SEEDLING QUALITY - RADIATA PINE AS A CASE STUDY

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Abstract. Seedling quality has traditionally been measured by morphological characteristics, including height, diameter at the root collar, sturdiness, and root/shoot ratio. While some of these characteristics give an indication of seedling quality, they are not ideal for predicting potential survival and growth rate.

Physiological characteristics are also important for later field performance. Water potential should be above -0.5 MPa. Seedling root growth potential appears to assess both food reserves and health of the root system. Frost tolerance can be reliably assessed using artificial frost chambers.

Quality of radiata pine seedlings is controlled by the way they are grown in the nursery, and handled from nursery to planting site. The two most important factors controlling seedling quality in the nursery are:

1. Seedling density. Seedlings must be spaced widely enough to encourage stem diameter development and fibrous root growth in response to conditioning, as well as allowing light to lower foliage.

2. Seedling conditioning. A programme of undercutting, wrenching, and lateral root pruning is essential to develop a compact fibrous root system with good food reserves on a sturdy plant.

Once seedlings are lifted the handling system must ensure that:

- seedling roots are kept moist at all times;
- foliage and roots are not bruised or crushed;
- storage time is kept short, (less than 48 hours) and storage temperature low, (2-4°C) to minimise respiration.

Additional keywords: bareroot seedlings, nursery, seedling density, conditioning

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The helpful criticism of Dr D.A. Rook, Mr C.G.R. Chavasse and Mr E.G. Mason is gratefully acknowledged.

INTRODUCTION

There is no clear definition of what is an acceptable seedling. A common viewpoint is that if field survivals exceed 85%, then seedling quality has been satisfactory. A seedling is often considered alive if it has a few green needles, or if the stem is still green at the base, even though such trees have little chance of contributing to a crop. Optimum and uniform early growth of the crop are also required.

Obviously a judgment of seedling growth and quality can be made six months or a year after planting, but the forester needs to be able to assess seedling quality before plants leave the nursery, to know if they are worth planting.

Traditionally this has been done by specifying certain morphological characteristics, including height, diameter at the root collar, sturdiness (height/diameter ratio), root/shoot ratio, and some root features, although there is no universal agreement on which variables are the most useful (Aldhous 1967; Cleary et al. 1978; Lavender and Cleary 1974; Schmidt-Vogt 1974). No single variable is sufficient. Tall trees are often preferred because they are thought to be better for weedy sites, or where animal damage can be expected, but tall trees can be produced by close spacing and high nitrogen fertilisation, both of which can result in poor quality seedlings (Schmidt-Vogt 1974). Similarly root/shoot ratio is not reliable as a single indicator since trees with the same ratio may have a large heavy taproot and few laterals, or a mass of fibrous root; the latter is considered more desirable (Cleary et al 1978). A combination of height, sturdiness, and root quality would seem desirable.

The physiological quality of a seedling is also important for successful establishment, but is more difficult to assess. Poor physiological condition is often apparent only after outplanting, when seedlings die without any new root growth or before flushing (Lavender and Hermann 1976). When a seedling is planted in the field, the first problem is usually to restore and maintain a suitable water balance. Stomatal closure will help conserve water, but may be insufficient to prevent wilting. The seedling must establish a good contact between its roots and the water supply in the surrounding soil. A large root surface area will help, but often it is the fine water-absorbing fibrous roots that are damaged and killed before planting. New roots must be initiated and elongated into the surrounding soil, using stored or current photosynthates. If the seedling is under water stress, with stomata closed, then the production of current photosynthates will be minimal, and any new root growth will be dependent on stored food reserves. The essential physiological attributes therefore include an adequate water content and food reserves, and a healthy root system, preferably with root initials already formed.

Radiata pine (Pinus radiata D. Don) has been planted extensively in New Zealand since the late 1920s. Initially, small nurseries were established close to the major planting sites, but there has been a trend in the last two decades to create large centralised nurseries to take advantage of better mechanisation. Nurserymen have learnt over the years how radiata pine seedlings can be manipulated in the nursery by practices such as sowing time, density of sowing, fertilisation, and mechanical conditioning. Two-year-old (2/0) seedlings were once favoured but now 1/0 seedlings are more widely used, and even 1.5/0 seedlings are becoming rare. Nurserymen can now readily change seedling morphological and physiological characteristics, if they are given specifications, and can therefore purpose-grow seedlings for specific sites. For instance, tall sturdy seedlings are desirable for sand dune sites; one-third of the stem may be buried with deep planting. However, often seedling characteristics are not well prescribed.

In this paper we shall discuss methods for raising bare-root radiata pine seedlings in New Zealand as a case study of the effects of these practices on seedling characteristics, before discussing radiata pine seedling quality. In New Zealand, most of the radiata pine seedlings are grown as 1/0, with sowing in spring (September-November) for lifting the following winter (June-August). A few 1.5/0 are still grown for late autumn/early winter planting, particularly in colder nurseries with a short growing season. These are sown in late summer (January-March) and carried through the following summer for lifting in May, when 1/0 seedlings may still be too small, or not sufficiently prepared by conditioning.

SEED QUALITY

Seed grading

Seed is graded into 4 grades, on the basis of seed size, with 95% of seeds falling in the middle 2 grades. Grading is critical for the 'Stanhay' agricultural sower, to minimise the number of doubles and trebles sown, but is not so critical for the recently developed Forest Research Institute vacuum drum sower. Seed cleanness is critical, however, to get all seed stations sown.

The number of seed per kilogram in each grade averages about 22,000 for Grade 1, 27,000 for Grade 2, 33,000 for Grade 3, and 38,000 for Grade 4. In a trial sown in October, 1983, seed was divided into three grades on the basis of seed weight; Grade A, 0.04-0.049 g; Grade B, 0.03-0.039 g; and Grade C, 0.02-0.029 g; corresponding to averages of 22,000, 29,000, and 40,000 seeds/kg respectively. The grades were also blended into A+B, B+C, and A+B+C. Four hundred seeds of each treatment were handsown in a randomised block design in three adjacent seedbeds. The germination percentage (5 weeks after sowing), and seedling heights (after one year) are given in Table 1.

Smaller seed had poorer germination and also poorer height growth. There was no evidence of seedlings from smaller seed being suppressed in blended grades at the seed density sown (6 x 12.5 cm), although there was no significant difference in height coefficients of variation between treatments.

TABLE 1 - Seed germination and height growth for different grades of seed (graded on weight)

Grade	A (large)	B (medium)	C (small)	A+B	B+C	A+B+C
Germination (%)	84a	81ab	70c	76bc	73c	76bc
Height (cm)	34a	31c	31c	32bc	32bc	33ab
Coefficient of Variation (height)	0.16a	0.16a	0.18a	0.19a	0.19a	0.16a

Treatment means followed by the same alphabetical letter are not significantly different (LSD test, $p = 0.05$)

Seed treatments

Seed is usually coated with a fungicide, such as thiram, before being stratified for 3 weeks, or given a 48 hour cold soak. Seed is normally stratified if it is sown in early spring, or if the seed is old, while seed that is sown later, or fresh, is given a 48 hour cold soak. Water temperature for soaking is important. When 200 seeds of each treatment were soaked for 48 hours at temperatures of 10, 15, 20, and 25°C before sowing, with and without water aeration, germination results were 76% for 10°C, 74% for 15°C, 70% for 20°C and 56% for 25°C. Only the 25°C soak was significantly different from any other treatment. Aeration did not give any significant improvement in germination (71 vs 65%), but it did significantly speed up germination (e.g. 60 vs 46% three weeks after sowing).

A trial was sown at the beginning of November, 1983 to compare thiram coating before and after 3 weeks stratification and 48 hour cold soak. Three hundred seeds of each treatment were handsown in a randomised block design in three adjacent seedbeds. Germination was better if thiram was applied before stratification or the cold soak (Table 2). Possibly some thiram entered the imbibed seed through split seed coats and inhibited germination when it was applied after stratification or cold soaking. Stratification for three weeks speeded up germination, but resulted in a lower germination figure. This experiment will be repeated with earlier sowings, when the soil temperature is colder.

TABLE 2 - Germination (%) of thiram-coated radiata pine seed before and after 3 weeks stratification or 48 hour cold soaking

Treatment	Thiram	Assessment Time (days after sowing)		
		15	25	39
3 week stratification	Before	73a	76ab	77b
3 week stratification	After	70a	72bc	73b
48 hour cold soak	Before	34b	79a	83a
48 hour cold soak	After	29b	68c	73b

Treatment means followed by the same alphabetical letter are not significantly different (LSD test, p = 0.05).

