PLANTING STOCK QUALITY: A REVIEW OF FACTORS AFFECTING PERFORMANCE

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ABSTRACT

Most research into treatments and quality of planting stock relies on measurements of the seedlings for one to three years after planting out. Numerous variables affect the seedlings throughout growing, handling and planting, and include the effects of both the nursery and the forest site, and of site preparation methods, which are superimposed on genetical variation. The mechanical, meteorological, biological and other factors affecting the performance of seedlings certainly have physiological effects, which must often be complex. While these may in time be elucidated using controlled-climate laboratories, the final evaluation must always be the performance of the seedlings in the forest.

This paper notes some of the factors involved, drawing mainly from N.Z. Forest Research Institute experience over the last ten years, supplemented by limited outside evidence. The scattered information on these factors is voluminous, but would have to be extracted from numerous papers and reports often covering other subjects. Even the New Zealand references have been limited, mainly to those covering nursery and establishment research on radiata pine (Pinus radiata)*. For example, no attempt has been made to study papers on genetical effects, however important they may be, and there are few references to studies of soils and nutrition, or to detailed physiological research.*

It is concluded that the only reliable way of evaluating a seedling is to know, as precisely as possible, the history of the seedling from seed collection until the time of evaluation.

INTRODUCTION

Most research into treatments and quality of planting stock relies on measurements of survival and growth after planting out. Owing to the large number of variables, it is inappropriate to conduct such trials without adequate control of those variables or, alternatively, without very careful records.

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There are numerous possible methods of evaluating seedlings. These can be morphological, physiological, or by field testing. Examples are:

1. *Morphological*
   (a) Shoot. Length of shoot; root collar diameter; height:root collar diameter ratio; foliage colour (related to nutrition); degree of damage (insects, fungal infection, wilting); visual indications of "hardness"; condition of shoot tip.
   (b) Roots. Fibrous root development; root:shoot ratio (visual assessment); mycorrhizae (abundance, type); amount of earth adhering to roots; root damage or loss; moisture status of roots (turgid, flaccid); taproot development.

2. *Physiological*
   Root:shoot ratio (dry weight determination); pressure bomb readings (shoot moisture stress); tetrazolium test (root deaths); mineral nutrient reserves and balance; carbohydrate reserves; evaluation of effect(s) of stress in controlled con-

3. *Field testing after lifting from nursery*
   ditions; root regeneration potential.

   Evaluation of tolerance to stress imposed by periods and methods of storage, delay in planting, periods of exposure, methods of handling (including lifting, packing, grading, culling, root dipping, etc.), effects of planting site and methods of site preparation, related to the time of year and/or weather (temperature, wind, rain, snow, frost). Evaluation is essentially the measurement of survival and growth (roots, shoots or bulk*).

The main factors which affect seedling quality up to the time of lifting are: the nursery site (soil, fertility, moisture, climate — including shelter — weather); genetic make-up of the stock; seed (size, variability, germination, treaments — including storage); methods of production (bare-rooted, rooted cuttings, container-seedlings); the space occupied by the seedling in the nursery bed; time of sowing and length of the growing period; age of seedling; time of year seedlings are lifted; weed control methods and effec-

*Bulk is determined by the the formula D^2H where D is diameter at stump level and H is height; this is normally expressed as a three-figure index.

tiveness; seedling nutrition; methods of seedling conditioning; insect attacks; diseases.

The main factors which affect field performance (that is, from the time that seedlings are lifted in the nursery) are: time of year; quality and hardness of seedlings; condition of nursery beds at time of lifting; methods of lifting, sorting, packing, grading, root trimming, and transporting (amount of handlng, exposure, type of package, damage, compaction, temperatures); time in storage and method of storing; handling and planting on the forest site; condition of the site; adequacy of site preparation, site factors; weather before, during and after planting; weed competition after planting; method of releasing; climatic and animal damage.

It must be stressed that the effects of these factors are rarely simple, and they interact wih one another. For example, a poorly hardened seedling may survive and grow well on a benign sheltered site yet fail on an exposed, but similarly prepared, site where a well-hardened seedling of the same age, species and size may do well. Again, the effect of releasing herbicides on small seedlings may be to reduce growth, while larger seedlings remain unaffected at the same rate of application. Such examples are legion. Nevertheless, this does not mean that one should necessarily "tailor" the quality of the seedling to the site; it is far better to produce high quality seedlings for all sites as, even on the best sites, they will out-perform poor quality seedlings.

The remainder of this paper gives examples of factors which have been found to affect planting stock, drawn mainly from N.Z. Forest Research Institute experience over the last ten years, supplemented by some outside evidence. The information is voluminous but scattered throughout numerous reports and papers, many of which are concerned with other matters. Even the New Zealand references are limited to those covering nursery and establishment research, mainly on radiata pine. No papers dealing with genetical effects have been studied, and there are few references to research into soils and nutrition, or to detailed physiological studies.

DISCUSSION OF THE FACTORS AFFECTING INHERENT SEEDLING QUALITY

The objective of the following notes is to draw attention to various factors which might have some bearing on the evaluation of the performance of planting stock, and which might well be overlooked by specialists working on one or a few aspects of the subject.

The quality of radiata pine seedlings, in terms of their ability to grow well after planting out in the forest, depends more on nursery treatment than on size or on any easily measurable morphological characteristic. This holds true even for benign sheltered and cultivated sites (Chavasse and Bowles, 1976). Shoot:root ratio (for what it may mean) is not easy to determine, and foliage colour may be misleading; Cameron (in Chavasse, 1969d, discussion) pointed out that "trees which did not look at all 'good' performed well [while] trees that looked very 'good' had poor survival and growth." Trees that have been properly conditioned (see below, (f)) to withstand the shock of lifting and transplanting, often had poor colour and reduced size (Stockley, 1969). This is associated with reduction in nutrients caused by severing roots; insufficient research has been done on this problem; for example, whereas radiata pine may become more frost-tender if nitrogen is applied late in the season to correct deficiences, eucalypts with similar treatment appear to become more frost-resistant (J. C. van Dorsser, pers. comm.).

