — gorse, *Gahnia setifolia*, bracken, manuka and scrub hardwoods — do, however, become relatively dense on land which has been logged in late winter and spring or on country where restocking has been delayed for more than 12 months.

In order that as much land as possible may be restocked in the winter following logging, clearfelling operations are planned to ensure that cutting boundaries are straight or at least follow well-defined topographical features up to which new stands may be planted. Logging proceeds in three or more compartments at any one time and thus restocking is dispersed. Accordingly, second-rotation stands tend to be relatively small (50 to 150 acres), whereas first-rotation stands are commonly between 200 and 500 acres in area.

Planting Costs. The relatively high productivity of planting crews on clean sites in comparison with weed and slash covered cutovers is reflected in the cost data for the planting of three areas in 1968 given in Table 1.
### TABLE 1: EXAMPLES OF PLANTING COSTS PER ACRE, RIVERHEAD FOREST, 1968

<table>
<thead>
<tr>
<th>Compt.</th>
<th>Area (ac)</th>
<th>Planting cost ($)</th>
<th>Supervision cost ($)</th>
<th>Condition of land</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>29</td>
<td>16.45</td>
<td>1.41</td>
<td>Very clean.</td>
</tr>
<tr>
<td>3</td>
<td>42</td>
<td>18.81</td>
<td>2.36</td>
<td>Some slash and undergrowth.</td>
</tr>
<tr>
<td>4</td>
<td>55</td>
<td>25.13</td>
<td>3.80</td>
<td>Slash, old undergrowth and regrowth.</td>
</tr>
</tbody>
</table>

Access into these stands and the topography of each (easy slopes up to 10°) are comparable.

**Pre-logging Crushing.** An aid in securing a clean site, as well as increasing the productivity of logging crews, is pre-logging crushing of undergrowth vegetation in low to moderately productive stands (1,000 to 3,500 cu. ft/acre) which are to be logged by tractors. Undergrowth vegetation is exceedingly dense in many places and before this operation was introduced considerable areas of undergrowth remained after logging, so that it was necessary to cut access lines before planting. Undergrowth vegetation beneath type I tractor logged stands, and of course beneath stands which are logged by hauler, is completely damaged by these operations and crushing is not necessary.

**Controlled Burning.** Since the land is left in a comparatively clean condition following logging, it has been necessary to use controlled burning on only one occasion to clear slash and remaining undergrowth, and this burn was in conjunction with the clearing of a much older cutover which supported dense *Gahnia* regrowth. However, where extensive areas of heavy slash do accumulate, as they might following logging of Corsican pine, controlled burning offers a means of effectively clearing the site and should be used with less hesitation than it has been in the past. The cost of not doing so will be incompletely stocked second-rotation stands.

Other aspects of the utility of a clean site are discussed later in this paper.

### PLANTING AND SURVIVAL RATES

The close proximity to the forest of the regional Kumeu Nursery enables the trees to be lifted, packed, transported and planted with a delay of only 1 to 2 days. In view of the short period that trees are out of the soil, they are not puddled but are packed bare-rooted in cartons for dispatch to the forest.

**Planting Season.** All planting must be carried out between June and August, as the soils are too hard and dry for trees to be effectively planted outside this period. Furthermore, some difficulty in producing adequately hardened tree stocks earlier or later than this has been experienced in spite of a
severe wrenching programme. The use of well-hardened trees is essential in order to secure good survivals and to reduce or obviate the need for blanking.

**Spit-planting.** Trees are spit-planted using spades, as upon these poorly structured and impoverished soils, especially Waikare clay and hill clay soils, notch planting without preliminary cultivation about each tree leads to root exposure and very often the death of trees when the soil dries and the notch opens during the warmer months. In the past all trees planted were of 1/0 age, but recently 1\%/0 (autumn sown) tree stocks have been successfully spit-planted upon the deeper and more fertile Waitemata clay loam complex of soils and in sites where competing regrowth vegetation is present. Except upon exposed sites, 1\%/0 tree stocks are also used for blanking work. The use of these larger and possibly more vigorous tree stocks is expected to increase, especially if recently developed motorized hole-digging proves applicable for large-scale forest operation. This machine would enable the soil to be more efficiently cultivated than is possible using spades, it would allow trees to be planted at a greater depth, and in consequence tree stock survivals would probably be higher than they are at present. In addition, the use of a hole-boring machine for tree planting would probably allow fertilizer, which is applied to each tree at the time of or shortly after planting, to be more readily accessible to the root systems of trees and allow the planting season at Riverhead to be extended.