SEED SOWING

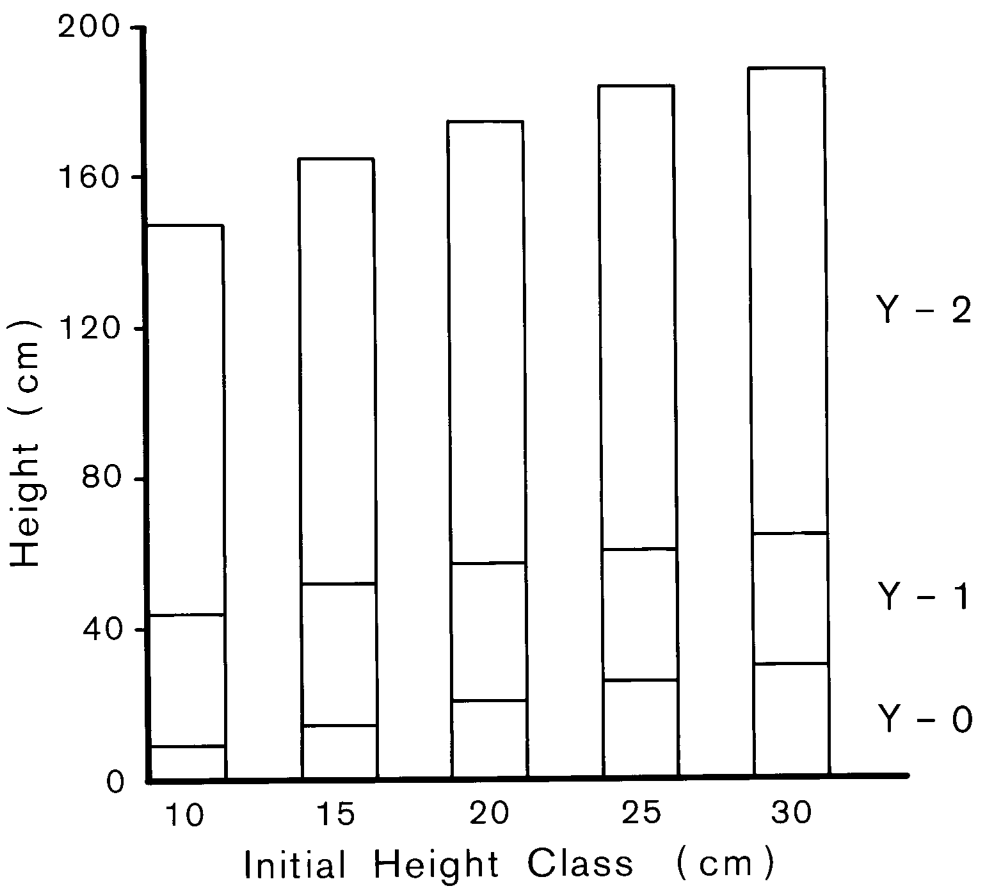
Timing of Sowing

For 1/0 radiata pine, seed is sown in spring (September-November), depending on climate, ground conditions, and final desired seedling size. Sowing commences shortly after the previous crop is lifted, as soon as weather and soil conditions permit cultivation. Base fertiliser dressing is applied at this stage, quantities depending on soil test results. After the ground is prepared, the sowing programme is completed as rapidly as possible so that germination occurs over a relatively short time. When the sowing period is prolonged, birds follow seedling emergence over the nursery, doing damage over the whole area. If the emergence time is short, bird damage is usually restricted to edge areas, adjacent to shelter. Few nurseries have irrigation available to help germination if there is a dry period. For 1.5/0 radiata pine, seed is sown January-March.

Sowing time regulates seedling height, smaller seedlings resulting from late sowing. Figure 1 shows results from a trial with 1/0 seedlings sown at different times to raise seedlings in 5 height classes from 10-30 cm tall (Chavasse 1977). Height increment after planting was greater with increasing initial height, the tallest seedlings after 2 years being those from the 30 cm height class.

In a similar trial with 1.5/0 seedlings of different initial heights, planted on both a benign and a hard frost site, the best increments came from the 20 and 30 cm height classes. The pattern of growth was similar at both sites; height growth at the first site is shown in Figure 2 (Chavasse 1977). Two years after planting there was little difference

Figure 1 - Mean Height Growth for 1/0 radiata pine seedlings rasied in five initial height classes (Chavasse 1977)

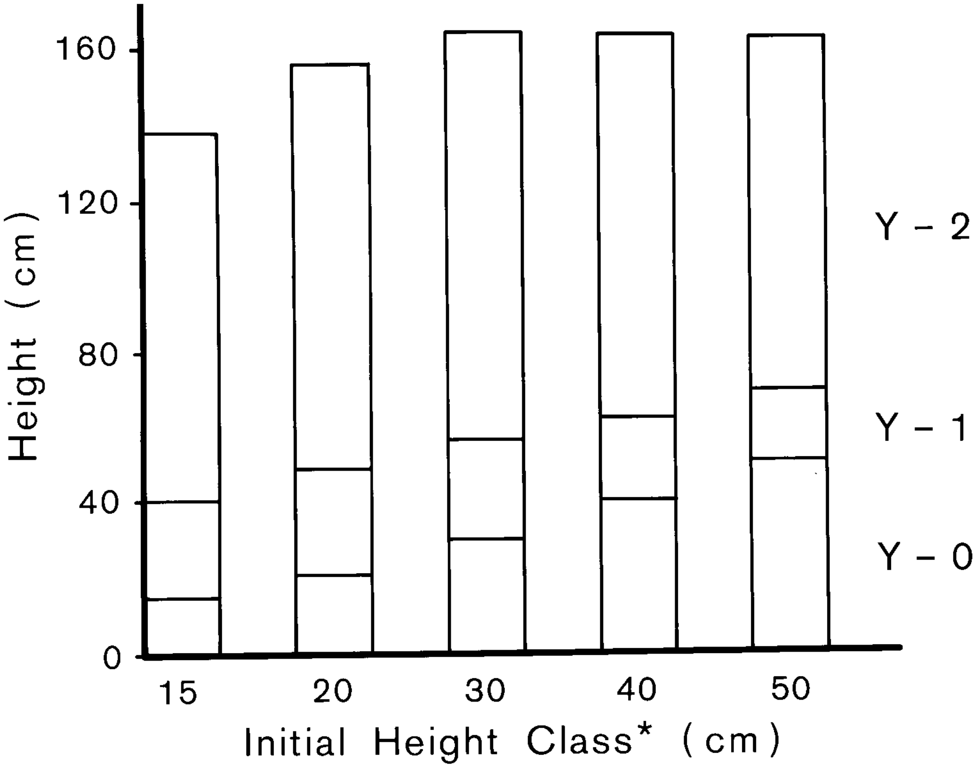


in height between the 30, 40 and 50 cm height class seedlings, indicating no advantage in growing seedlings too tall in the nursery. On average, seedlings should be between 20-30 cm tall for both 1/0 and 1.5/0 seedlings. It is important that seedlings are tall enough by February to allow mechanical conditioning to begin.

Sowing Depth

Sowing depth affects both germination percent and crop uniformity. The results of a trial sown in the FRI nursery using grade 3 radiata pine seed sown at 6 x 15 cm spacing at different depths are given in Table 3. The optimum depth was 6 mm. If the seed is sown too shallow it is subject to drying and bird predation. If it is sown too deep, it may not have the germinative energy to emerge, or emergence may be delayed, resulting in an uneven crop. Sowing depth is more critical with small (Grade 3 and 4) seed.

Figure 2 - Mean height growth for 1.5/0 radiata pine seedlings raised in five initial height classes (Chavasse 1977)



*Initial height class adjusted to nearest actual 5cm class

TABLE 3 - Percentage of viable seeds emerged after sowing at different depths

Sowing depth (mm)	3	6	10	13	16	19
% of viable seeds emerged	38	99	76	62	27	11

Sowing Density

The density at which seeds are sown can have a major effect on morphological characteristics of the planting stock. One trial to raise 1/0 seedlings at the Forest Research Institute required seed to be sown at 4, 6, 8 and 12 per foot of drill (approx 7.6, 5.1, 3.8 and 2.5 cm spacing respectively), and 1.5/0 seedlings at 4, 6 and 12 per foot of drill (approx. 7.6, 5.1, and 2.5 cm spacing respectively). Seedlings were graded after lifting into three sturdiness classes, based on height/root collar diameter ratios of 60, 61-80, and 81+; the percentage of seedlings in each grade is shown in Table 4. The wider the spacing, the higher the percentage of seedlings achieving more desirable sturdiness grades. The morphological characteristics of height, root collar diameter, sturdiness (height/root collar diameter ratio), and root volume for 1/0 seedlings, are shown in Figure 3. Trends were similar for 1.5/0 seedlings. While there was no consistent height pattern, the other characteristics were all better at lower densities; root collar diameter was greater, seedlings were more sturdy, and they had a larger root system at lower densities. However these improved morphological characteristics are not always reflected in improved later field performance. Seedlings from this trial were planted on two sites, neither very severe, and after two years there was no clear height improvement from seedlings from lower density seedbeds; often the height increment was better for seedlings from denser seedbeds. However, height growth was consistently poorer for grade 3 trees (sturdiness ratio higher than 80); this grade can be avoided or minimised by growing 1/0 seedlings at least 3.8 cm apart for 1/0 seedlings and 5 cm apart for 1.5/0 seedlings.