Other features of seedlings may be misleading. Burdon and Bannister (1973) found that multileaders on young radiata pine seedlings were not of genetic significance and led to little subsequent malformation.

Probably the most useful measure of seedling quality is either the height:diameter ratio, or simply the root collar diameter (Wilkinson, 1969). Optimum height:diameter ratio, for any one species and age class, is related to the nursery site (Chavasse, 1974a) with higher ratios in the north or at lower altitudes and on more favourable soils and lower ratios in the south, or at higher altitudes and in heavier soils. Optimum for 1/0 radiata pine at the FRI experimental nursery is 60:1 (van Dorsser, 1969a) but for Milton Nursery in Otago the ratio should be 45:1 or less (Balneaves and McCord, 1976). The cultural means of achieving high quality are correct spacing of seedlings in the nursery and the process which has come to be called conditioning (formerly "hardening").

A. GENETIC EFFECTS

Genetic effects are not dealt with in detail, although they could ultimately be very important. Two examples will be given. First, strong clonal differences have been found within radiata pine in intolerance of clay soils where the phosphorus supply is low (Burdon, 1971). Secondly, in regard to behaviour of radiata pine seedlings on frosty sites, there is evidence of important genetic differences in frost tolerance (Chavasse, 1973e.) Significant differences between control-cross families in frost resistance were found by Menzies (1976a).

In addition, it has frequently been observed that the growth of radiata pine and Douglas fir (*Pseudotsuga menziesii*) seedlings, when subjected to the same nursery treatment and planted out on the same site, is unrelated to the initial height of seedlings (Chavasse, 1977). This would seem to imply that the heights of individual seedlings are not genetically controlled.

Beyond this there is no evidence that genotype would in practice have a material effect on quality of planting stock of radiata pine, except perhaps through genetic differences in seed size.

B. EFFECTS ON SEEDLINGS DURING PRODUCTION IN THE NURSERY

(a) *The Nursery Site*

There are many site factors which have not been adequately researched. For example, shelter is considered to be important in several countries (Chavasse, 1969a; 1978) to mitigate climate, especially wind. In both Puha and Pakipaki nurseries (Poverty Bay and Hawke's Bay) wind can adversely affect seedlings which, in extreme cases, can be abraded by soil particles. The less obvious effects of exposure on other sites are uncertain.

The nursery site has a strong effect on frost tolerance of radiata pine seedlings. Trees raised at Sweetwater Nursery, in the north of Northland, when subjected to frosting, are far less tolerant than those raised in more southerly climates and higher altitudes (McKinnon and Nicholson, 1974; Washbourne, 1978). In controlled climate trials Menzies (1976a) reported that there were significant differences in behaviour of radiata pine seedlings from different nurseries, related to altitude, latitude and temperature of the site. The most frost-tolerant seedlings came from the nursery at the highest altitude.

Soils are clearly of great importance. For example, Stockley (1969) recorded how poor drainage leads to reduced growth and health of seedlings in clay/silt soils. Bassett and Will (1964) showed that soil sterilisation can strongly affect mean height, and more especially mean weight, of radiata pine seedlings. Morrison and Lloyd (1972) showed that soil sterilisation has a major effect on kauri (*Agathis australis*) seedlings, but that a similar improvement can be obtained by incorporating 5 cm of taraire (*Beilschmiedia tarairi*) leaf mould into the top 15 cm of seed beds. However, there is some evidence (Gleed, 1976) that soil sterilisation can lead to lack of mycorrhizae in patches, where seedlings tend to be stunted.

Knight (1978) discussed exhaustively the maintenance of nursery soil fertility. He determined satisfactory foliar nutrient levels for seedlings grown in a number of New Zealand nurseries, and discussed nutrient supply in relation to physiological quality of seedlings, including their ability to withstand drought and frosting, and to produce new roots after transplanting. He stressed the need for nutrient balance. Knight (1973) also documented the effect of nitrogen supply on growth and morphology of seedlings. Nitrogen levels, and timing of application can have a dramatic effect on development of eucalyptus seedlings (A. E. Summers, pers. comm.). Will and Knight (1968) have demonstrated equally dramatic effects on seedling development caused by shortages of single nutrients. The importance of evenness of spread of fertilisers over nursery beds can therefore not be over-emphasised.

Nursery soil moisture, irrigation and rainfall can all have important effects on seedling development. For example, soil splash from heavy rain, or large irrigation droplets, can retard growth of small seedlings.

The soil texture can affect wrenching. In very light soils, the seedlings may be poorly anchored, making it difficult to cut taproots cleanly, and wrenching may lead to severe wilting, or even death. In very heavy soils, on the other hand, control of depth of wrenching may not be possible so that seedlings in different parts of the nursery, or even in the same bed, may be subjected to different stresses, resulting in different responses.

Little work has been done on the effect of temperature in relation to germination and growth. Barton (1978) found that optimum temperature for germination and early growth of kauri seedlings was 25.5°C; below 19.5° and above 27.5° growth fell off rapidly. Doubtless there are optima for other species.

(b) *Seed Treatments*

Because the quality of individual seedlings depends on the growing space available to them in the nursery bed, seed treatments (which affect, for example, evenness, speed and amount of germination) can indirectly affect seedling quality. Much work has been done on stratification, which can give more rapid, even and complete germination. However, if soils dry out after sowing, the effects of stratification can be vitiated, resulting in slow, sporadic and incomplete germination, and hence an uneven crop. Gleed (1976) found that if soil is excessively wet during sowing the germination period can be lengthened, leading to an irregular crop. Long periods of germination lead to complications in the use of weedicides, which may also affect the crop differentially, depending on seedling size at time of application.

