RESEARCH INTO THE DIRECT SEEDING OF WOODY PLANTS IN HIGH COUNTRY REVEGETATION

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Abstract

Revegetation of high country by direct seeding with woody species was investigated in the Craigieburn Range, using Pinus contorta, P. mugo, and Alnus viridis.

Cover was essential to protect seedlings from extreme climatic effects, particularly winter frost heave, and the most practical way of providing cover was with a sown sward of grasses and legumes.

Although survival of P. mugo on bare ground was assisted by the application of a complete fertiliser mix, on sward-covered ground high rates of fertiliser increased interplant competition and depressed the survival of tree seedlings.

Tree seed pelleting with a variety of nutrients did not improve seedling survival or growth.

In pot trials mycorrhiza development in the roots of pines greatly increased seedling growth. Coating seeds with basidiospores of these fungi has not, so far, proved a practical means of field inoculation.

Spring sowings were more successful than autumn sowings except on sites covered with snow throughout the winter.

INTRODUCTION

The objective in revegetation research is to develop methods leading to closed vegetation cover on eroded slopes, in order to control soil and stone movement. The aerial sowing of woody plants, well-adapted to eroded soils, would clearly be a desirable technique if it could be developed effectively.

Aerial seeding of pines for erosion control has been used on a large scale in Marlborough (Slow, 1970; Hayward and Wishart, 1975) and in Hawke’s Bay (Faulkner et al., 1972). The latter authors concluded that aerial seeding of P. contorta could be used to revegetate the main areas of eroding and erosion-prone surfaces up to 1220 m a.s.l. in Kaweka Forest.

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However, their data show that, 6 months after sowing, seeding had been unsuccessful on 46 to 70% of the plots established on the six site types described. Even on those plots where seedlings did establish in the first season, there were losses of up to 90% over the next 4 years. This emphasises the need for considerable improvements if aerial seeding is to be fully effective.

The trials reported here were carried out by the Forest Research Institute, Rangiora, on sites in the Craigieburn Range, an area which typifies the eroded mountain lands of the South Island. The dominant climatic patterns and geography of the area have been described by Morris (1965). The natural instability of the basement rocks, excessive grazing, and fires have led to the loss of the topsoil from much of the area, thus removing over 90% of the available plant nutrients. The remaining exposed subsoils are not only extremely infertile but also particularly prone to erosion by frost heave and wind action. The climate, whilst not unfavourable for plant growth, is insular and unpredictable so that unseasonal climatic extremes of temperature and precipitation, coupled with frequent strong winds, tend to dominate growth patterns.


Since 1963 most trials have involved Pinus contorta, P. mugo, and Alnus viridis as these species have proved well-adapted to growth in high altitude climates and on eroded soils.

This report summarises some of the results obtained and discusses the need for further research to make direct seeding more reliable. Many of the trials discussed here are treated more fully in the unpublished report of Ledgard (1974).

RESULTS OF INDIVIDUAL STUDIES

Site and Species

The earliest trials were established between 1000 and 2000 m a.s.l. on a range of sites, including intact vegetated topsoils, broken grasslands, exposed subsoils, and mobile screes.
Assessments carried out 8 years after sowing (McCracken, 1969) located seedlings of only the last eight species listed above. Survival rate was very low, and was influenced noticeably by site factors. On all sites most species had germinated but on scree and exposed subsoils seedlings failed to survive. In areas of broken grassland vegetation, where there was some topsoil and cover, few seedlings survived but their growth after a few years was adequate.

The reason for the poor survival on eroded sites was not certain, but it seemed that exposure, particularly to frost heave, was the principal cause. Frost heaving (or frost lifting) results from the successive freezing at and just below the soil-surface of moisture drawn upwards by capillary action. The severity of a heave depends primarily upon the amount of water available and the nature of the temperature fluctuations (Graber, 1971). The fine-textured clay-like high country subsoils are particularly susceptible to frost heaving when exposed. Graber also noted that the retention of some of the plant cover on areas to be direct-seeded reduced the number of seedlings affected by frost heave.