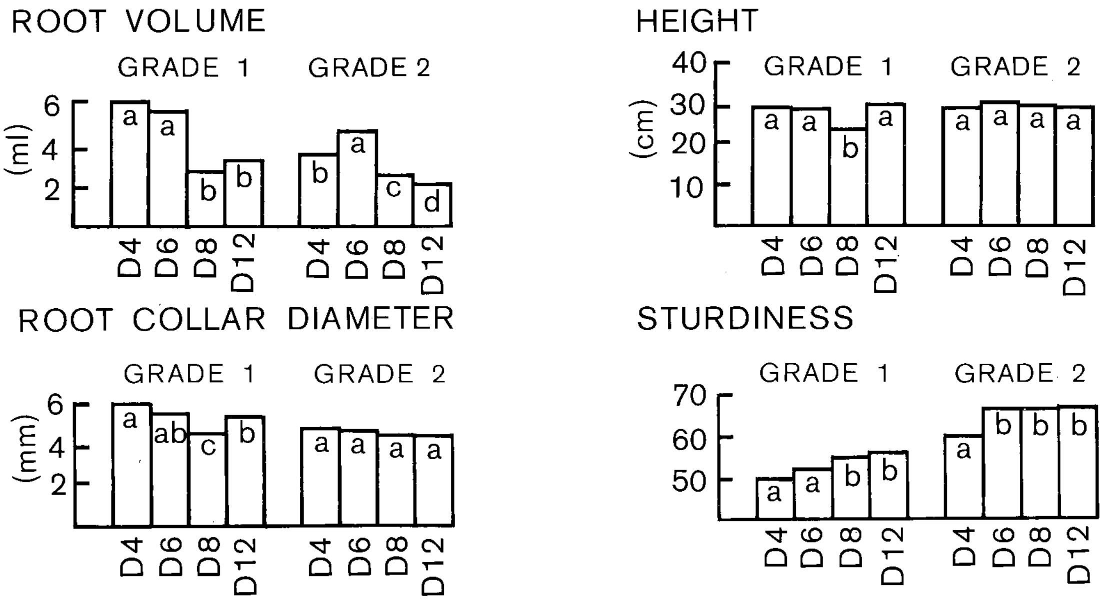
TABLE 4 - Effect of seedling density on grade returns from seedlings at time of lifting

Seedlings per running foot of drill	Sturdiness Grades 1	2	3	Cull
	H/D: 60 or less	H/D: 61-80	H/D: 81 or more	-
	Percentage grade return - 1/0 precision sown			
4	81	13	-	6
6	75	20	-	5
8	64	31	-	5
12	49	44	7	-
	Percentage grade return - 1.5/0 precision sown			
4	36	48	9	7
6	30	53	10	7
12	6	44	46	4

4/ft = 7.6 cm apart
6/ft = 5.0 cm apart
8/ft = 3.8 cm apart
12/ft = 2.5 cm apart

In a later study with 1/0 and 1.5/0 seedlings sown at different spacings, and raised with different initial heights, height after 2 years for 1/0 seedlings continued to improve with lower seedbed densities, even up to a seedling spacing of 6.5 cm in the nursery bed (Figure 4).

Figure 3 - Morphological characteristics of 1/0 seedlings sown at different densities in the nursery bed



Treatment with the same alphabetical letters are not significantly different. (L S D tests P=0·05)

GRADE 1	= Height / stem diameter ratio	⩽ 60
" 2	= " " " "	61 - 80
" 3	= " " " "	⩾ 81

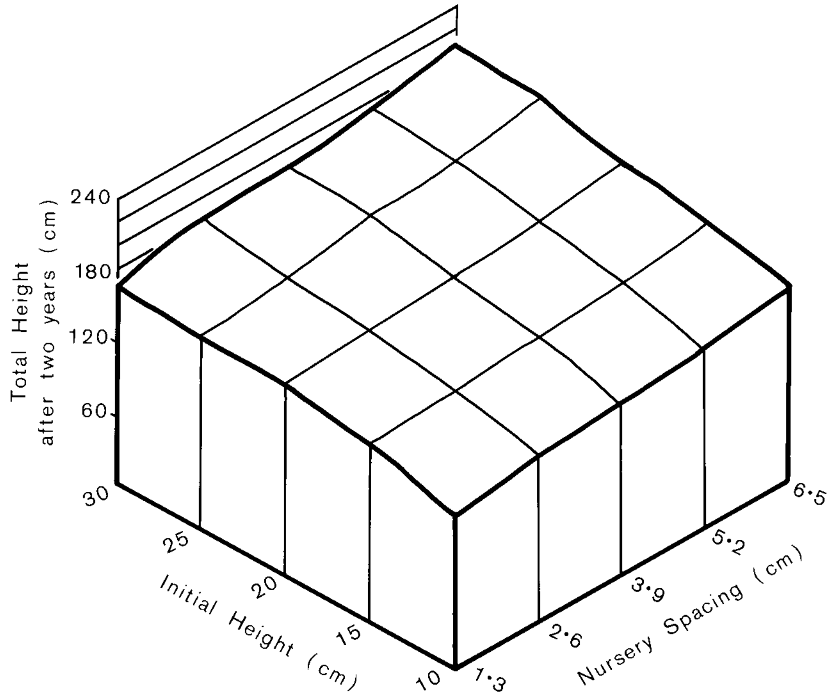
D4	= 4 seedlings / ft of drill	= 7·6cm apart
D6	= 6 " " "	= 5·0cm apart
D8	= 8 " " "	= 3·8cm apart
D12	= 12 " " "	= 2·5cm apart

Similar results showed with 1.5/0 seedlings, except that there was not much advantage in going from 6 to 8 cm spacing in the nursery bed (Chavasse 1977).

Based on these and other results, spacings at the FRI nursery are now 5 cm x 12.5 cm for 1/0 seedlings, and 7 cm x 15 cm for 1.5/0 seedlings.

The optimum density for seedling quality varies according to the climate of the nursery locality. Seedlings from higher elevation nurseries, or those with heavier soils need to be more robust, (Chavasse 1980), with an optimum sturdiness of 60 or less at the FRI Nursery in Rotorua (van Dorsser 1969), and less than 45 in the south of the South Island at Edendale Nursery (Chavasse 1980). Sturdiness of seedlings is improved by widening seedling spacing (Figure 3); the optimum spacing for seedlings at Edendale Nursery is at least 6 cm rather than the 5 cm

Figure 4 - Mean height growth after two years for 1/0 radiata pine seedlings raised at different nursery bed densities (adapted from Chavasse 1977)



at the FRI nursery in Rotorua. In a trial sown at Edendale Nursery, increasing spacing within drills from 4 to 6 cm reduced the percentage culls from 30% to 6%, gave a similar number of plantable seedlings per metre of bed (80 versus 82), increased yield from seed from 55 to 80 plantable seedlings per 100 seed sown, increased root growth potential (RGP), and increased growth of seedlings after planting in the field (Balneaves 1983). Seedlings were graded by morphological characteristics to determine why these improvements occurred (Balneaves and Fredric 1983). Neither height nor sturdiness were correlated with later growth. Diameter at the root collar was one of the main morphological characteristics affected (Table 5), with the percentage of larger diameter seedlings increasing as spacing increased. Similarly RGP, height, diameter, and oven dry weight (ODW) of tops and roots after planting increased with increasing diameter classes within individual spacings and with increasing spacings (Table 6, Figure 5). The reasons for improved later performance with an increase in spacing within a root collar diameter class are not known; it could possibly be due to the concurrent increased ODW (Figure 5). Certainly the initial ODW of shoots or roots was a good indicator of growth potential (significant at $p = 0.001$).

TABLE 5 - Percentage of seedlings within root collar diameter classes (Balneaves and Fredric 1983)

Spacing (cm)	Root Collar Diameter (mm) 3	4	5	6	7
4	23a*	39a	31a	7a	-
6	16b	23b	39b	22b	-
8	-	18b	43b	33c	6

* Using a chi-square test. Treatments sharing a common letter are not significantly different (0.05 level) [Vertical direction].

TABLE 6 - Root growth potential in relation to seedling diameter classes and spacing (Balneaves and Fredric 1983)

Diam. Class (mm)	New Root Growth: Mean No./Plant 4 cm	6 cm	8 cm	Total Length/Plant 4 cm	6 cm	8 cm
3	4a[1](a)[2]	10a(a)	-	7a(a)	15a(b)	-
4	8a(a)	13ab(a)	7a(a)	8a(a)	22a(b)	38a(c)
5	9a(a)	13ab(a)	13ab(a)	19b(a)	37b(b)	51a(c)
6	11b(a)	18b(a)	18b(a)	17b(a)	27ab(b)	36a(b)
7	-	-	17b	-	-	42a