Seed sorting can affect tree sizes and evenness of crop (*e.g.*, Chavasse, 1977). Seed covering can also have an effect. Fairhurst (1974) found that size of grit used for seed covering could affect germination and that covering the whole bed, rather than drills only, gave faster and more complete germination, so influencing the uniformity of the crop. Will *et al.* (1962) stressed the necessity for coating seeds with bird-repellent materials if predation is to be avoided, but G. W. Hedderwick (pers. comm) has found that some birds can become "educated" to take coated seeds. G. W. Hedderwick (pers. comm.) has also found that pelleting seed with fine sand/clay can lead to irregularity, delay and depression of seed germination. Any of these factors, because they affect seedling stocking, can affect the quality of individual seedlings.

(c) *Weed Control*

Seedlings can be affected by weed competition, and they can be damaged during hand-weeding. Weed control in New Zealand has for many years been achieved mainly by the careful use of herbicides (*e.g.*, van Dorsser, 1969b; Chavasse 1969b). However, seedling growth can be adversely affected by weedkillers if they are not used with precision in relation to the growth stage of the seedlings and to weather conditions. Different species require quite different herbicide regimes, and "fine tuning" has to be applied to each nursery for optimum results. Long-term trials at the FRI experimental nursery indicate that, in pumice soil, there is no effect on successive tree crops, but there have been reports (Chavasse, 1976, p. 39) that in heavy soils triazine build-up may depress growth. Propazine or "Caragard" applied when the soil is very dry can damage seedlings, leading to a very uneven crop. Aromatic oils can depress growth (van Dorsser, 1969c). Gleed (1976) was uneasy about long-term effects of weedicides and reported that in the Tasman Nursery the frequency of seedlings with multiple leaders was increasing (but see (d)).

In most respects, weedicides are beneficial, and preferable to hand-weeding, in that nursery beds can be kept weed-free, allowing tree seedlings untrammelled growth.

(d) *Insects and Disease*

Nursery insects and diseases are described by Alma (1977) and Gilmour (1977). Will *et al.* (1962) stress the need for using fungicides and insecticides to maintain seedling health. Insects can be readily controlled by conventional means, but some (*e.g.* Tortricids) may eat terminal buds and cause multi-leaders. J. M. Balneaves (pers. comm.) reported that thrips may be the cause of multi-leaders and some stunting of radiata pine seedlings in Canterbury, but this is by no means certain.

Fungi are often less easy to detect or control. Terminal crook (*Colleotrichum acutatum* f.s. *pinea*: FRI, 1975), if not adequately controlled, can greatly reduce height growth of pine seedlings in the nursery. Root rot fungi may cause damage before any above-ground effects are visible. Bassett (1969) reported that attack by *Phytophthora* may not readily be apparent on stock sent out for planting, but affected trees may later die or show severely reduced growth.

Control of *Dothistroma pini* in the nursery with copper-based sprays can cause reduced growth if applied in cold weather.

(e) *Seedling Spacing*

The point to grasp is that simply achieving a certin average spacing does not result in maximum production of healthy vigorous seedlings. The space occupied by the individual seedling is critical (Chavasse, 1973a). Seeds should therefore be sown evenly at the optimum spacing for a particular nursery site or, alternatively, the nursery beds should be thinned to the correct spacing soon after seedlings have begun to grow (at about 4 cm tall). It is also necessary to sow seeds at the correct depth; too deep delays emergence and may prevent it for smaller seeds, resulting in an irregular crop. The seed covering material can also have an effect on the evenness and rapidity of emergence.

Seedling spacing affects root collar diameter, height growth of seedlings in all conditions, often for several years after planting, and survival in adverse conditions. The less the spacing, the poorer the seedling performance (van Dorsser, 1969a). Menzies *et al.* (1974) demonstrated that, where spacing between drills was 15 cm, the *minimum* spacing in drills for 1/0 radiata pine at the FRI nursery to obtain high quality trees was 25 mm; for 1½/0 stock it was 45 mm. Density in the seed beds had a small effect on growth where seedlings were planted on well-cultivated sheltered sites, but a substantial effect when planted on less fertile, exposed, high-altitude sites.

Balneaves and McCord (1976) showed that seedlings grown at even spacing performed better than seedlings grown at irregular spacing. The optimum spacing in drills at Milton Nursery for 1/0 radiata pine was found to be 7 cm which, compared with irregular spacing, reduced culling (on the basis of root collar diameter) from 28% to 4%, increased survival from 81 to 99% (after culling), and increased height growth over two years from 55 to 73 cm. For 1½/0 radiata pine Balneaves (1976b) showed that seedlings grown at 9 cm spacing, when compared with those grown at 4 cm spacing, reduced culls from 31 to 5%, improved survival from 83 to 97% (at two years from planting), and improved mean growth from 118 to 156 cm over two years. There was some evidence, in both of these trials, that spacing greater than optimum may lead to poorer performance.

The root collar diameter of seedlings with adequate growing space continues to increase throughout the winter, while height growth is negligible. The height:diameter ratio thus alters (J. C. van Dorsser, pers. comm.)

(f) *Conditioning*

There is abundant evidence that conditioning enables seedlings to withstand the stresses which occur between lifting from the nursery and planting in the field (*e.g.*, Armitage, 1969). Most work has been done on radiata pine seedlings, but Bunn and van Dorsser (1969) reported that several species of eucalypts can be conditioned in much the same way, inducing "a stiff upright plant with leathery foliage and abundant roots, that does not wilt when roughly lifted from the bed".

