PINUS RADIATA SEEDLING WATER POTENTIAL AND ROOT AND SHOOT GROWTH AS AFFECTED BY TYPE AND DURATION OF STORAGE

J.M. BALNEAVES,

New Zealand Forest Research Institute,
P.O. Box 31-011, Christchurch, New Zealand

M.I. MENZIES, and S.O. HONG

New Zealand Forest Research Institute,
Private Bag 3020, Rotorua, New Zealand

(Received for publication 21 April 1992; revision 20 April 1993)

ABSTRACT

One-year-old *Pinus radiata* D.Don seedlings were raised at Rangiora Nursery, Canterbury, and subjected to five storage treatments. Seedlings were lifted and packed into waxed cardboard planting boxes which were stored in transporting/ storage crates, or under tarpaulin tents, or in a cool-store for up to 12 days. The crates and tarpaulin-covered boxes were stored either on an exposed site or under heavy shade in an adjacent sheltered position. Seedlings were sampled daily from the two treatments on the exposed site, and after 1, 6, and 12 days from the other treatments. Assessments included stem water potential, root growth potential, and growth performance after 24 months in a field trial.

Seedlings stored on an open exposed site under a tarpaulin tent had unacceptable water potentials by 6 days. Seedlings under heavy shade had significantly better water potentials than seedlings on the open exposed site. Cool-stored seedlings had the best water potentials after 12 days' storage. Similar results were recorded for root growth potential.

Height increment was best with cool-stored seedlings, followed by seedlings stored in crates, and then by seedlings stored under a tarpaulin. Height increment fell significantly with longer storage time, more negative water potential, lower root growth potential, and accumulated storage time above 2°C. The results highlighted the importance of ensuring that seedlings are firstly packed into a crate system and then stored (where cool-stores are not available) under sheltered heavy shade to minimise temperature rises above 2°C within the boxes of seedlings.

Keywords: packaging; storage; root growth potential; water potential; growth; *Pinus radiata.*

INTRODUCTION

Quality of 1-year-old *P. radiata* seedlings is closely related to how they are grown in the nursery, and handled from the nursery to the planting site (Menzies *et al.* 1985). The two most important factors controlling seedling quality in the nursery are seedling density and seedling conditioning. Once seedlings are lifted the handling system must ensure that seedling roots are kept moist at all times (Balneaves & Menzies 1990), that foliage and roots are not bruised or crushed (Menzies *et al.* 1985), that storage time is kept short (under 48 hours), and that storage temperature is low (2–4°C) to minimise respiration (McCracken 1979; Balneaves 1991).

Evaluation of the lifting and handling system at Edendale Nursery (Balneaves & Menzies 1988) highlighted the important stress points in their system that had a deleterious effect on 1-year-old *P. radiata* seedlings. Further trials demonstrated that handling seedlings through the FRI integrated out-planting system (Trewin & Cullen 1985) resulted in less stress than the conventional packing-shed system used at that time in Rangiora Nursery (Balneaves 1991). However, stress points did occur in the improved system. Firstly, lifting seedlings under dry soil conditions placed undue stress on seedlings, resulting in reduced growth after planting. To minimise this effect, nursery beds should be irrigated before lifting as required, and seedling roots should be dipped in water at packing if necessary (Trewin & Cullen 1985; Trewin & Menzies 1989). These practices, coupled with overnight cool-storage after packing, can alleviate seedling water deficits. Where longer-term storage is required, it appeared advantageous to envelop seedling roots with a water-soaked hessian "blanket". The direct "on-bed" packing system, however, is not suitable for long-term storage of tree stocks. Rather, emphasis should be on rapid turnover of seedling stock on the planting site so that time from lifting to planting does not exceed 48 hours (Trewin & Cullen 1985; Balneaves 1991; Balneaves & Menzies 1990).

Despite good intentions, inclement weather or other factors can delay planting for considerable periods, and stock may be held over either at the nursery or on the planting site until operations can resume. It has been observed that tree stocks packed in planting boxes and transport crates may become desiccated within 2 days even when held in cool-storage. While this can be related to condition of seedling beds at lifting (Balneaves & Menzies 1990), other factors relating to storage conditions may be involved. The effect of different storage conditions and storage time were examined in a trial reported here to provide information to help nursery and forest managers decide on the best course of action for their situations.