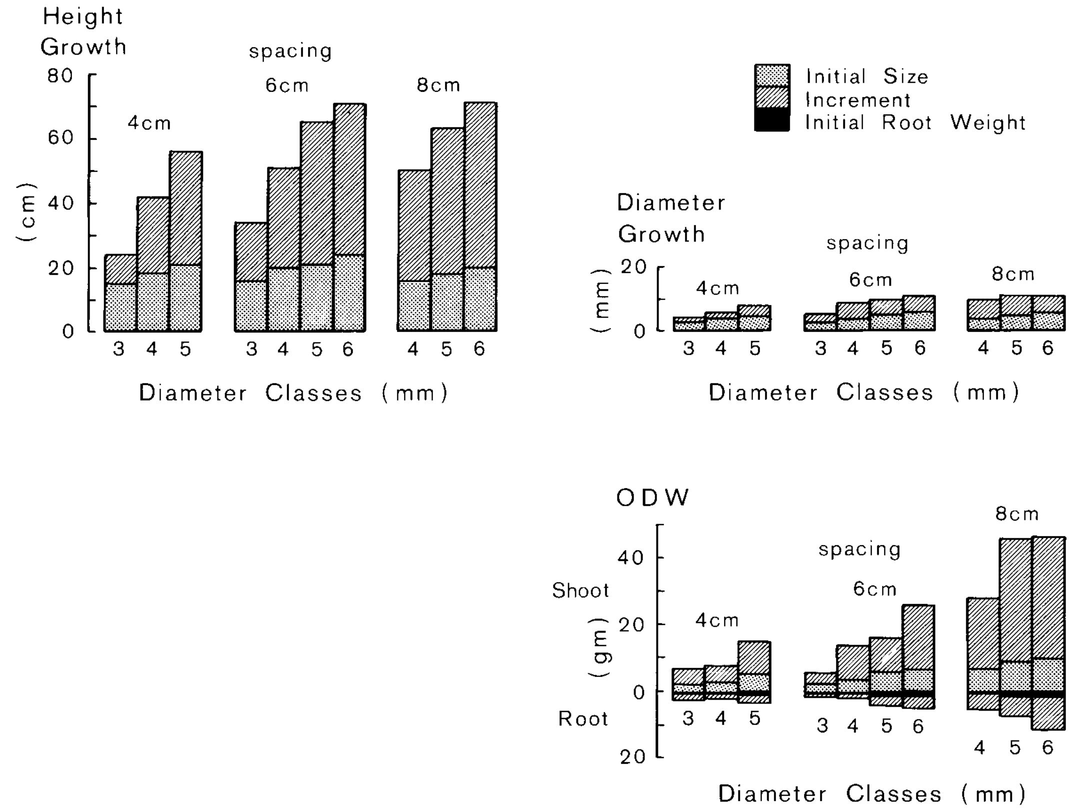
[1] Using Duncan's M.R. test. Working down the column, those treatments sharing a common letter are not significantly different (0.05 level).

[2] Using Student's t-test and Duncan's M.R. test. Working across the columns, those treatments sharing a common letter are not significantly different (0.05 level).

CULLING

Some seedlings are forked or multileadered near the ground, and appear to have been damaged soon after germination by birds or insects. These defects tend to persist, even after outplanting, although one leader may eventually become dominant, leaving the other leaders as ramicorn branches. Also some plants are persistently smaller than the main crop, and these runts, identified early in the crop as less than two-thirds the

Figure 5 – Growth of seedling for Edendale Nursery for 12 months after planting in relation to spacing and initial diameter class in the nursery.



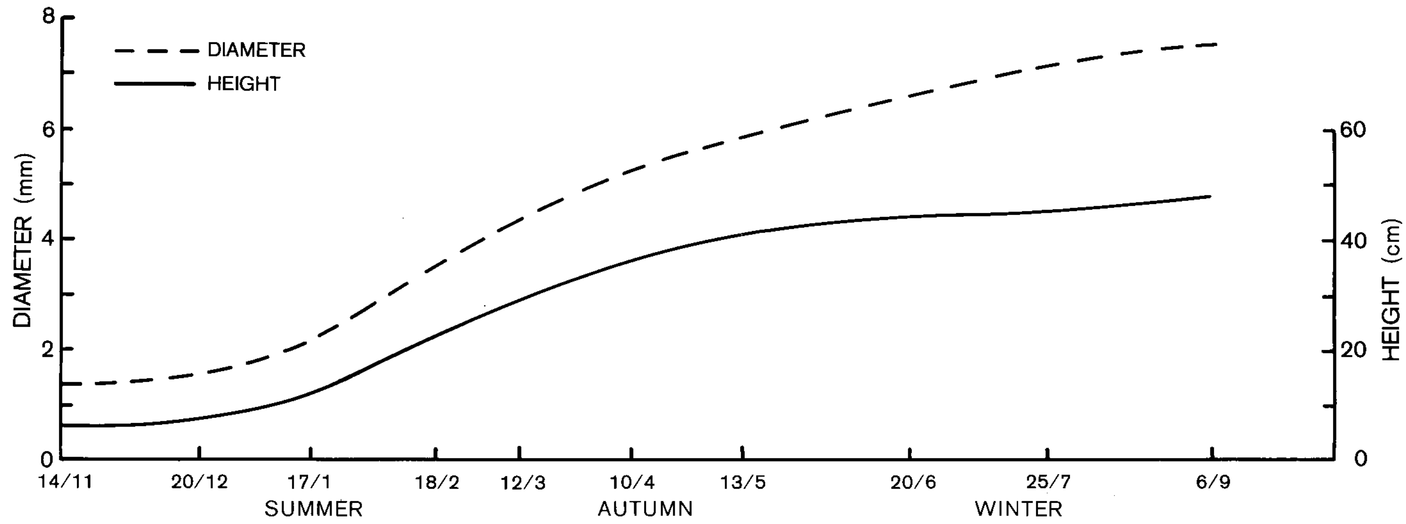
average height of the crop, continue to perform poorly. These malformed seedlings and runts should be removed early, when the crop is 10-20 cm tall, while they can be easily identified, and their removal minimally disturbs neighbouring seedlings (Trewin 1981a). Precision sowing has made identification easier, and there is a period of approximately one-two months to treat the crop when seedlings are small enough to remove easily. In-bed culling at this time also allows thinning of any extra seedlings at seed spots resulting from sowing of doubles or trebles. Removal of reject seedlings early in the crop life is easier and cheaper than sorting them at the time of lifting, and is also beneficial to the remainder of the seedlings.

CONDITIONING

Principles of Conditioning

In their first year, radiata pine seedlings make most of their height growth from the end of December until mid-April; the pattern of diameter growth is similar (Figure 6; van Dorsser 1981). Juvenile radiata pine

Figure 6 - Growth pattern for unconditioned radiata pine seedlings (van Dorsser 1981)



does not form a true dormant bud during winter months; seedlings continue to grow if conditions are suitable, although the rate of growth is slower. There is a greater reduction in height growth than in diameter growth (Figure 6), so the seedlings become sturdier. This is part of a natural conditioning process, as the seedlings harden initially in response to shortening photoperiods, and then in response to lower temperatures, particularly frost (Weiser 1970; Greer and Warrington 1982).

However, this natural conditioning is not sufficient to harden seedlings off for transplanting. They need to be mechanically conditioned to produce a compact fibrous root system, and to slow down height growth. A regime of undercutting, lateral root pruning, and repeated wrenching is required to achieve this objective (Rook 1971; van Dorsser 1981). In nurseries where natural (winter) conditioning takes place it may augment conditioning by mechanical means. Where natural conditioning is minimal, reliance needs to be placed on mechanical conditioning. Similarly if seedlings have to be prepared during the growing season for early winter planting this can be done only by mechanical means.

There has been some confusion in the literature over terminology of mechanical conditioning (Rook 1971). Undercutting is the process of passing a horizontal, flat, thin, sharpened blade beneath the seedbed to sever the taproots of seedlings at a predetermined depth, usually 5-8 cm for radiata pine. Wrenching is the process of passing a horizontal, thicker, tilted, generally blunt blade beneath the seedbed, usually just below the undercutting depth, although in heavy soils it may need to be done at the undercutting depth. Wrenching severs any small roots growing down below the undercutting depth, and aerates the root zone, encouraging fibrous root and mycorrhizal development.

Lateral root pruning is the process of passing vertical knives or coulters between rows of seedlings, severing any lateral roots down to the wrenching depth. The combination of wrenching and lateral root pruning aims to restrict fibrous root development within a limited soil volume. Further improvements are possible if lateral root pruning could be done on all four sides of the seedling (box pruning; Chavasse 1978) but machinery still needs to be developed before this operation is feasible on a large scale.

The mechanical conditioning machinery has been described previously (van Dorsser and Rook 1972). Improvements since that date have been to the reciprocating undercutter/wrencher, with a faster blade speed, a self-sharpening undercutting blade, and hydraulic depth control. The lateral root pruner is now mounted on a steerable tool frame at the rear of the tractor, with an operator to guide the coulters accurately between seedling rows (van Dorsser 1981).

Timing of undercutting and wrenching

Timing of these treatments is important. If undercutting and wrenching are done too early, seedlings will not reach plantable size, since shoot growth slows down considerably following severing of the tap root. On the other hand if undercutting is postponed until the autumn or later, seedlings do not become fully conditioned. Seedling responses to undercutting and wrenching in summer (December), in late summer to early autumn (March), and in autumn to early winter (May) were compared by Rook (1971). Undercutting and wrenching after late summer were largely ineffective. After late summer the seedlings were not photosynthesising rapidly enough, and in addition a smaller proportion of the seedlings' current photosynthates was translocated to the roots for growth than in seedlings wrenched earlier in the growing season.

This could account for less rapid rates of root growth and lower root/shoot ratios, e.g., 0.40, 0.32 and 0.25 for summer, autumn and early winter wrenched seedlings respectively as compared to root/shoot ratios of 0.20-0.27 for unconditioned stock (Rook 1971). Seedlings must be undercut and wrenched when the climate is favourable for growth, and in radiata pine when vigorous height growth is taking place.

In order to allow conditioning to start at a given time in the growing season, at mid-summer (January-February) in Rotorua, time of sowing has to be regulated to produce seedlings of the desired size at the prescribed time. For instance, if conditioning is to start in mid-January, seed is sown in mid-February of the previous year.