**Cover**

A number of trials were established to investigate the effect of cover. In one trial, *P. contorta* was sown on exposed subsoil, amongst native grasses, and under mountain beech (*Nothofagus solandri* var. *cliffortioides*) canopy at two altitudes and survival was observed over 18 months. The results (Table 1) showed that, although germination was good on bare ground, most seedlings failed to survive the first winter. Under the native grasses there was less germination but

<table>
<thead>
<tr>
<th>Altitude (m)</th>
<th>Germination (%)</th>
<th>Survival (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsoil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>1500</td>
<td>38</td>
<td>2</td>
</tr>
<tr>
<td>Native tussock*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 (short tussock)</td>
<td>16</td>
<td>11</td>
</tr>
<tr>
<td>1500 (snow grass)</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Under beech canopy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>1500</td>
<td>12</td>
<td>0</td>
</tr>
</tbody>
</table>

*Seedlings difficult to locate.
greater survival, notably at the lower altitude site. Moderate germination under the beech canopy was followed by death of all seedlings, not, however, because of frost heave.

With maximum germination on bare ground, the problem was to improve seedling survival and growth on those sites which were subject to frost heave over winter. A pilot trial was set up (U. Benecke, pers. comm.) to examine the effects of thatching (manuka brush), beech litter, and fertilised and unfertilised exotic grass/clover sward on the survival and growth of \textit{P. contorta}, on an exposed subsoil slope 1000 m a.s.l. Thatching and beech litter improved survival approximately three-fold by reducing the effect of frost heave. The grass/clover sward initially depressed survival, especially in fertilised treatments, but over winter the fertilised sward maintained its number of tree seedlings better than the unfertilised or control plots.

These results suggested that grasses and legumes should be fertilised to give effective cover, and that by varying fertiliser levels this cover could be manipulated so as to decrease frost heave and still allow survival of sown pines.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Effect of cover and fertilisers on the survival of \textit{P. contorta} after one winter in Craigieburn Range.}
\end{figure}
In 1969 a factorial trial was laid out in the Craigieburn Range to examine the effect of the legumes white clover (Trifolium repens) and Lotus pedunculatus, a grass, Yorkshire fog (Holcus lanatus), and fertiliser in the form of superphosphate and nitrogen, on the survival of P. contorta. Sward growth did not exceed 5 cm in height and, particularly in grassed plots, nitrogen produced a marked effect on the survival of P. contorta at most levels of superphosphate (Fig. 1). However, the magnitude of this effect declined when superphosphate was applied at 2000 kg/ha. At this level, clover growth was so dense that it severely limited pine survival. A similar trial was established in the Kaweka Range, Hawke's Bay. There, sward growth was up to 20 cm high and increased levels of superphosphate application, with the consequent increase in cover, clearly depressed tree survival (Fig. 2).

A further field trial was carried out to determine the merit of seeding pines and Alnus viridis into a sward aerially sown 2 years previously and visibly deteriorating. Survival of the

![Graph showing the effect of cover on survival of P. contorta after one winter in Kaweka Range.](image)
tree species was still low (Pinus contorta 0.5%; P. mugo 0.4%; Alnus viridis 0.03%) but competition was less severe than under more complete younger swards.

A pot trial involving fortnightly harvests was conducted at 1000 m in the Craigieburn Range to establish the level of seedling growth depression caused by a competing grass mulch (Fig. 3). After 26 weeks' growth seedlings growing in a vegetative cover of browntop (Agrostis tenuis) and Yorkshire fog produced less than half the dry weight of those in the ungrassed controls.

**Moisture**

Within the same pot trial an attempt was made to determine whether the poor performance of seedlings under grass could be attributed to moisture stress. Plant water potential was determined using a "pressure chamber" technique (Scholander et al., 1965). It was found that P. mugo seedlings from the grass treatments were under greater moisture stress than those from ungrassed control pots. Although lower water potentials were associated with reduced growth, seedlings did not die until after prolonged droughting.
Mycorrhizas and Fertilizers

Ectotrophic mycorrhizal fungi are important in growth of pines, and both ectotrophic mycorrhizal fungi and the nodule endophyte are important to *Ahuus viridis*. Benecke (1969; 1970) has covered some aspects affecting nodulation of *A. viridis* and the distribution of the nodule endophyte in New Zealand soils.