METHODS

One-year-old *P. radiata* planting stock was raised from seed sown at 12.5 × 8 cm spacing at Rangiora Nursery. As seedlings developed, appropriate side dressings of fertiliser were made to ensure vigorous plants. Seedling roots were undercut at 10 cm depth with a reciprocating wrencher in March. Subsequent root wrenching was done as required (at approximately 3-weekly intervals) with the last wrench made 24 hours before lifting. Lateral root pruning with a rolling coulter pruner was done between the line of drills 7 days after the initial root undercut. Lateral root pruning was also carried out at 3-weekly intervals with the first prune along the line of drill and every alternate lateral root prune being made across the drill using a specially sharpened spade. A final lateral root pruning was made on all four sides of the seedlings 7 days prior to lifting. This obviated the need to root trim at lifting.

At lifting in winter, uniform seedlings were selected with seedling shoot length between 30 and 35 cm and root collar diameter between 5.6 and 6.4 mm. Any seedlings deemed to have a poor root system were culled.

Trees were lifted, root-dipped in water, and packaged on-bed in polythene-lined planting boxes (120 seedlings/box) and then placed in a cool-store at 1500 hours. Foliage temperatures were then 20–22°C in the centre of the packages. During the first 8 hours in the cool-store (set at +2°C and 95% RH) the temperature in the packages dropped at an average rate of 2°C/hour down to 4–6°C. The temperature declined a further 3°C during the following 4-hour period. The 33 boxes of seedlings were distributed to one of five storage treatments at 0900 hours the next morning.

On an exposed site, 12 boxes of seedlings were stored in a crate and 12 were placed under a tarpaulin tent. On an adjacent sheltered site, three boxes of seedlings were placed in a crate and three under a tarpaulin tent. Three boxes of seedlings were kept in the cool-store as a control. The transport crates were made to the Trewin design (Trewin & Cullen 1985), but with the addition of a 7-mm-thick polystyrene board lining on the inside of the crate in an endeavour to give an additional buffer against outside heat-load. Thermistors were placed in selected boxes (three thermistors for each storage option) to measure temperature changes at 1-hour intervals in relation to ambient temperature (one ventilated and shaded thermistor per site). One box of seedlings was drawn daily for 12 days from each of the crate and the tarpaulin tent treatments on the exposed site, and after 1, 6, and 12 days from each of the crate and the tarpaulin tent treatments on the sheltered site and from the cool-store treatment. Fifteen seedlings were selected from the centre of each box and measured for water potential (ψ) using a pressure chamber (Cleary & Zaerr 1980). A further 15 seedlings were extracted from each box to measure root growth potential (RGP) over a 21-day period using the displacement technique (Burdett 1979) and the water-bath system (Balneaves 1987).

Seventy-five of the remaining seedlings from each box were planted out at a spacing of 1 × 1 m in a randomised complete block design consisting of five blocks of 15 seedlings each. The total number of seedlings planted was 2475 (((2 treatments × 12 sampling days) + (3 treatments × 3 sampling days)) × 15 seedlings × 5 blocks). A two-row buffer was planted around the perimeter of the plot to avoid edge effects. The planting site was located in the Rangiora Nursery on a Wakanui silt loam soil of high nutrient status, low organic content, and a pH of 4.8. The site was grubbed and disced prior to planting and kept weed-free throughout the experiment by applying terbuthylazine at 7.5 kg/ha in early spring after planting and again 12 months later.

Seven days after planting all seedlings were measured for height; their height and ground-level diameter were also measured 24 months after planting.

Statistical Analysis

Analysis of variance (ANOVA) was done on seedling water potential and the root growth potential data to examine the treatment effects on them. The least significance difference (LSD) test was carried out to compare treatment means after ANOVA by the SAS procedure.