Depth of undercutting and its effect on root growth

Currently seedlings are undercut at a depth of 5 to 8 cm. This is as shallow as a seedling 20 cm tall will allow without toppling. Such a tap root is also of sufficient length to accommodate the seedling's main lateral roots. In some nurseries with warm summer soils there is no lateral root development until 1-1.5 cm below the soil surface, and the undercutting depth needs to be deeper, at 10 cm. Seedlings should be undercut as shallowly as possible to impose a sudden severe shock. Undercutting at this depth causes severe wilting under dry atmospheric conditions, and the art in this technique seems to be to make the seedling wilt as much as possible without killing it. Many nurserymen play safe by undercutting not at 8 cm but at a greater depth and this does not appear to shock the seedling sufficiently, especially in a humid climate. Wrenching depth is generally maintained at just below the undercutting level. On heavy soils this cannot always be achieved and depth of wrenching may be the same as the depth of undercut (van Dorsser 1981).

Whereas undercutting and wrenching reduce shoot growth, rates of root growth for wrenched and unwrenched seedlings are similar on an oven-dried weight or volume basis. However root systems are very different in form; cutting the taproot causes loss of apical dominance in the root system as a whole. Radiata pine normally has a well-developed tap root, whereas undercut and wrenched seedlings have a compact mass of fibrous roots. Severing the tap root causes increased lateral root growth and development of many new roots, mainly tertiary in origin (Rook 1971).

Conditioning period

Studies in which seedlings were allowed to photosynthesise $^{14}CO_2$ to determine where the current photosynthate was being used (Rook 1971) indicated that the maximum effect of wrenching occurs 2-2.5 months after the seedlings are undercut. Thereafter there is a falling proportion of total photosynthate translocated to the roots. Thus undercutting should be timed to start 2.5 months before seedlings are to be lifted, or so that 2.5 months of the active growing season remains. Continued wrenching during winter months causes a slight further reduction in both height and diameter development (Figure 7 and 8). These reductions are minor compared with those sustained during the active growing season.

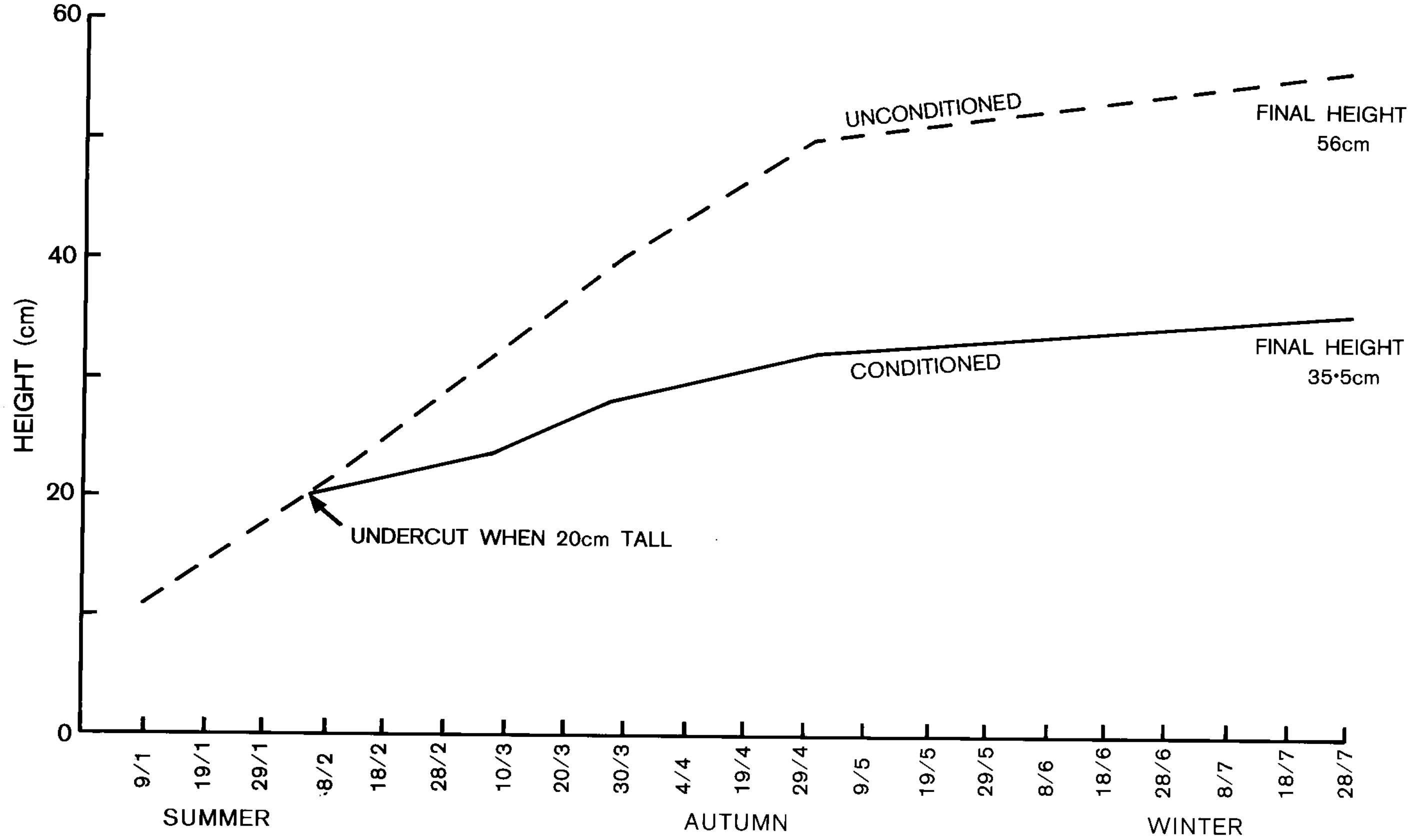
Intensity of wrenching

Once the initial undercut has been done, seedlings must be wrenched and lateral root pruned. After several wrenchings, lateral root growth can be extensive, and lateral root pruning is necessary to restrict root growth close to the main taproot, although there can still be long lateral roots along seedling rows (van Dorsser 1981).

Undercutting and wrenching cause a loss of chlorophyll. This can be checked by applications of nitrogen before and during the conditioning period. Unless nitrogen is applied during extended conditioning periods seedlings become very chlorotic. Such seedlings stagnate after planting.

Frequency of wrenching has a significant effect on the type of planting stock produced (Rook 1971). Wrenching at weekly or two-weekly intervals produces planting stock with high root/shoot ratios, and slightly higher starch levels than seedlings neither undercut nor wrenched. Wrenching at monthly intervals reduces root/shoot ratios, and greatly increases total and reducing sugar and starch contents compared

Figure 7 - Height growth of radiata pine seedlings undercut at 7.5 cm when 20 cm tall, wrenched at 4 week intervals, seedling spacing 5 cm (van Dorsser 1981)



with those of weekly or two-weekly wrenched seedlings. Wrenching at about three-weekly intervals until winter has proved best at FRI. This has resulted in good fibrous root development without too many long lateral roots running along the rows. Lateral root pruning at six week intervals is sufficient to control lateral root growth between rows.

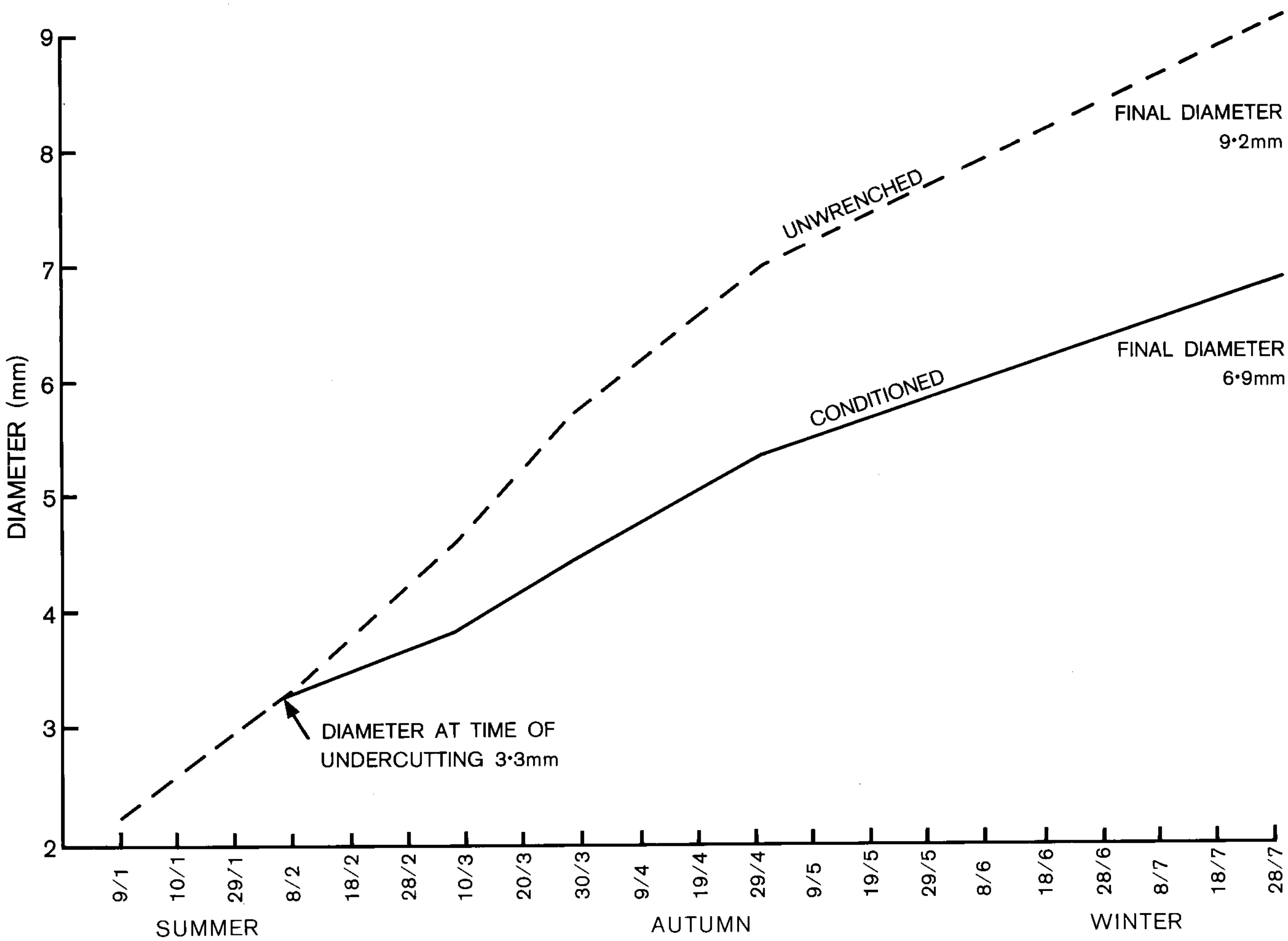
If wrenching is more frequent, resulting in development of too many long lateral roots, there can be problems at lifting time, with much root stripping, particularly for 1.5/0 seedlings.