**Tree Stock Survivals.** From observations on both ages of tree stocks, there is no clear evidence that higher survivals are associated with the use of the larger 1\%/0 tree stocks than for 1/0 age trees. The highest survivals are recorded upon predominantly weed-free sites where deep spit-planting of adequately hardened stock is readily practicable. Data in Table 2 illustrate this point further.

It is clear that much more investigation is necessary to examine the utility of large trees in comparison with smaller trees from the points of view of tree stock survival, and tree

<table>
<thead>
<tr>
<th>Compt.</th>
<th>Time of planting</th>
<th>Survival %</th>
<th>Tree stock age</th>
<th>Condition of site</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 (part)</td>
<td>Jun.-Jul., 1968</td>
<td>60-76</td>
<td>1/0</td>
<td>Old undergrowth and some heavy slash</td>
</tr>
<tr>
<td>4 (part)</td>
<td>Aug., 1967</td>
<td>85</td>
<td>1/0</td>
<td>Generally clean</td>
</tr>
<tr>
<td>4 (part)</td>
<td>Aug., 1968</td>
<td>75</td>
<td>1/0</td>
<td>Slash, old undergrowth and some regrowth</td>
</tr>
<tr>
<td>2</td>
<td>Jul.-Aug., 1968</td>
<td>88</td>
<td>1/0</td>
<td>Generally clean</td>
</tr>
<tr>
<td>8</td>
<td>Aug., 1968</td>
<td>84</td>
<td>1/0</td>
<td>Very clean</td>
</tr>
<tr>
<td>3</td>
<td>Aug., 1968</td>
<td>81</td>
<td>1/0</td>
<td>Generally clean</td>
</tr>
</tbody>
</table>
stock vigour in relation to competition from regrowth vegetation and rate and mode of application of fertilizers applied at about the time of planting.

I would mention here that mortalities of planted tree stocks are not known to be caused by *Hylastes ater*, although this insect is present in the forest and has occasionally killed young trees of regenerated origin.

**Spacing of Second Rotation Stands.** The standard espacement for planting radiata pine in Riverhead is 8 ft × 6 ft (907 s.p.a.). There is, however, some evidence (Sutton, 1968) which suggests that the establishment of stands at a lower density than this will lead to more profitable timber production. Although it is possible, indeed probable, that much of the second-rotation radiata pine will be sawn to framing rather than to board grades, for which proposals embodying wide spacing have been made (Fenton and Sutton, 1968), it is considered that, because of the good form of trees in many first-rotation stands, the adoption of a wider espacement, at least to 10 ft × 6 ft, would be advantageous upon all sites in the forest. For this change to be successful, the forest manager must endeavour consistently to plant second-rotation stands which have high survivals (i.e. > 90%). More efficient planting (possibly using motorized hole-diggers) on clean sites may lead to this ideal condition.

**MANUAL TOPDRESSING OF YOUNG STANDS**

Manual topdressing of young trees has become a regular management operation in Riverhead but much work is necessary to develop this technique further. Hand application of phosphatic fertilizers at the time of or shortly after planting is the first stage in accelerating the early growth of trees and of forming stands which will be significantly more productive than at least 4,000 acres of first-rotation stands have been. Equally important, manual topdressing is also the first stage in the formation of forest stands which will be far less variable in unit productivity than are most first-rotation stands. Notwithstanding that a continuum of natural soil phosphate concentration with respect to topography will continue to be expressed as variations in tree growth rate, the addition of phosphatic fertilizers at intervals through the rotation, commencing with an application at the time of planting, is expected to make the expression of natural fertility much less marked. In consequence, the greater uniformity of second-rotation stands will simplify some aspects of forest management work — for instance, the planning of inventory and thinnings — while the more homogeneous and predictable log size categories which will be produced will enable industrial planning to be undertaken more confidently and log conversion carried out more efficiently.

**Rate and Technique of Application.** At present, hand dressing of trees with superphosphate is undertaken in the spring or early summer after planting. The fertilizer is applied at the
rate of 4 oz per tree (equivalent to 2 cwt/acre) and is placed in a notch made with a spade 6 to 9 in. from the tree. Where it is practicable to do so, the notch is made and superphosphate is applied on the uphill side of the tree. The purpose of placing superphosphate in notches is to bring the material closer to tree roots and to confine it within close proximity of each tree. Although much of the fertilizer becomes chemically bound to the soil at an early date (D. J. Mead, pers. comm.) — in fact, the majority is probably not immediately available to trees at all — any attempt to prevent superphosphate from becoming available to competing vegetation, in particular gorse, is worth while. Placement of superphosphate upon the soil surface surrounding each tree causes it to be much more readily available to gorse, while erosion by rain or slopes distributes it more widely to competing vegetation. The prolific growth of gorse immediately surrounding trees in several fertilizer trials is evidence of the serious disadvantage of surface application. True, notch application of superphosphate has the disadvantage of making an unbalanced dressing, but this method of application appears to reduce fertilizer availability to competing vegetation yet allows responsive, early growth of the trees.