In a field trial at 1300 m, *P. mugo* seedlings (2 cm high) transplanted into subsoil survived where a complete fertiliser (N, P, K, Mg, S, and micro-nutrients) was added, but not in P alone or in unfertilised plots (C. M. Kelland, pers. comm.). In order to obtain more information on response to nutrients and to mycorrhizas, a glasshouse pot trial using Bealey subsoil was established to examine the individual and combined effects of nitrogen, phosphorus, and mycorrhizas on the growth of *P. mugo* seedlings. Mycorrhizal inoculation was effected by placing a 1 cm deep pine duff layer just below the subsoil surface. The controls contained sterile duff. The main effects after 16 weeks are shown in Fig. 4. There was a consistent increase in growth of mycorrhizal plants when P was added up to 160 kg/ha superphosphate, whereas there was a peak in response to N at 20 kg/ha. The ratio of N to P seemed to be critical, with the best individual growth of mycorrhizal plants (1.70 g) occurring at the N40:P160 kg/ha

![Figure 4](image-url)
level (data for fertiliser combinations are not shown in Fig. 4). For either P or N individually, the growth of non-mycorrhizal plants was consistently less than that of the inoculated plants at all but the highest levels of added P.

The results suggest that fertiliser application and mycorrhizal inoculation could be important in the field in promoting early seedling vigour before the onset of winter frosts. Because of the considerable inefficiency in applying a blanket fertiliser treatment when only 1000 to 2000 trees/ha are required, it would be better to apply the necessary nutrients close to the tree seed.

A series of trials with pelleted tree seed (Ledgard, 1974) has produced no evidence to support the use of pelleted rather than broadcast fertiliser. However, different formulations of pellet, perhaps combined with winter sowing to allow complete pellet disintegration before germination in spring, could improve the practical use of large extruded pellets, particularly when inoculation with symbionts is desired.

A number of glasshouse trials have proved the efficacy of soil-incorporated duff in ensuring mycorrhiza development in pines (Benecke, 1974; Ledgard, 1974). In two trials the inoculation of seed with spores failed to promote the same amount of mycorrhiza development or plant growth, although this has been done successfully in Australia (Bowen, 1965; Bowen et al., 1972). Similar methods of inoculation have been examined using P. mugo seed inoculated with basidiospores of Suillus luteus, a common mycorrhizal fungus found in pine stands in the Craigieburn Range. Spore inoculation alone did not improve mycorrhiza formation in subsoil (Table 2) but, where sterile pine duff was added to the seed, spore inoculation was effective in promoting mycorrhizas. This suggests that a source of organic matter may be needed near the seed to maintain the viability of the spores, or the growing mycelium, prior to infection of the root.

<table>
<thead>
<tr>
<th>Mycorrhizal plants (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
</tr>
<tr>
<td>Spore inoculated</td>
</tr>
<tr>
<td>Spore inoculated with sterile pine duff (pellet)</td>
</tr>
<tr>
<td>Inoculated with non-sterile pine duff (pellet)</td>
</tr>
</tbody>
</table>

*Significantly different from controls at 5% level.
†Significantly different from controls at 1% level.
Other trials have shown that the infection of uninoculated seedlings in the glasshouse is increased by phosphate fertilizer and depressed by nitrogen (Table 3). A marked positive response of mycorrhizal fungi to phosphates has been found by Lamb and Richards (1974).

**TABLE 3: EFFECT OF N AND P ON MYCORRHIZA DEVELOPMENT ON P. MUGO SEEDLINGS GROWING IN SUBSOIL**

<table>
<thead>
<tr>
<th>kg/ha</th>
<th>0</th>
<th>20</th>
<th>40</th>
<th>80</th>
<th>120</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>20</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>80</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>160</td>
<td>12</td>
<td>12</td>
<td>3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**Time of Sowing**

Autumn and spring sowings of *P. mugo* have been examined in three areas — Mt Cockayne (1300 m, Craigieburn Range), Mt Fyffe (1400 m, Kaikoura Range), and Mt Morris (1500 m, inland Marlborough). In the autumn, conditions for aerial sowing tend to be more favourable than in spring, and natural soil turnover caused by frost heave during winter can be used to bury seed. However, the results shown in Table 4 indicate that it is not yet possible to generalise about a best time to sow.

**TABLE 4: SURVIVAL OF AUTUMN- AND SPRING-SOWN P. MUGO SEEDLINGS AFTER ONE GROWING SEASON**

<table>
<thead>
<tr>
<th>% Survival (No. of seedlings)</th>
<th>Autumn</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mt Cockayne (1300 m)</td>
<td>0.05 (10)</td>
<td>0.03 (5)</td>
</tr>
<tr>
<td>Mt Fyffe (1400 m)</td>
<td>0.8 (70)</td>
<td>0.3 (56)*</td>
</tr>
<tr>
<td>Mt Morris (1500 m)</td>
<td>0.2 (42)</td>
<td>1.0 (215)*</td>
</tr>
</tbody>
</table>

*Significant difference between autumn and spring sowings at 1% level.