Purpose growing

Based on the growth pattern in a particular nursery it is possible, within local climatic limitations, to purpose-grow seedlings. In nurseries with a short growing season, radiata pine stock for planting in late autumn/early winter is best produced as 1.5/0. By sowing during the previous growing season conditioning can start at an earlier date than is usual for 1/0. At Edendale Nursery, in the south of the South Island, the growing season is often wet and cold, and it is rarely possible to grow 1/0 large enough as well as conditioned for early winter planting. A

1.5/0 crop is sown in February for conditioning to commence a year later. This planting stock is used for planting in late May and June, with 1/0 being phased in from late June onwards, when both natural and mechanical conditioning have hardened the seedlings.

Figure 8 - Diameter growth of radiata pine seedlings undercut at 7.5 cm depth when 20 cm tall, wrenched at 4 week intervals, seedling spacing 5 cm (van Dorsser 1981)



It may also be possible, in some nurseries, to make several sowings in spring. The resultant seedlings can then be conditioned by adjustment of undercutting dates and wrenching frequency for lifting during a predetermined period. Because of natural conditioning there is less need to mechanically condition stock for late winter planting. For such stock a combination of mechanical and natural conditioning is successful in producing vigorous stock that is not over-wrenched. The time for height growth manipulation of radiata pine seedlings is during the active growing season from December onwards for 1.5/0, from February onwards for 1/0.

Another regime being evaluated in trials is the use of a late shallow undercutting regime. In some nurseries, the initial undercut in February is delayed, or is deeper than usual (10-14 cm), because seedlings are not tall enough, or the soil is too dry for a normal shallow undercutting depth of 5-8 cm. If the initial undercut is at 10-14 cm, the growth check is not as severe, but some lateral root growth is stimulated. Seedlings can then be wrenched and lateral root pruned at this deeper level. In autumn, (April-May), seedlings can be re-undercut at a shallower depth of 6-8 cm, using the new high speed undercutter/ wrencher. This technique also removes any swept sinker roots from poor wrenching operations. If the late undercut is timed correctly, the severed taproot will callus before lifting, but not have any soft fleshy new root tips which might be damaged during lifting and planting operations. This technique should allow rapid new undistorted sinker root growth after planting, and avoid the tree toppling problem that distorted taproots can give. At FRI, Rotorua, timing of the late undercut is about 8 weeks before lifting for early winter planting, lengthening to about 12 weeks before lifting for end of season planting.

Topping

Topping of radiata pine seedlings is aimed at producing a tree with distinct but not advanced fascicle buds. It may be carried out in conjunction with undercutting and wrenching. Under favourable growing conditions it may be necessary to top more than once. Should this be the case it is best to top successively downwards to final height rather than to top previously produced regrowth which is not only difficult to harden off but also progressively less able to regenerate a strong shoot (van Dorsser 1981). There have been some fears of double or multiple leaders resulting in the field after topping, but one shoot usually asserts dominance rapidly after planting, and topping is standard practice in the north of the North Island to control height growth.

Effect of conditioning

Conditioning by undercutting and wrenching causes morphological and physiological changes in seedlings. There is a significant reduction in height and diameter growth. Since height growth decreases relative to diameter growth, improved seedling sturdiness results (Figures 7, 8; Rook 1971). Although rate of root growth of wrenched and unwrenched seedlings is similar, wrenched seedlings have a compact mass of fibrous roots, mainly tertiary in origin, while unwrenched seedlings have a well-developed taproot and fewer fibrous roots (Rook 1971; van Dorsser and Rook 1972). Wrenched seedlings have a higher root/shoot dry weight ratio (0.4 vs. 0.2 for unconditioned seedlings; Rook 1971).

Conditioning also induces physiological changes. Undercutting and wrenching causes a threefold increase in the relative flow of ^{14}C-assimilates from foliage to roots. Monthly wrenching increases the concentration of reducing and total soluble sugars and starch content of seedlings, with the roots of wrenched stock particularly well supplied with total sugars and starch (Rook 1971). Well conditioned seedlings may have chlorotic foliage because of loss of chlorophyll. Applying urea to seedlings during conditioning checks the loss of chlorophylls and builds up nitrogen reserves, especially in the roots (Coker in prep.).

Because of these morphological and physiological differences, wrenched seedlings have withstood more stress and survived and grown better in a range of trials compared with unconditioned seedlings. Wrenched seedlings withstood midday exposure of shoots and roots for twice as long as unwrenched seedlings, and tolerated both high temperature and cold storage better (van Dorsser 1969). Unwrenched trees planted after 6 weeks cold storage at 1.5°C failed almost completely whereas wrenched seedlings survived well after 12 weeks (NZ Forest Service 1965). Transplanted wrenched seedlings showed higher rates of transpiration, relative turgidity, and root regeneration potential under more severe exposure treatment than did unwrenched seedlings (Rook 1969). When planted in field trials, wrenched seedlings not only survived better than unwrenched seedlings, but also had better height increment after planting (van Dorsser and Rook 1972). Height increment over the first two growing seasons in a trial at Kaingaroa Forest was 41.5 cm for unwrenched seedlings, but 63.3 cm for wrenched seedlings. Wrenching also allows seedlings to be conditioned for planting at any time of the year (Moberly 1970).

LIFTING AND HANDLING

Lifting and handling procedures can have a marked effect on seedling establishment (Trewin 1981b).

Time of lifting

Survival of seedlings after planting is higher if seedlings are lifted later in the winter rather than at the beginning of winter. In a recent trial with different conditioning regimes, survival of all treatments was over 85% in August-lifted seedlings, but ranged between 40% and 85% for May-lifted seedlings. Similarly, survival on a frost trial was over 85% for seedlings planted in August, and less than 40% for those planted in May (Menzies and Chavasse 1982). Seedlings can be conditioned to enable planting at any time of the year on an experimental basis, but careful handling is necessary for unseasonal planting, and drought following planting can be a problem in summer and autumn.

Lifting and handling methods

Before lifting, the soil must be loosened, so that seedlings can be easily removed without stripping off roots. This is done by passing a wrenching blade repeatedly under the bed at about double the normal wrenching speed, so that the soil is well broken up, and the seedling roots loosened. The seedlings can then be pulled up easily, either singly, or preferably in groups, to minimise loss of fibrous roots. In a comparison where seedlings were carefully hand-lifted in one nursery, and machine-lifted in an unloosened nursery bed of another nursery in the same district, samples were evaluated for water potential and root regeneration potential. There was no difference in water potential (both - 0.16 MPa), but the seedlings from the machine-lifted beds had a significantly lower root growth potential (0.9 vs 1.9, on a 0-3 scale from none to prolific new root growth) (Menzies unpublished data).