Conditioning methods and seedling responses are covered in detail by van Dorsser and Rook (1972). Conditioning is effected by undercutting, wrenching and lateral root pruning (although in the early experimental stages other methods were tried — *e.g.*, van Dorsser, 1969c). The effect of this treatment is to inhibit shoot growth, stimulate tertiary root production and increase root: shoot ratios. The importance of well-spaced seedlings (which can respond) is stressed, and different responses have been recorded in different nurseries. Conditioning induces morphological and physiological changes in seedlings. "A well-conditioned [radiata pine] seedling has a dry, hardened, brown shoot to within 3 to 5 cm of the tip and loss of chlorophyll makes its foliage somewhat chlorotic." The importance of proper nutrition during the conditioning process, especially adequate nitrogen, is noted.

Conditioned trees show improved survival and root regeneration potential. For example, van Dosser (1969c) reported that regularly wrenched trees showed greater growth and surival after 6 and 12 weeks' storage than unwrenched, that wrenched trees were able to withstand higher temperatures, and were much better able to withstand exposure to sun and wind. Rook (1969a) demonstrated major morphological differences, in both shoots and roots, between wrenched and unwrenched seedlings, and gave details of their behaviour when subjected to water stress. Frequently wrenched seedlings could withstand fairly severe stress and had the greatest root regeneration potential as well as a substantial increase in root: shoot ratio. With seedlings subjected to drought stress shortly after transplanting, Rook (1969b) found that frequently wrenched seedlings were unaffected, those undercut once were slightly wilted, while unwrenched seedlings suffered severe internal water deficits, even though the wrenched seedlings unexpectedly showed higher transpiration rates. Rook *et al.* (1977) found that seedlings conditioned in various ways, planted in different soil types, and subjected to various temperature regimes under controlled conditions, behaved differently in respect of survival, rates of transpiration, water potential, root regeneration, root growth and ^{14}C distribution. Seedlings wrenched at fortnightly intervals performed best.

Cameron and Rook (1969) further discuss anatomical, morphological and physiological changes. Cameron (1969) showed that, although wrenched seedlings at lifting were smaller (both tops and roots) than unwrenched seedlings, the wrenched seedlings had a shoot : root ratio of 2.7 compared with 4.4 for unwrenched. With controls = 100, the surface area per gram of fresh root weight for seedlings wrenched fortnightly was 183, even though total fresh weight of the root system of the controls was higher (19.45 g as against 15.99 g).

A disadvantage of wrenching is that the seedlings' taproots often fail to develop. For this reason and because of root damage caused by lifting methods, studies have been made of "box" pruning (root pruning on four sides and undercutting). Brunsden (1977) found that box-pruned stock (1/0 radiata pine) can withstand root exposure better than stock wrenched in the conventional way, especially late in the planting season (September), as shown by pressure bomb and tetrazolium tests and by height growth after planting out. Brunsden (1976b) also found that box-pruned trees often had a conspicuously strong taproot growth after planting out, whereas wrenched trees usually had little taproot development.

C. EFFECTS OF HANDLING FROM LIFTING TO PLANTING

Chavasse (1969c) found that high survivals of seedlings depend closely on care in handling at all stages from lifting to planting. He found (Chavasse, 1973d) that the main need is to reduce conditions in which trees may be stressed. The "look" of the trees is an unreliable guide to subsequent survival and growth, nor does previous conditioning indicate behaviour of trees planted late in the season (October). Any treatment where roots are allowed to dry out, or where trees are heated, is deleterious. Moistening roots before planting improved survival and growth. He concluded (Chavasse, 1974a), following a compehensive survey of nursery management in New Zealand, that machine lifting, with on-lifter packing and root trimming (or previous box pruning of roots in the nursery beds) and immediate despatch to forests in insulated crates would be the optimum method for maintaining tree viability; storage, if required, should be at the nursery in cool stores.

Brown (1969), in a literature review, documented the detrimental effect of undue handling, exposure and unsuitable methods of packing and storage. He stressed the need for adequate "hardening" if trees are to be stored for more than a few days. Trees can be subjected to many depressing influences between lifting and planting due to poor techniques, exposure, delays, compression, etc.

Seedlings can be damaged during lifting, whether by hand or machine (A. R. D. Trewin, pers. comm.). In hand lifting, seedlings are often hit against the lifter's boot, which tends to remove not only soil but also fine roots and a large proportion of the mycorrhizae. In machine lifting the roots, in being torn out of the soil, can be stripped and reduced. Growth of trees with damaged roots can be severely depressed and, on harsh sites, survival can also be lowered.

There has been much inconclusive research on providing roots with "puddle" or "slurry". Attempts to develop artificial root dips to improve survival and growth are not always successful. Sodium alginate, for example, can be detrimental, and Brunsden and Menzies (1974) found that an artificial root dip had deleterious effects which increased with prolonged storage. Water alone is preferable.

There is now general agreement that the traditional procedure (which includes lifting, culling, sorting, grading, root trimming, tying, and packing) is detrimental and should be obviated if possible. This has led to the development of mechanical lifters and immediate packing; provided only plantable trees are left in the nursery beds, this is now clearly the best treatment (A. R. D. Trewin, pers. comm). Machinery must, of course, be used skilfully.

The form of packaging is important. Plastic bags are unsatisfactory because they allow trees (especially roots) to be damaged or broken during transport, and also because, should they be left in the sun, the trees tend to "cook", severely reducing vitality. Packages should be firm. N.Z. Forest Products Ltd has developed a strong cardboard box which can be packed on the machine lifter, transported to the forest, and used as a planting "bag", which ensures that the trees are planted in excellent condition. The need for a firm package has been amply demonstrated (van Dorsser, 1969c; Balneaves, 1974). Compression during transport can be lethal. If packed too tightly, trees tend to heat; if too loosely, they tend to dry out; in both cases survival and subsequent growth are depressed. There is an optimum number per package depending on tree size. Balneaves (1973) reported that 1/0 radiata pine seedlings are more sensitive to differences in packaging than 1½/0 stock.