For the height and diameter data, analysis of covariance (ANCOVA) was done using initial height as a covariate. Treatment means adjusted for the covariate were compared after the ANCOVA using the SAS GLM procedure. The temperature sum above 2°C (average cool store temperature) was accumulated for each storage condition. Correlation and regression analyses were done on the treatment means to determine relationships between height increment and storage time, water potential, RGP, and accumulated temperature; water potential and storage time; and RGP and storage time and ψ, using the growth data of the exposed crate and tarpaulin tent treatments with 12 days' storage matching the physical parameters.

RESULTS AND DISCUSSION

Influence of Storage Condition and Duration on Seedling Package Temperature Patterns

Cool-storage resulted in some fluctuation of temperature and this was related to times when tree stocks were shifted in or out of the cool store. Increases in temperature (above 2°C) within the boxes of seedlings occurred between 0900 and 1100 hours while other stock was moved out. At this time temperature rose to 4°C but by 1200 hours had settled back to 2°C. A similar rise in temperature was noted at 1500–1600 hours when freshly lifted tree stocks were placed in the cool store. Again, temperature fell to 2°C within an hour.

Temperatures within seedling boxes stored under a tarpaulin tent on an open exposed site were consistently higher than the ambient temperature and on one day rose as high as 22°C (Table 1). Seedlings stored in crates did not reach the same high temperature levels (maximum 11°C), but were nevertheless well above the recommended level of 2°C (McCracken 1979).

For those seedlings stored in a sheltered, heavily shaded site, temperatures were not so severe, especially inside the crate (maximum of 6°C).

TABLE 1–Maximum daily temperature and mean daily maximum temperature for ambient and storage conditions in boxes

Storage condition		Absolute daily maximum temperature (°C)	Mean daily maximum temperature (°C)
Ambient	exposed	20	12
Tarpaulin	exposed	22	15
Crate	exposed	11	8
Ambient	heavy shade	14	10
Tarpaulin	heavy shade	12	8
Crate	heavy shade	6	4

Seedling Water Potential (ψ)

Storage treatments had a significant impact on seedling water potential (Table 2).

Earlier work (Menzies *et al.* 1985) recommended that water potential should not exceed negative values of –0.50 MPa. In this trial cool-storage ensured that seedlings had a higher

TABLE 2–Seedling water potential (–MPa) in relation to condition and duration of storage

Storage condition		Storage duration (days)		
		1	6	12
Tarpaulin	exposed	0.29 d*	0.89 e	1.45 e
Crate	exposed	0.26 c	0.46 d	0.72 d
Tarpaulin	heavy shade	0.23 b	0.44 c	0.67 c
Crate	heavy shade	0.21 a	0.33 a	0.58 b
Cool-store		0.22 ab	0.35 b	0.45 a

* Means with the same alphabetical letter for a given column are not significantly different (LSD test, $p < 0.05$).

water potential while those seedlings stored on an open exposed site under a tarpaulin tent recorded lower water potentials by 6 days (–0.89 MPa) and were in a considerably worse condition after 12 days (–1.45 MPa). By locating the storage site in a sheltered, heavily shaded position, seedling water potential was significantly improved for both the "tarpaulin" and "crate" stored seedlings. There was a significant interaction between storage treatment and storage duration.

Root Growth Potential (RGP)

Root growth potential was reduced by increased storage time and was low for seedlings stored under a tarpaulin tent on the open exposed site (Table 3).

TABLE 3–Seedling root growth potential (g new root growth) in relation to condition and duration of storage

Storage condition		Storage duration (days)		
		1	6	12
Tarpaulin	exposed	2.1 b*	1.5 d	0.8 d
Crate	exposed	2.3 b	1.9 c	1.4 c
Tarpaulin	heavy shade	2.5 a	1.9 c	1.7 b
Crate	heavy shade	2.6 a	2.3 b	1.8 a
Cool-store		2.5 a	2.4 a	1.8 a

* Means with the same alphabetical letter for a given column are not significantly different (LSD test, $p < 0.05$).

There was little difference in RGP between those seedlings cool-stored or placed in crates in a sheltered, heavily shaded site. Those seedlings stored under a tarpaulin "tent" in heavy shade showed a marked decline in RGP after 6 days' storage, but only a slight further decline after 12 days' storage. Those seedlings stored on the exposed site showed a marked decline in RGP after 6 and 12 days' storage and this was particularly severe for those seedlings stored under tarpaulin. There was a significant interaction between storage condition and storage duration.