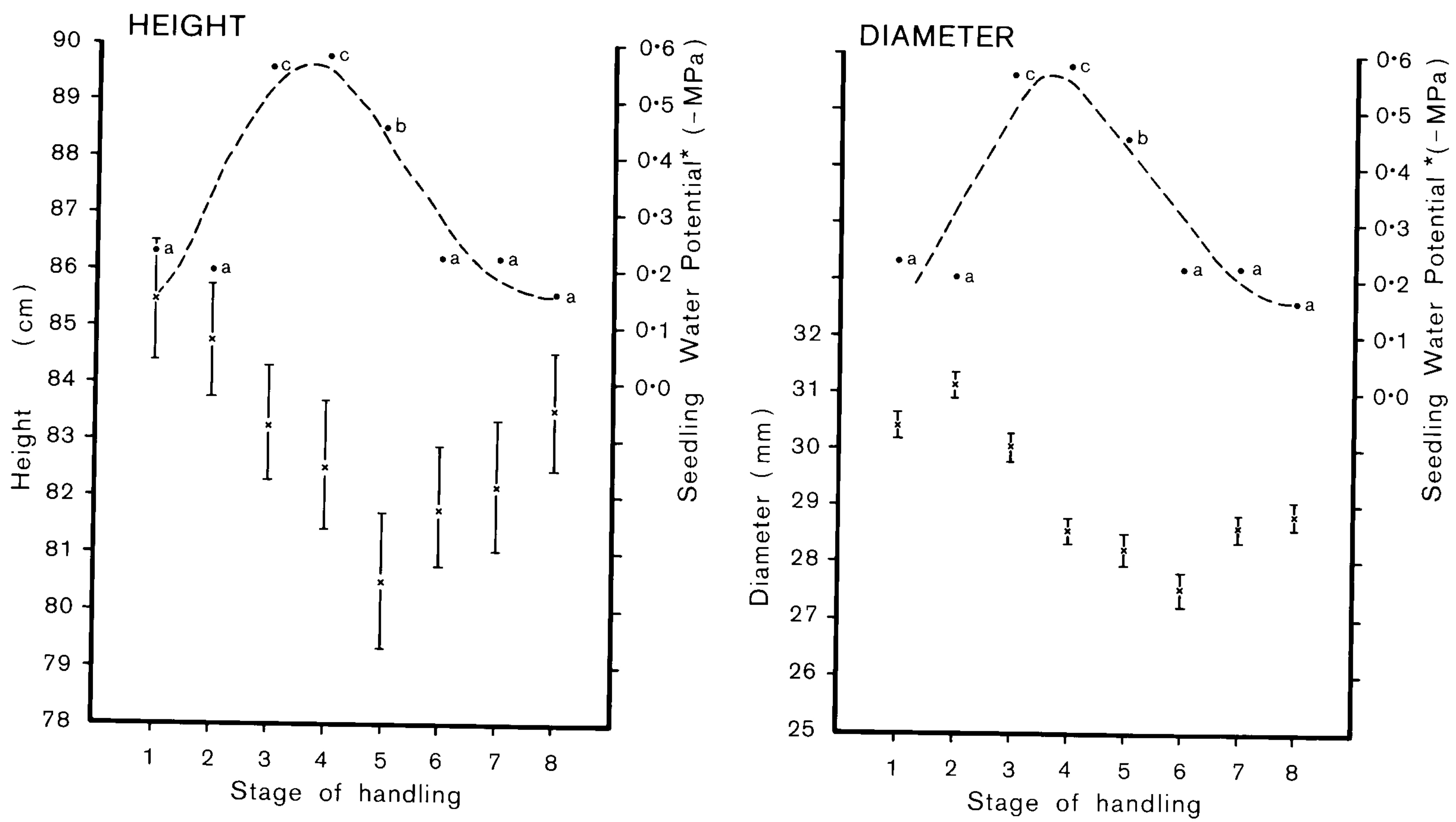
Lateral roots tend to grow along the rows where they are missed by lateral root pruning. Seedlings must be carefully separated, and the seedlings root trimmed in small bundles of five (for large stock) or ten (for small stock), so that they are all of even length. This allows planting without tangling or distorting root systems. Root trimming in large bundles gives uneven results, with some trees missed in the middle of bundles, and edge trees often overtrimmed (Trewin 1981b).

Once seedlings have been lifted and root trimmed, they have a fixed morphological quality that is not affected by handling treatment. However, the physiological quality can be affected. For example, water content of seedlings can be replenished by wetting the roots. Food reserves will decline with time, due to losses by respiration, but storage conditions can minimise the losses. Therefore handling procedures must be designed to minimise any loss of these food and water reserves.

<u>Recommendations to conserve food and water reserves</u>

(i) Roots must be kept moist at all times. When roots are allowed to dry out, it is the fine tertiary roots, and succulent, actively growing tips that succumb first (NZ Forest Service 1968); these are the roots that are vital for root elongation and water uptake after transplanting. Packaging seedlings into containers on the nursery bed is preferable to taking seedlings to a packing shed, because less handling is involved. Ideally, roots should be dipped in water, without shaking off excess water, so that seedlings can take up water after packing. Seedling tops can become dessicated in warm windy conditions, particularly mid-afternoon, and even if the soil is moist there may not be enough water on the roots to alleviate this water deficit. If seedling roots have free water on them, then the water deficit may be alleviated after overnight storage. In one example, when seedlings were lifted and packed into plastic bags in a packing shed instead of being packed on the seed bed, the average water potential of seedlings decreased throughout handling stages until the seedlings were watered after packing. After watering, the seedling water potential improved, and after overnight storage it was even higher than when the seedlings were lifted (Figure 9). Ninety seedlings from each treatment were planted in a field trial in a randomised block design, and their height and diameter after two years followed the pattern of water potential (Figure 9). However, although seedling water potentials recovered completely after watering, growth after planting did not, possibly due to other factors such as loss of food reserves during the handling phase.

FIGURE 9 - Relationship between seedling water potential before planting, and growth for 2 years after planting



Handling Stage

Day 1 — 1 on nursery bed 5 mins after lifting
2 on trailer 30 mins after lifting

Day 2 — 3 on trailer after overnight storage
4 on sorting table after culling, root trimming
5 after packing, and 15 mins after watering

Day 3 — 6 after overnight storage
7 at forest planting site

Day 5 — 8 at forest planting site just before planting

* mean of 10 seedlings

Treatment means followed by the same alphabetical letter are not significantly different (L S D test, p = 0·01)

(ii) Avoid crushing or bruising foliage and roots, as these will be the site of uncontrolled water loss after transplanting. Normally, seedlings close their stomata after transplanting in response to their water deficit, and this restricts loss of water, but any damaged plant parts will allow leakage and evaporation of water from seedlings, and increase the water deficit. Rigid cartons are recommended to protect seedlings from damage. An impervious layer next to the seedlings avoids water loss from seedlings to containers; this can be achieved by using waxed cardboard cartons, plastic cartons, or a plastic bag liner.

(iii) Seedlings should be stored on their side. When seedlings are packaged and transported vertically, the taproot is often bent and fractured, leading to death or distortion of the broken part of the taproot (Trewin 1981). Good straight taproot or sinker root regrowth is essential for tree stability, so the taproot must be protected (Chavasse 1978).

(iv) Storage time must be kept short, preferably less than 72 hours, and at a low temperature, preferably 2–4°C. This minimises loss of food and water reserves. Loss of food reserves by respiration increases with increasing storage temperature and time. The resources required for one day at 25°C can last a seedling 14 days at 2°C, (McCracken 1981). He suggested a maximum of 6 weeks cold storage at 2°C for radiata pine seedlings, which would be the equivalent of 3 days at 25°C.

ASSESSMENT OF SEEDLING QUALITY

Morphological features

Several morphological characteristics have been used to assess seedling quality. The most common ones are height, stem diameter at the root collar, sturdiness (height/diameter ratio), and root/shoot ratio. Less quantifiable criteria include fibrous root development, foliage colour, stem stiffness, and bud development.

The main criteria studied have been:

(i) Height

Seedling height is affected by time of sowing (Figures 1 and 2), time of the initial undercut for mechanical conditioning, and the nursery climate during the growing season. Seedlings need to be a certain minimum height for ease of handling and planting, about 20 cm for radiata pine. Once a seedling is more than 30 cm tall, there seems to be little advantage in height growth after planting (Figures 1 and 2). Seedlings in New Zealand are often up to 40 cm tall before topping is considered. However, height alone is a poor indicator of later field performance (Chavasse 1977).

(ii) Diameter (at the root collar)

Diameter is affected mainly by spacing in the nursery bed (Figure 3), and to some extent by the conditioning regime, since height growth is suppressed more than diameter growth by both natural and mechanical conditioning. In general, the wider the spacing in the nursery bed, the higher the proportion of seedlings exceeding a given diameter. Field trials have shown that larger diameter seedlings have had better survivals and growth, and that a diameter of at least 4 mm is necessary (Prior 1969; Wilkinson 1969; Anstey 1971; Balneaves and Fredric 1983). Smaller diameter seedlings should be planted on mild sites, while larger diameter seedlings are kept for harsher sites with frost or exposure problems (Balneaves and Fredric 1983).

(iii) Sturdiness (height/diameter ratio)

Sturdiness is affected both by density in the seedbed (Figure 3), and by conditioning, since height growth is slowed more than diameter growth (Figures 6-8). Since height growth slows more than diameter growth throughout the winter, sturdiness improves throughout the winter. When seedling density is lowered to obtain the desired diameter, seedling sturdiness is also improved (Table 3, Figure 3). The optimum sturdiness ratio is about 45 for seedlings from higher elevation nurseries, or those with heavier soils (Chavasse 1980). At the lower elevation FRI nursery in Rotorua with lighter soils, the optimum ratio is about 60 (van Dorsser 1969).

(iv) Root/shoot ratio (oven-dry weight basis = ODW)

The oven-dry weight of the shoot and root systems, and the ratio of root/shoot are not often measured in production nurseries. The ODW of shoots and roots increase with increasing spacing in the nursery bed, while the root/shoot ratio declines (Balneaves and Fredric 1983). Conditioning increases the root/shoot ratio (Rook 1971). The effect of changes in ODW on field performance was evaluated by Balneaves and Fredric (1983). Shoot ODW was the best indicator of subsequent growth in diameter and height, followed by root ODW, and then root/shoot ratio.