The available evidence points to the need for cool stores, rather than more haphazard methods of storage. Heeling-in at the forest can adversely affect survival and growth (*e.g.*, Stockley, 1969; Wilkinson, 1969). The effect of heeling-in is related to the time of year, the quality of tree stocks, and site conditions (warm dry, or frosty, sites are least favourable). Survival of heeled-in seedlings can be significantly improved by providing complete cover. However, after three weeks in favourable conditions, viability falls off sharply (Chavasse and Balneaves, 1971a). Balneaves and Jones (1978) found that methods and duration of storage are more critical at the beginning (May) and end (late August-September) of the planting season, but are not critical in July, irrespective of conditioning treatment. Fluctuations of temperature during storage, even in cool stores, can be detrimental. Chavasse (1974b; 1978) discusses the use of stores. It would seem that the operation of cool stores (their efficacy is not in doubt) needs to be further evaluated. There is evidence that speed of cooling is important and that optimum temperature varies with the time of year. In Ontario, for example, the optimum autumn store temperatures were found to be –3 to –4°C, while in spring +1° gave superior results. Rook *et al.* (1974) found that seedlings stored for 10 weeks in a cool store maintained at +1°C were less affected by a spring frost of –10°C than seedlings lifted from the nursery beds at the same time and planted immediately. However, Menzies (1976b) showed that the outdoor weather (where seedlings were kept before and after controlled frosting) had a significant effect on the degree of frost damage. Water deficits in the seedling proved to be the major influence upon frost damage; doubling the water deficit from –12 bars to –24 bars nearly halved the frost damage.

Trees may deteriorate in planting bags. Chavasse (1973b) found that growth and survival were depressed when trees were left too long in bags (especially dry canvas bags, where roots dried out), when seedlings are stuffed too tightly into bags, or when trees are too large for the size of bag used.

In operations where the whole sequence from lifting to planting is not rigidly controlled, the loss of tree vitality is considerable. Poor practice here probably has a more detrimental effect on survival and growth than in any other phase of the establishment system.

D. EFFECT OF SITES AND SITE PREPARATION

The effect of site conditions on survival and growth of planted or regenerated seedlings has been widely researched and there is no need to elaborate here. Effects may be due to soils, aspect, altitude or location. In New Zealand a sometimes unexpected hazard is salt damage several kilometres from the sea coast. In Southland, for example, Douglas fir may be severely stunted, and grow to one side only, even as far as 35 km from the south coast. In Otago, Edmonds (1976) found that eucalypts tend to be sensitive to saline winds, but species vary quite widely in their response. Damage often leads to bushy growth and multiple leaders. In general, depression of growth is worse where trees are under some form of stress, such as hot dry sites, but results vary with the time of year and in different climates or regions (Chavasse, 1976, p. 46).

Previous vegetation can affect growth: a cover of clovers or gorse (*Ulex europaeus*) may increase fertility (nitrogen) in the soil, which can boost growth of trees subsequently planted (Chavasse, 1969e). Plants growing with trees can perform a similar function. Tree lupin (*Lupinus arboreus*) growing on sand dunes can supply nitrogen to the soil at a rate of some 160 kg/ha/yr. Some of this is taken up by marram grass (*Ammophila arenaria*) which, as tree canopy closes and the grass dies, continues to be released into the soil and is then available for tree nutrition. Without nitrogen, trees on these sites have yellowish foliage and are unthrifty (FRI, 1977).

Of plants that affect tree growth, grass is one of the most widespread and can be fatal in dry climates. Smail (1975) found that, on a gravelly loam soil in Canterbury, control of grass resulted in 99% survival of 1½/0 radiata pine planted deeply (half to two-thirds of shoot buried); height after the second growing season was 55 cm. Where grass was not controlled, survival was only 20% and height 30.5 cm. Preest (1977) found that, in the dry summer climate of Oregon, survival and growth of planted Douglas fir was severely reduced by grass competition for several years after planting.

Balneaves (1976a) found that herbicides were much more effective in preventing grass competition than scalping or discing which allowed reinvasion of grass and led to reduced tree growth. As soon as grass competition re-occurs on dry sites, tree growth is again reduced. Where grass was completely controlled for two years, mean height was more than twice that of trees planted on disced or scalped sites, even where temporary relief had been obtained by releasing trees with a mixture of atrazine and amitrole-T.

Knowles and Klomp (1976) found that, where large vigorous radiata pine seedlings are used, and there is adequate spring and summer rain, herbicides are not necessary to control grass and may be harmful in that vigorous growth of tree tops may lead to serious toppling. However, J. M. Balneaves (pers. comm) found that, on dry sites, there was more toppling in grass than where grass was controlled for two years and where trees were twice as tall. It would seem, therefore, that grass could affect root development on some sites. In contradistinction to the findings of Knowles and Klomp, Bowers (1976) found that, even in a benign climate where one would not suspect that moisture would be limiting, grass competition can be a major factor in survival and growth of 1/0 radiata pine. Survival in grass can be as low as 63%; where it is controlled on the same site, survivals are 92-3%. Where grass was controlled, mean height and diameter at two years were 234 cm and 53 mm, respectively, compared with 150 cm and 30 mm where grass was not controlled. Results were much superior when herbicides were applied in September, compared with application in October and November, when amitrole-T may be harmful.

Revell (1976) reported that grasses have a competitive advantage over trees and prevent sufficient moisture reaching tree roots. This can result in reduced root growth, stunted top growth, and, on dry sites, considerable mortality. Revell and Deadman (1976) found that growth of poplars (in a climate with well-distributed rainfall), where grass was controlled by herbicides, was better than where fertilisers (750 g 12-10-10 per tree) were applied and grass was not controlled. *Eucalyptus regnans* on the same site grew slightly more where the fertiliser was applied over grass than where grass was controlled without applying fertiliser. Both grew best where grass was controlled and fertiliser was applied.