Of the three sites examined, that on Mt Fyffe carried the most snow cover throughout winter. On the other sites snow was present for only 1 to 2 weeks at a time, and premature germination during the warmer spells of winter could have led to the early death of many autumn-sown seedlings. It seems that snow cover throughout winter may be necessary for successful autumn sowings. This trial also included pel-
leted and unpelleted pine seed. No significant difference in pine seedling growth was noted between the two treatments.

**DISCUSSION**

There are three main stages in the establishment of a direct-sown seedling in the field — germination, establishment during the first season, and seedling survival thereafter (particularly during the first winter). Provided that the seed is of good quality, germination appears to present least problems although the governing factors in the high country have not been adequately covered. Prior to and during germination it is possible that mice and birds are causing losses. In fact, the poor result of some past oversowing operations could be partly attributable to this. J. D. Hayward (pers. comm.) has reported seed losses up to 60% within 4 days of sowing at 1000 m in the Wairau catchment, Marlborough. During mid-summer in pilot trials 900 to 1600 m a.s.l. in the Craigieburn Range, mice were at least partly responsible for seed losses of 25 to 50%.

Once germination has started, the presence of stones on the soil surface can improve early seedling growth by improving the micro-environment (particularly moisture) around the seedling (Harper et al., 1965), and possibly by providing pressure to assist the seedling radicle to penetrate the subsoil (Dowling et al., 1970). A living vegetative cover, on the other hand, impedes seedling vigour by competing for moisture and nutrients (Miles, 1974). The varying effects of different cover types on seedling growth are at present being investigated to find the most satisfactory degree and types of cover which can be used. For survival over the first winter, the presence of cover is obviously essential to modify the effects of frost heave, and certain exotic grasses and legumes have proved efficient at rapidly producing the cover necessary to protect tree seedlings over winter. On exposed surfaces herbaceous species require added fertiliser (particularly with N and P) in order to attain satisfactory growth levels and, without maintenance fertiliser, any introduced vegetative cover cannot be expected to last for more than 3 years (Dunbar, 1970; 1971). Hence, the aim is to promote rapid initial tree-seedling growth so that the plant is sufficiently well-established to withstand climatic extremes once the protective cover has disappeared. By controlling the application rates of fertiliser, some control can be asserted on grass/legume vigour and thus on the degree of interplant competition. There is obviously much room for practical research on interactions between various types of herbaceous cover, fertilisers, symbiotic microorganisms (e.g., mycorrhizal fungi), and tree seedlings.
The limited work carried out on seed pelleting has given no indication of benefits over unpelleted seed. Nevertheless, greenhouse trials have shown a potential response of tree seedlings to nutrients, and to mycorrhizal fungal inoculation, suggesting that there will be a place for some type of pellet in future years.

The greatest attraction of pellets at present is their potential as carriers of symbiotic mycorrhizal fungi (particularly in the form of spores). The present problems in the basidiospore inoculation of pine seed are, first, the retention in a viable state of basidiospores collected from fruiting bodies in autumn until the time of sowing in spring and, secondly, the maintenance of viable spores on or around the inoculated seed until a rhizosphere develops after germination. The large numbers of spores required on each seed, especially when using stored material (at least $1 \times 10^9$ spores/seed—Theodorou and Bowen, 1973) indicate the need for further work on the viability of spores used in inoculation, and on their germination and mycelial growth in soil prior to infection.

Poor establishment of tree seedlings at higher altitudes is related to soil infertility and lack of mycorrhizal development limiting seedling growth, combined with inadequate cover to moderate frost heave over winter. It should be possible to effect improved establishment by:

1. Sowing herbaceous species to provide cover to lessen frost heave;
2. Using fertilisers to improve seedling growth;
3. Inoculating seed with mycorrhizal fungi to hasten the development of mycorrhizae.

On present evidence no single treatment is likely to promote maximum survival and growth, and the need in future research is to obtain an optimal balance of treatments.

ACKNOWLEDGEMENTS

The data presented in Table 1, and Figs. 1 and 2 are from trials conducted by U. Benecke and A. H. Nordmeyer, respectively. The author is grateful to them for making the data available.

REFERENCES