Influence of Storage on Seedling Survival, Height, and Diameter Growth after Planting

Seedling survival was 100% for all treatments. The main effects of storage condition and duration of storage on growth were highly significant (Table 4). Irrespective of duration of

TABLE 4–Effect of storage on height and diameter growth after planting

Storage condition		Height after 2 years (cm)	Diameter after 2 years (cm)
Day 1			
Tarpaulin	exposed	190 c	3.7 d
Crate	exposed	204 a	4.2 b
Tarpaulin	heavy shade	195 b	3.8 c
Crate	heavy shade	205 a	4.6 a
Cool-store		205 a	4.2 b
Day 6			
Tarpaulin	exposed	180 e	3.3 d
Crate	exposed	196 b	3.7 c
Tarpaulin	heavy shade	183 d	3.3 d
Crate	heavy shade	195 c	3.9 b
Cool-store		207 a	4.2 a
Day 12			
Tarpaulin	exposed	125 e	2.7 e
Crate	exposed	163 c	3.0 c
Tarpaulin	heavy shade	148 d	2.9 d
Crate	heavy shade	178 b	3.4 b
Cool-store		203 a	4.1 a
Overall			
Storage		**	**
Time		**	**
Storage × Time		**	**

** difference significant at $p = 0.01$

Means with the same alphabetical letter for a given column are not significantly different ($p < 0.05$)

storage, seedlings drawn from the cool-store grew most rapidly. Conversely, seedlings stored under a tarpaulin "tent" on an exposed site showed consistently poor growth after planting. As storage time increased, height and diameter increment decreased. Assuming cool-storage is not available to forest managers, these data suggest that the use of a crate system placed in a sheltered heavily shaded site is appropriate. Seedlings stored in this manner performed well with only a slight (albeit significant) reduction in height increment after 6 days' storage. However, after 12 days' storage, reduction in height increment was more severe. Further, there was little difference in growth response relative to storage conditions (exposed *v.* sheltered) with the crate system after 1 or 6 days' storage, but those seedlings stored on the exposed site exhibited markedly reduced growth after 12 days' storage.

Relationship Between Duration of Storage, Accumulated Temperature Sum, ψ, and RGP and Field Growth

The data fitted a non-linear model, $y = A + B \cdot R^x$, better than a linear one, with r^2 values from 0.66 to 0.98. There was a high correlation between height increment and diameter after 2 years ($r = 0.93$) and so only height increment was used as a variable for field growth.

Results of regression analyses of the two storage treatments on the exposed site are given in Table 5.

TABLE 5–Non-linear regression analyses for height increment and days in storage, ψ, RGP and accumulated temperature sum

Influencing factor	Regression	r^2
Days in storage (days)	Ht Incr. (cm) = $179.3-10.3 \times 1.163^{days}$	0.66
Water potential (MPa) (ψ)	Ht Incr. (cm) = $193.6-22.0 \times 2.65^{\psi\ (MPa)}$	0.88
RGP (g new root growth)	Ht Incr. (cm) = $190.3-201.9 \times 0.3619^{RGP\ (g)}$	0.94
Accum. temp. > 2°C (Temp)	Ht Incr. (cm) = $187.2-17.9 \times 1.000889^{Temp.\ (°C)}$	0.91

Height increment decreased with increasing time in storage, more negative water potentials, less new root growth, and greater accumulated temperature above 2°C.

Accumulated temperature above 2°C during storage had a highly significant effect on ψ and RGP, viz:

$$\psi\ (MPa) = -1.299 + 1.470 \times 1.000363^{Temp\ (°C)} \quad (r^2 = 0.98)$$

$$RGP\ (g) = -2.88 + 5.18 \times 0.999813^{Temp\ (°C)} \quad (r^2 = 0.95)$$

A further regression analysis also indicated, as expected, that RGP is affected by ψ, viz:

$$RGP\ (g) = 0.274 + 2.387 \times 0.401\psi^{(MPa)} \quad (r^2 = 0.93)$$

While the observation that high temperatures attained in boxes of seedlings has a deleterious effect is well documented (McCracken 1979; Tabbush 1987; Tabbush & Gregory 1987; Nelson 1991), these results illustrate the severity of that impact on ψ, RGP, and field growth after planting of *P. radiata* seedlings even under favourable planting conditions on a nursery site. In the first instance it results in a deterioration of ψ which is reflected in reduced RGP and field growth.