Chavasse (1969a) comments on the ability of rather poor radiata pine seedlings (not conditioned, spindly and with unbalanced root : shoot ratio) to show strong root regeneration on well-aerated cultivated soils in relatively warm conditions. He also reports on the "ash-bed" effect, where growth of seedlings is markedly increased when planted where piles of forest debris have been burnt. This effect is commonly observed in Australia and New Zealand; where it is not clearly observed, there could still be measurable effects.

Before going in more detail into the question of site cultivation (see, *e.g.*, Chavasse, 1969e 1973a), some general comments are in order to confirm that results can be favourable or unfavourable, depending on site factors. Beveridge (1969) lists the favourable factors as: removal of vegetation and reduction of frost levels; creation of an improved rooting medium leading to increased growth. The unfavourable factors are: the creation of an ash-bed effect where heaps or windrows are burnt; encouragement of weeds, which may compete with trees; removal, redistribution, compaction or "pugging" of soils, leading to uneven growth of trees or encouragement of grass.

Poor site preparation may lead to a very uneven crop and may lengthen the rotation. Repeated burning may lower site fertility, so reducing tree growth (Chavasse, 1969e, p. 158).

Cultivation need not be undertaken over the whole site. For example Balneaves (1971b), using portable powered spot cultivators, found that growth of trees planted in spots was in several instances twice that of trees planted in uncultivated ground on the same site; indeed, lack of cultivation was sometimes fatal. However, results are rather variable. This could be said equally of other methods.

Guild (1971) reporting on windrowing and ripping in Canterbury, demonstrated that site preparation methods can greatly improve survival of newly planted seedlings and evenness of height growth. Ballard (1978), on the other hand, found that windrowing led to marked differences in growth. Topsoil was removed from skid sites and between windrows. Trees planted in windrows showed superior growth and foliar nutrient levels to trees planted on the same site where windrowing had not been undertaken, because the topsoil had been pushed into the windrows. Trees planted between windrows showed reduced growth and low foliar nutrient levels. Growth on skid sites (where most soil had been removed) was poor, even when nitrogen fertiliser was supplied; the trees on skid sites showed markedly low foliage nitrogen. The effect of soil compaction, possibly reinforcing loss of topsoil, was not evaluated.

In regard to frosty sites, Chavasse and Kearns (1973) showed that, for successful establishment of radiata pine (where midwinter frosts may be below −14°C and December and January frosts may be of the order of −3 to −5°C), it is necessary to use large vigorous tree stocks and to maintain a bare cultivated site for two years after planting. This has been amply confirmed by subsequent trials and operations (*e.g.*, Washbourn, 1978). Menzies (1976b) found that the effect of cultivation on these sites (compared with grassed areas) was to raise minimum air temperatures near the ground by as much as 4°C in both winter and summer. This degree of warming is enough to allow radiata pine to survive and grow sufficiently fast to get the growing part of the crown above frost levels within two years.

Various forms of cultivation (with or without herbicide application) can influence weed spread and vigour, with a consequent effect on trees. Recently, ripping and "bedding" or "mounding" have become popular. From a nation-wide questionnaire Chavasse and Brunsden (1977) found that objectives of ripping were mainly to obtain improved survival and growth and to allow greater root growth which, in turn, would improve stand stability, mainly on clay soils or compacted areas, or soils with pans. Most respondents reported that these objectives were met by ripping. Hetherington and Balneaves (1973) found that 1½/0 radiata pine planted in ripped (to 45 cm) and non-ripped lines showed markedly different patterns of growth. In the first two years the growth of stems in the ripped lines was 57 cm, as compared with 67 cm in the unripped lines (which was the opposite to the expected results). However, in the following year, the trees in the ripped lines grew 82 cm, while those in the non-ripped lines grew only 41 cm. Three years after planting there were major differences in oven-dry weights of tops (320 g in ripped lines, compared with 134 g); and roots (133 g vs. 42 g), in root collar diameters (28 mm vs. 18 mm), in depth of taproots (32 cm vs. 10 cm) and in number of lateral roots (19 vs. 9), while toppling was reduced (43% vs. 68%). Poorest growth was on screefed sites; growth on disced sites was better than on screefed sites but markedly inferior to growth in ripped lines. This is a relatively high altitude site, and results could be affected by the degree of exposure to cold winds.

In regard to bedding or mounding, results can vary. In some cases root development may be inadequate, leading to toppling. Pearson and Everts (1978), monitoring soil conditions on raised beds, found that radiata pine seedlings suffered no more stress (because of lack of soil moisture) than seedlings planted on adjacent unbedded sites. The mean soil temperature (and temperature range) was also unaffected.

There are marked interactions between cultivation, weed competition, and soil fertility (or applied fertilisers). Chavasse (1973c) found that the form of fertilisers is important (*e.g.*, blood and bone is often ineffective, while urea and superphosphate are usually highly effective, in stimulating growth on poor sites). The effect of fertilisers is almost invariably enhanced by soil cultivation. On some sites there is little response to fertilisers unless weeds are eliminated. Fertilisers placed in slits in the soil 15-20 cm from the tree are much more effective than when the same quantity is placed on the soil surface. If fertilisers are put under the tree, or mixed with the soil in the planting hole, they can cause mortality without greatly stimulating growth. Berg (1975) reported that at Riverhead Forest (on heavy phosphate-deficient clay soils) growth of planted trees was substantially enhanced by cultivation, weed control and fertiliser applications, especially where sites had been compacted by logging operations. The responses are cumulative. On weedy sites fertiliser alone may stimulate weeds more than trees.