It is partly for this reason that fertilizer is not applied from aircraft at this stage. The other reason is that aerial topdressing of young stands simply does not make sufficient superphosphate available to each individual tree. The aggregate area of root systems of newly planted trees projected on to the ground surface is about 0.5% of the surface of a stand and accordingly the weight of fertilizer falling above the root system of each tree at a rate of 2 cwt/acre, assuming uniform distribution, is only 1/50th of one ounce per tree.

Manual topdressing is clearly a most important forest operation and the addition of superphosphate must give each tree a boost in growth sufficient at least to last for 6 to 8 years, when a substantial degree of canopy closure and suppression of competing vegetation is expected to have occurred and the root systems of trees are comparatively extensive. Only when this stage is reached can the first of a series of aerial applications of fertilizer be contemplated.

The inevitability of some competition for added phosphate at an early stage, especially from gorse, emphasizes the high utility which must be placed upon sites which are largely weed-free for the establishment of new crops.

Costs of Manual Topdressing. The cost of hand application of superphosphate is considerably less than for tree planting or pruning operations as the data in Table 3 for topdressing 560 acres in spring, 1968, illustrate.

The cost range for application of superphosphate over the five stands treated is from $4.00 to $10.00 per acre. This variability is caused by differences in access to stands for distribution of fertilizer and access for men, and differences in topography and cleanliness of the site. Of the total cost per acre, 4% is a supervision charge.
TABLE 3: COST OF MANUAL TOPDRESSING YOUNG RADIATA PINE STANDS

<table>
<thead>
<tr>
<th>Cost item</th>
<th>Cost per acre ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wages and salaries</td>
<td>8.88</td>
</tr>
<tr>
<td>Superphosphate</td>
<td>2.18</td>
</tr>
<tr>
<td>Transport (men and materials)</td>
<td>0.25</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11.31</strong></td>
</tr>
</tbody>
</table>

_Fertilizer Trials._ The use of superphosphate in preference to other forms of fertilizer is based upon measurements and observations in several trials which have been set up in the forest. Some recent results of one trial in which different rates of superphosphate and calcined Christmas Island rock phosphate are compared upon Waikare clay soil in compartment 12 are shown in Table 4. These measurements are based upon four replications, each of 25 trees.

Magamp (2 oz/tree) and superphosphate (4 oz/tree) have produced the greatest responses, followed by rock phosphate (4 oz/tree). While magamp contains two macronutrients (N and Mg) in addition to a higher phosphate content, this slow-release fertilizer has produced only marginally better growth than superphosphate. A commercially available form of this fertilizer (40% P) containing a fourth nutrient (K) is more than 10 times the price of superphosphate (9% P) and for these reasons is not employed for general forest use. Calcined rock phosphate is also a slow-release fertilizer but, notwithstanding the higher P content (14%), this material does not have the ability to accelerate the early growth of radiata pine to the extent of a similar weight of superphosphate.

While this evidence suggests that the use of superphosphate is preferable to other phosphatic fertilizers for securing rapid tree growth during the establishment of second-rotation stands, it is important to enquire whether this tentative advantage, particularly over rock phosphate, is maintained in older crops when fertilizers will be applied from aircraft.

During 1967, manual topdressing was carried out in different stands using superphosphate and calcined Christmas Island rock phosphate, each in mixture with ammonium sulphate and applied at a rate of 4 oz per tree (3:1 ratio). The addition of the nitrogen fertilizer was considered to be beneficial in accelerating early height growth. Recent interim analyses of limited growth data by the Forest Research Institute, for a trial in which the fertilizer mixture is represented, indicate that the addition of ammonium sulphate to superphosphate has produced only a small positive growth response over the application of 4 oz of superphosphate alone (Mead, 1968b). The addition of a nitrogenous fertilizer was discontinued, at least in the meantime, for this reason and also because the 3:1 mixture is up to 15% more expensive than 4 oz of superphosphate alone.