Every effort should be made to minimise duration of storage. The above information highlights the importance of ensuring that seedlings are firstly packed with moist roots into a crate system and then stored (where cool-stores are not available) in a sheltered, heavily shaded site to minimise temperature rises above 2°C within the packages of seedlings.

ACKNOWLEDGMENTS

The advice of Dr Ian McCracken when setting up this trial has contributed to its success. Staff of the Rangiora Nursery and Messrs Coslett and Denton assisted with much of the work. We acknowledge the helpful comments of Dr R. Burdon, Dr D. Whitehead, Mr R. Trewin, and Mr P. Carter.

REFERENCES

BALNEAVES, J.M. 1987: Root growth capacity of *Cupressus macrocarpa* and *Pinus radiata* seedlings. *N.Z. Forestry 32*: 24–5.

———1991: Advantages of on-bed packaging *Pinus radiata* seedlings in a droughty climate. Pp. 109–14 *in* Menzies, M.I.; Parrott, G.; Whitehouse, L.J. (Ed.). Proceedings of IUFRO Symposium on "Efficiency of Stand Establishment Operations", Rotorua, September 1989. *New Zealand Ministry of Forestry, FRI Bulletin No. 156.*

BALNEAVES, J.M.; MENZIES, M.I. 1988: Lifting and handling procedures at Edendale Nursery—Effects on survival and growth of 1/0 *Pinus radiata* seedlings. *New Zealand Journal of Forestry Science 18(1)*: 132–4.

———1990: Water potential and subsequent growth of *Pinus radiata* seedlings: Influence of lifting, packaging and storage conditions. *New Zealand Journal of Forestry Science 20(3)*: 257–67.

BURDETT, A.N. 1979: New methods for measuring root growth capacity: Their value in assessing lodgepole pine stock quality. *Canadian Journal of Forest Research 9(1)*: 63–7.

CLEARY, B.D.; ZAERR, J.B. 1980: Pressure chamber techniques for monitoring and evaluating seedling water status. *New Zealand Journal of Forestry Science 10*: 133–41.

McCRACKEN, I.J. 1979: Packaging and cool storage of tree seedlings. *New Zealand Journal of Forestry 24(2)*: 278–87.

MENZIES, M.I.; van DORSSER, J.C.; BALNEAVES, J.M. 1985: Seedling quality—Radiata pine as a case study. Pp. 384–415 *in* South, D.B. (Ed.) "Proceedings of an International Symposium on Nursery Management Practice for Southern Pines". Montgomery, Alabama, U.S.A.

NELSON, Derek G. 1991: Developing an efficient restocking system for conifers in the uplands of Great Britain. Pp. 115–24 *in* Menzies,M.I.; Parrott, G.: Whitehouse, L.J. (Ed.). Proceedings of IUFRO Symposium on "Efficiency of Stand Establishment Operations", Rotorua, September 1989. *New Zealand Ministry of Forestry, FRI Bulletin No. 156.*

TABBUSH, P.M. 1987: The use of co-extruded bags for handling bare-rooted planting stock. *Forestry Commission, Edinburgh, Research Information Note 110/87/SILN.*

TABBUSH, P.M.; GREGORY, S.C. 1987: Guidelines for monitoring and management of cold-stores. *Forestry Commission, Edinburgh, Research Information Note 118/87/SILN.*

TREWIN, A.R.D.; CULLEN, A.W.J. 1985: A fully integrated system for planting bare-rooted seedlings of radiata pine in New Zealand. Pp. 524–48 *in* South, D.B. (Ed.) "Proceedings of an International Symposium on Nursery Management Practices for the Southern Pines". Montgomery, Alabama, U.S.A.

TREWIN, A.R.D.; MENZIES, M.I. 1989: Machinery performance and uniformity: A case study with radiata pine (*Pinus radiata* D. Don). *Forestry 62 Supplement*: 61–8.