Mead *et al.* (1976) reported a case of seedlings responding to ripping by improved growth, which was further enhanced by application of boron and phosphorus. Growth was less where ripping and discing were undertaken. Discing enhanced growth, but also stimulated weed growth and increased nitrogen mineralisation in the soil. The result was that by age 7 (from planting) trees on disced plots showed a lower N status than on undisced areas.

Moberly and Kimberley (1978) found that the behaviour (especially growth) of *Eucalyptus saligna* and *E. delegatensis* was significantly influenced by the timing and number of fertiliser applications and, additionally, by initial site fertility. Fertilising in the field led to some mortality in *E. delegatensis*.

The effect of fertilising on the planting site on frost hardiness needs more elucidation. Brunsden (1976a) found that application of a mixed fertiliser (NPKMgCa) at time of planting on a frosty site led to a small increase in growth, but a marked increase in mortality and frost damage.

E. EFFECTS ASSOCIATED WITH PLANTING

Time of planting can be important. In a trial at Kaingaroa Forest, all planting stock, irrespective of origin or conditioning, has survived and grown better when planted in March than when planted in April or May (Chavasse, 1969d, p. 135). Menzies (1976c) found that on frost flats poorest results, for both survival and growth, were from May plantings. Best results were from plantings after July.

Depth of planting can be important. On sand dunes, for example, the operational prescription is to plant trees with half their foliage buried, in order to ensure that seedlings' roots are able to obtain moisture and therefore survive. On heavy clay soils in Southland and Otago, however, such burying is fatal; roots rot and trees die. Balneaves and Saunders (1974) showed that, in the dry Canterbury climate, 1½/0 radiata pine seedlings planted with the root collar at ground level showed only 69 to 81% survival and relatively little height growth. When planted with one-third to two-thirds of the stem below the soil surface, survivals were over 96% on all sites and growth was substantially improved.

In a number of establishment trials it has been found that there is great variation between planters. This has been revealed by statistical analysis. In these cases the work of poor planters often has to be discarded.

Balneaves (1970) illustrated a range of root deformities resulting from different methods of planting, including machine planting. Method and depth of planting can affect survival, growth of stems, root development and toppling. In heavy soils, trees should not be "stamped" home, as this leads to lack of aeration at the roots and poor top growth. Menzies (1973), in evaluating hand-planting methods, found that survival and growth can be significantly affected but no method resulted in a sound root system (as compared with that of a naturally regenerated seedling). The best method (in a heavy soil) was to use a spade to dig a pit, or form a T-notch or an X-notch. Other workers have found other methods (*e.g.*, a wedge) preferable.

Machine planting is a form of cultivation, and may lead to an initial boost in growth compared with hand-planting in the same site conditions (Chavasse, 1969e). Page (1977), however, found that on most sites there is little to choose between machine and hand planting. On sites where cultivation can have a marked effect on survival and growth (*e.g.* heavy clays) machine planting is likely to give superior results. Where high production rates are attempted with machines, tree roots tend to be "swept" into the furrow, and this can lead to stand instability.

F. EFFECTS ASSOCIATED WITH RELEASING

It is well understood that weed competition can lead to reduced tree growth, or to mortality. The effect of grass has been discussed above (section D). Balneaves (1971a) showed that delay in releasing trees from bracken seriously reduced both survival and growth. Chavasse (1970) reported that, if trees are not to be affected by weed competition, then releasing must be done at the correct time. Better results are obtained if site preparation methods obviate the need for releasing. Chemical control of vegetation is often superior to hand methods. Gleason (1978) found that once seedlings have been suppressed by weeds recovery is often slow, and an uneven crop results.

However, herbicides can affect trees. Davenhill and Knowles (1976) found that applications of 2,4,5-T + picloram, MCPA, and amine and ester of 2,4-D, applied to radiata pine trees in the second season after planting, did not damage trees in June. The 2,4-D ester caused some scorching in September. In November, only 2,4,5-T + picloram at low rates (1 litre/ha) caused no damage; otherwise trees were slightly distorted by low rates of the other chemicals. At higher rates (4 and 8 kg/ha) trees were all moderately to severely distorted by these herbicides. It is possible that, where morphological changes are not detectable visually, there can still be physiological effects.

Balneaves (1978) found that growth of radiata pine can be affected by application of a number of commonly used herbicides. Timing of application was critical. Autumn applications of 2,4,5-T + picloram caused a significant decline in growth in the second growing season. 2,4,5-T + asulam resulted in a sharp decline in growth, irespective of rate per hectare or timing of application. Atrazine and 2,2-DPA applied in October had less effect than when applied in August or September. At lower rates of 2,2-DPA (1.85 kg/ha a.i.) together wth 4 kg/ha atrazine, tree growth was greatly accelerated. Bowers (1976) found that mixing atrazine with amitrole-T reduced the harmful effects of the latter. Chavasse and Davenhill (1972) found that both 2,2-DPA and amitrole-T, on their own, depressed tree growth but, when mixed with atrazine, the harmful effects were markedly reduced. Atrazine, on its own, tended to stimulate tree growth. They found that hand-releasing is ineffective in grass, while screefing may depress tree growth. Application of herbicides can cause stunting, multi-leaders or stem malformation when applied over trees, especially when the trees are growing actively. Radiata pine is more susceptible in the second year of growth than immediately after planting (Davenhill and Preest, 1976). The effect of mixtures can be unpredictable. For example, asulam on its own has a negligible or undetectable effect on tree growth, but damage can occur if it is applied in hot weather, or if it is mixed with a triazine (the opposite to the effects of a triazine mixed with some other chemicals, as noted above). The trees may be stunted, with multiple leaders, and heavy branching; they may take some time to recover (Chavasse, 1976, p. 48).

Methods of application and amount of diluent can affect results. For example, Miles (1976) reported that retention of asulam by target species was much greater at low volumes of water diluent (44 litres/ha) than at high volumes (330 litres/ha). The addition of surfactants increased herbicide retention at low volumes of diluent.