Upon this trial area the application of a mixed nitrogen/phosphate fertilizer has caused 4-year-old trees to develop
## TABLE 4: HEIGHT GROWTH RESPONSES FOLLOWING THE APPLICATION OF FERTILIZER TREATMENTS TO INDIVIDUAL TREES

<table>
<thead>
<tr>
<th>Height measurements and results</th>
<th>Nil (Control)</th>
<th>Magamp 2 oz</th>
<th>Superphosphate 4 oz</th>
<th>2 oz</th>
<th>Rock phosphate 3 oz</th>
<th>1 oz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean heights Oct., 1965 (in.)</td>
<td>12.66</td>
<td>15.94</td>
<td>16.60</td>
<td>13.33</td>
<td>15.10</td>
<td>13.66</td>
</tr>
<tr>
<td>Mean heights Jan., 1968 (in.)</td>
<td>42.96</td>
<td>76.93</td>
<td>75.12</td>
<td>56.81</td>
<td>60.54</td>
<td>51.76</td>
</tr>
<tr>
<td>Differences (in.)</td>
<td>30.30</td>
<td>60.99</td>
<td>58.52</td>
<td>43.48</td>
<td>45.44</td>
<td>38.10</td>
</tr>
<tr>
<td>Height growth indices*</td>
<td>100.0</td>
<td>201.3</td>
<td>193.1</td>
<td>143.5</td>
<td>150.0</td>
<td>125.7</td>
</tr>
</tbody>
</table>

*The height growth of the control is taken as a base index of 100.0.
more bushy crowns than in plots where a superphosphate only treatment was made (D. J. Mead, pers. comm.). The significance of this feature in relation to the early formation of a closed canopy and subsequent suppression of competing vegetation is being followed upon the stands topdressed with the mixed fertilizer in 1967.

The results from several experimental areas in Riverhead certainly justify the use of chemical fertilizers as a means of dramatically accelerating the early growth of radiata pine trees, but there is nevertheless a considerable amount of work to do to answer the many questions which are presented by the broad gaps in this novel aspect of forest establishment work. For instance — What is the most effective means of applying fertilizer? Are there any significant advantages in adding nitrogenous or other nutrients to the phosphatic fertilizer? and, Is the application of very high rates of superphosphate justified, and for what reasons? These problems must necessarily be examined in relation to other aspects of forest establishment, tree stock size and survival, planting methods, and the growth and control of competing vegetation. Some of these questions may shortly be answered from future remeasurements on experimental areas established over the past 2 to 4 years.

**CONTROL OF COMPETING REGROWTH**

It will be evident from the remarks made in different sections of this paper that the growth of vegetation upon restocked cutover land can be a very real problem in satisfactorily establishing second-rotation crops in Riverhead Forest. Effective control of regrowth which can offer severe competition to trees for added fertilizers, light and soil moisture cannot be over-emphasized.

Experience in establishment work since 1966 has indicated to the forest manager that “prevention rather than cure” is the most realistic way of meeting this problem. Accordingly, the practice of planting land as soon as possible after logging is a satisfactory means of allowing young trees to have a substantial period of “free growth” before serious competition develops. Indeed, in places where gorse is absent, this procedure is the only vegetation “control” which is employed; releasing after planting is unnecessary.

Gorse is the most important single species of regrowth and is more extensive in Riverhead than early forest records or inspections of vegetation beneath first-rotation stands have indicated. While hand release-cutting is effective in controlling it, and is regularly used where patches of gorse require attention, this method is relatively expensive and with a limited labour force it is not always possible to repeat the operation when it is required.

Alternative approaches on vegetation control are based upon the use of chemical solutions sprayed from ground equipment or from aircraft. The growth of an extensive area of gorse in one young stand was effectively limited for an 8- to 10-week period following an aerial application late in 1968.
of a picloram ("Tordon 75-T") solution (1.2 pt/15 gal of water per acre) with only negligible damage to the trees. Inverted cone and "Arbogard" hand-held sprayers have been used to apply paraquat and 2,4,5-T solutions and, while this means has in some instances been of value, the overgrowth of gorse from unsprayed plants between rows has required supplementary slasher releasing.

A potential handicap in using spray releasing techniques, but which fortunately have not yet been restrictive, is the Agricultural Chemicals Regulations, 1968. Approximately half of the area of Riverhead Forest lies within five miles of an extensive area of vineyards in the Kumeu District to which these regulations apply. To overcome this problem, a winter-time, aerial application of a mixed paraquat/2,4,5-T solution was attempted before planting, but was unsuccessful.

CONCLUSION

Successful establishment of young trees is the first stage in the practical management of forests. For Riverhead, the principal points in the establishment of second-rotation stands of radiata pine are efficient planting of nursery-raised stock upon clean, weed-free cutover land, adequate manual top-dressing with superphosphate, and vigilance towards competing regrowth vegetation. The application of establishment techniques incorporating the results of enquiry and research will contribute to the useful role that Riverhead Forest can play in the production of timber early in the twenty-first century.

REFERENCES