The morphological characteristics of height, diameter, sturdiness, and ODW distribution of seedlings from five North Island nurseries (three Forest Service and two private) are given in Table 7, for two dates of lifting, in June and July. There was a range of seedling height, with seedlings from Nursery B being topped. Diameters were satisfactory from all nurseries. Nurseries A and E had seedlings that were not quite sturdy enough in the June lifting. Based on diameter, sturdiness and ODW, seedlings from nurseries B and D should have been best at both lifting times. Seedlings from these nurseries also had better fine and total root lengths, although seedlings from Nursery C had the best root/shoot ratio at both lifting times, and a good root length in July. Seedlings for nurseries C and E had smaller diameters, ODWs and root length (C had good root lengths in July). Seedlings from nursery A also had poor sturdiness in June, and a poor root/shoot ratio and root length at both lifting times. These results will be compared with those of physiological quality later.

Physiological features

The main physiological attributes of seedlings are water potential, food reserves, root growth potential, and frost tolerance. Biophysical tests of electrical impedence and diffusate electroconductivity have been

TABLE 7 – Morphological measurements for seedlings lifted at two dates in the winter from five North Island nurseries (30 seedlings/nursery)

Nursery	Height (cm)	Stem Diam. (mm)	Sturdiness	ODW(g) Top	ODW(g) Roots	ODW(g) Root/Shoot	Root length (m) Fine	Root length (m) Total
June lift								
A	39a	5.7b	70b	7.2b	1.1b	0.15c	2.3cd	4.1cd
B	36b	6.5a	57a	8.5ab	1.7a	0.20a	8.6a	11.3a
C	26d	4.4c	60a	3.6c	0.8c	0.22a	2.8c	4.5c
D	36b	6.3a	59a	9.3a	1.6a	0.17b	7.1b	9.8b
E	31c	4.6c	70b	4.7c	0.7c	0.16bc	1.7d	3.2d
July lift								
A	39a	6.2b	62c	8.1b	1.3b	0.15c	2.4c	4.3c
B	36b	6.9a	54b	9.7a	1.7a	0.17b	4.7a	7.2a
C	30c	5.2c	59bc	5.9c	1.2b	0.20a	4.1ab	6.6ab
D	35b	6.5ab	55b	8.6b	1.5a	0.17b	3.7b	5.9b
E	24d	5.5c	45a	4.9c	0.8c	0.16c	0.7d	2.1d

Treatment means followed by the same alphabetical letter are not significantly different (LSD test, $p = 0.05$).

used successfully for some species, but have been of limited value for radiata pine, perhaps because radiata pine does not become truly dormant in winter (Rook and Menzies 1981). Both techniques have been used successfully for radiata pine to assess frost injury following artificial frosting, rather than relying solely on a visual assessment taken some time after the injury occurred (Green and Warrington 1978; Greer 1983a; 1983b). However, they are not widely used.

(i) Seedling water potential

Water potential is easily measured using a Scholander pressure chamber, (Ritchie and Hinckley 1975).

In the technique, a leafy shoot, needle fascicle, or individual needle is sealed in a specially constructed pressure chamber, with the cut surface protruding. Pressure is applied, via gas flow from a cylinder, until sap appears at the cut surface and this amount of pressure is regarded as being equal to the negative water potential of the cells in the attached leaves. One measurement takes about 2 or 3 minutes. Cleary and Zaerr (1980) note that guidelines have been established for conifer seedlings based on field experience and research studies with Douglas fir and ponderosa pine in the Pacific Northwest. Ideally, bareroot seedlings should have a water potential of greater than -0.5 MPa; if the water potential decreases to -1.0 MPa, the seedlings have probably suffered significant damage which would impair their performance after planting; if the water potential decreases to -2.0 MPa, the likelihood of severe physiological damage to root tissue is so high that seedlings are probably best destroyed. A water potential less than -5.0 MPa is probably lethal for most seedlings. Values of water potential for radiata pine are similar (cf Rook 1973; McCracken 1978; Stupendick and Shepherd 1980), and these guidelines could probably be used safely for radiata pine until more specific data become available.

After transplanting, there is little photosynthetic activity in radiata pine seedlings until the water potential is above about -1.2 MPa, because of stomatal closure (McCracken 1978; Stupendick and Shepherd 1980), while stomatal resistance is least when the water potential increases to -0.9 MPa. These studies are also in agreement with data for older radiata pine trees, where transpiration slowed when the water potential declined below -0.8 to -1.0 MPa (Rook et al. 1976).

(ii) Food reserves

Food reserves include both mineral nutrients and carbohydrates. A balanced adequate supply of mineral nutrients is necessary to produce vigorous plants that can quickly and effectively overcome transplanting shock (Ingestad 1962; Baule and Fricker 1970). Levels that might be "luxury consumption" in the nursery can be important for enhanced growth or survival after planting (Krueger 1967). The critical minimum foliar nutrient levels required for radiata pine are given by Knight (1978) (Table 8), who stresses the importance of balance between nutrients as well as absolute concentrations.

Carbohydrate reserves are important for successful seedling storage, and for early and vigorous seedling growth (McCracken 1979a; 1979b; Garber and Mexal 1980; Ritchie and Dunlap 1980), but carbohydrates are not usually monitored because of the cost. In Douglas fir, increased root activity was strongly correlated with lowered reducing sugar concentrations, suggesting that root growth was from stored reserves (Krueger and Trappe 1967). It is possible therefore to estimate the level of food reserves indirectly by an assessment of root growth.

TABLE 8 - Provisional critical minimum foliar nutrient levels used as guidelines for evaluating nutrient status of radiata pine nursery crops in New Zealand (Knight 1978)

Nutrient		Approximate lower end of sufficiency range
Nitrogen	N	1.4-1.6%
Phosphorus	P	0.12-0.14%
Potassium	K	c. 0.35%
Magnesium	Mg	0.06-0.08%
Calcium	Ca	c. 0.10%
Sulphur	S	0-80 ppm SO_4-S c. 0.12% total S
Boron	B	c. 8 ppm
Copper	Cu	2-3 ppm
Iron	Fe	25-40 ppm
Manganese	Mn	5-14 ppm
Zinc	Zn	5-10 ppm

(iii) Root growth potential

Health and vigour of the root system is best evaluated by measuring seedling root growth potential (RGP) (Stone 1955). There is a compelling body of evidence that there is a close correlation between RGP and seedling survival after planting (Ritchie and Dunlap 1980; Sutton 1980; Burdett et al 1983). In this test, seedlings are lifted, new white root growth removed, and the seedlings potted up and grown under ideal conditions for 28 days. The seedlings are then lifted, and the new white root growth assessed subjectively or counted and measured. The growing period can be shortened by measuring root volume changes over a 7 day test period with very favourable conditions for growth (Burdett 1979).

Besides evaluating root initials and early root growth, the test also involves food reserves to support this new growth, and so a measure of seedling RGP and water potential give a good indication of physiological seedling quality. Seedling RGP and water potential results from five North Island nurseries sampled in June and July are given in Table 9.

These are the same nurseries sampled for morphological measurement in Table 7. Seedlings from all nurseries had satisfactory water potentials in the June lifting, but the water potentials were lower in July, presumably because of dry windy conditions prevailing when seedlings were lifted. However, there were larger differences in RGP between nurseries. Seedlings from nurseries B and D were expected to perform well, based on the morphological data, but in June, seedlings from nurseries A and D were best, and in July, those from A and C. Seedlings from nurseries A and C did not perform as poorly as expected but the seedlings from Nursery A were specially lifted in June for this study. Nursery E was suspected of producing inferior seedlings because of insufficient conditioning and excessive root stripping during lifting, and this poor quality was confirmed by the RGP test.

TABLE 9 - Root growth potential and water potential values for seedlings lifted at two times in the winter from five North island nurseries

	June lift		July lift	
Nursery	RGP*	Water potential (MPa)	RGP	Water potential (MPa)
A	115 a	-0.15 b	83a	-0.60a
B	34 b	-0.10a	64 b	-0.61ab
C	39 ab	-0.17 b	103a	-0.56a
D	56 a	-0.45 c	20 c	-0.51a
E	1 c	-0.09a	2 d	-0.93 b

* RGP = new root length (mm)

Treatment means followed by the same alphabetical letter are not significantly different (LSD test, P = 0.05).

(iv) <u>Frost tolerance</u>

Frost is an impediment to establishment on many sites in New Zealand (Washbourn 1978; Menzies and Chavasse 1982). Frost tolerance is a seedling quality that can be reliably assessed in artificial frost rooms (Robotham <u>et al</u> 1978; Warrington and Rook 1980). Frost tolerance of radiata pine varies seasonally, ranging from slightly less than -6°C in summer to about -12°C in winter (Menzies and Holden 1981). Frost tolerance develops slowly in the autumn to a peak in late winter, but is rapidly lost in spring (late September/early October). The main factor controlling frost tolerance appears to be nursery site, with seedlings from inland higher altitude nurseries developing more frost tolerance than those from coastal nurseries (Menzies et al. 1981).

CONCLUSION

The quality of bareroot radiata pine seedlings can be assessed from morphological and physiological characteristics. It is controlled by treatment in the nursery, especially seedling density and conditioning. The nursery site is also of importance.

Morphological characteristics are fixed and cannot be changed once seedlings are lifted and root-trimmed. On the other hand physiological quality is affected right up to the time of planting. Once lifted, delay in planting the seedlings will lower seedling food and water reserves. Water reserves may be replenished by watering, although fine roots may die if they dry out. Food reserves decline because of respiration and cannot be replenished. Therefore any assessment of field performance must evaluate seedlings at the planting site.

Establishment should be successful if seedling morphological characteristics are optimal, water potential is above -0.5 MPa and storage time is less than three days.

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