The well-known "striping" effect, when herbicides are applied by aircraft, shows that volumes are by no means uniform across the swath width. Inaccuracy of flying (although most pilots are very skilled) accounts for further variations. Garden (1976) found that windspeeds and patterns of wind movement can have a dramatic effect on spray deposition. Distribution of droplet sizes can also be important. Most distribution patterns are characterised by two peaks of higher application rates which appear to be due to wing-tip or rotor-tip vortices, but are related to droplet sizes. However, aerial application is often much safer than hand methods. Trees released with knapsack pumps and spray tips often show considerable stunting or spray damage, because it is often difficult to maintain application rates at the correct level (Chavasse, 1976, p. 161).

G. DEVELOPMENT OF THE PLANTED CROP

Mortality or poor growth can clearly be due to a number of factors, in the nursery, or as a result of handling practices, or site factors. Assuming nursery and handling practice is adequate, mortality and poor growth of trees may be due to poor site preparation or poor planting which itself can be due to poor site preparation. For example, if debris is left on the site, both hand and machine planting can be difficult, leading to great variation in planting quality. Similarly, poor planting and survival may be due to weed growth, itself a product of inadequate site preparation. Alternatively, very fierce burns can lead to excessive exposure and desiccation of newly planted seedlings reducing growth or survival. It would be difficult to enumerate all the possible interactions (Chavasse, 1969e, p. 156 ff.).

Most attention (in both research and operations) is given to height growth. However, many of the effects are related to root growth. There are some studies which indicate that poorly planted trees, with distorted root systems, show more top growth (sometimes for several years) than properly planted trees. Little work has so far been done to quantify results of root distortion, but it is common in most artificially established plantations; it is related to instability and may be related to windthrow.

Leaf *et al.* (1979) consider that the crucial seedling quality consideration is the ability of newly planted seedlings to regenerate new roots rapidly when planted in the forest. The ability of seedlings to do so depends on their quality and vigour, the effects of handling and the site conditions (soil, weed competition, etc.). Seedlings able to regenerate roots vigorously cannot be recognised by morphological characteristics nor, as yet, by nutrient status and food reserves within the seedling.

Root development of planted trees is essentially different from that of naturally regenerated trees. Root areas are less for bare-root seedlings, and substantially less for container-seedlings, especially plug seedlings, compared with roots of trees originating from seed *in situ* (Grene, 1979). Potter and Lamb (1974) substantiate this point for trees growing in gravel soils in Canterbury, irrespective of site preparation methods. They found substantial differences in root systems between naturally regenerated or seeded trees, and hand and machine planted trees. Stroszek (1979) found that many factors can lead to post-planting stress, including deficient root development. This in turn may lead to reduced growth and may be caused initially by methods of site preparation, methods of planting, and partial attack by *Armillaria mellea* root rot. When seedling vigour is impaired, then additional problems from insects and diseases can be expected. There is some evidence in New Zealand (A. Zandvoort, pers. comm.) that attack by *Armillaria* may be related to distorted root systems and tree toppling.

Malformed root systems can lead to breaking-off at ground level, poor growth and instability. Root systems can be profoundly affected by transplanting practice in the nursery (Harris, 1979; J. C. van Dorsser, pers comm.; J. M. Balneaves, pers comm.). The phenomenon of toppling has been examined in some detail in New Zealand, where high winds are common, although no connection between early toppling and later windthrow has yet been demonstrated. Chavasse (1969b) following a survey taken after a serious gale, found that toppling occurs in wet soils, on sites subject to wind turbulence, and during snowfalls. Susceptibility of trees to toppling can be due to unsatisfactory tree stocks, high soil fertility, heavy soils and excessive weed competition. Menzies (1974), in further studies on a clay soil, confirmed some of these findings. He found that trees with taproot and lateral root development in more than one plane tended to be more stable, but there was very great variability in root development irrespective of type of tree stock and method of planting.

In several countries, adoption of container-seedlings in order to overcome difficulties with root development of bare-rooted seedlings was seen as a solution. However, in many instances it has been found that root development of container-seedlings, when planted in the forest, is poorer than that of bare-rooted seedlings. Chavasse and Balneaves (1971b) observed a case of highly significant differences in percentage toppling between tubed and bare-rooted seedlings; the bare-rooted seedlings were superior. Hultén and Jansson (1979) found that after planting, while bare-rooted trees had numerous roots with large cross-sections, plug seedlings had numerous small roots with small cross-sections, and paperpot seedlings had few roots with large cross-sections. The bare-rooted seedlings were to be preferred. Lindgren and Orlander (1979) found that, although plug seedlings showed greater reduction in root area compared with bare-rooted trees, top growth of the plug trees was greater. This, however, may make them more susceptible to toppling.

Burdett, (1979) agreed that planted trees were less well anchored than those emanating from seed *in situ*. He considered that one way of eliminating the problem is to use planting stock raised in containers coated with a root growth inhibitor to prevent elongation of lateral roots until after planting. There is also a need to adopt planting methods which do not cause any persistent modification in the natural pattern of root morphogenesis.

The debate continues. Chavasse (1978) gives details of various types of container-seedlings and their growth, including root growth, when planted in the forest. There are major differences within species, related to container type. There is a long way to go before a container will be developed which does not affect the growth and root form of seedlings.

CONCLUSIONS

These notes on the factors which can influence the behaviour and growth of seedlings in the nursery and the forest indicate that all experiments to investigate seedling quality need to be very carefully controlled. One way of doing this would be to conduct the complete experiment in a controlled environment chamber using clonal material. But this would essentially show how that particular clone would behave in that particular environment. The final analysis of good or bad practice must be conducted in the field. The notes confirm that the experimenter must conduct such research with his eyes wide open, maintaining clear and precise records of all those factors which may affect his experiment.

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