WATER POTENTIAL AND SUBSEQUENT GROWTH OF *PINUS RADIATA* SEEDLINGS: INFLUENCE OF LIFTING, PACKAGING, AND STORAGE CONDITIONS

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ABSTRACT

The integrated system widely used in New Zealand for planting out *Pinus radiata* D. Don seedlings minimises handling and facilitates the smooth flow of tree stocks from nursery to field, reducing the time between lifting and planting. However, some instances of desiccation have been reported, especially in seedlings at the top of cartons, and so various methods of minimising this problem were evaluated.

Where soil conditions are dry, irrigation of nursery beds can help minimise the early afternoon water deficit. Seedlings lifted early in the morning or late in the afternoon, with their roots dipped in water, and with overnight cool storing, gave the best growth after planting. In one trial, dipping the roots of the seedlings from the top third of the carton in water, spraying the roots with water, and folding plastic flaps over the roots in cartons were all beneficial compared with no watering. In another trial where seedlings were dipped in water, a wet hessian blanket over the roots was slightly more effective than a plastic liner, and both were significantly better than no extra protection.

Keywords: seedling water potential; packaging; cool storage; root moistening; *Pinus radiata*.

INTRODUCTION

An integrated system for outplanting 1/0 *Pinus radiata* seedlings and other bare-root tree stocks has been developed at the Forest Research Institute (FRI), and is now widely used in New Zealand (Trewin & Cullen 1985). In this system, seedlings are lifted and packed horizontally into cartons on the nursery bed, and the cartons are placed in containers for transport to the planting sites. The cartons are used as planting boxes in the field, minimising handling of seedlings. Ideally, the time between lifting and planting should not exceed 48 hours (Balneaves 1990).

However, there have been reports of seedling roots drying out, particularly those at the top of the cartons. Drying could cause death of some roots, especially fine roots, and thus reduced survival and growth of seedlings (Menzies *et al.* 1985). Recommendations have been made for irrigating dry soil before lifting, root dipping or spraying, or the use of moisture pads or plastic sheets in cartons (Trewin & Cullen 1985; Trewin & van Dorsser 1985), but these methods are rarely used. Further, it was noted that when *P. radiata* seedlings undergo some stress during processing, resulting in seedling water potentials (ψ) decreasing to –600 kPa (and as a result of root dipping in water and overnight storage returned to less than –200 kPa), subsequent field growth was reduced compared to those seedlings whose water potential had not decreased below –200 kPa (Balneaves & Menzies 1988).

Nevertheless, field growth of *P. radiata* seedlings processed by the FRI integrated system with packing at the nursery bed is still superior to those seedlings processed through a packing shed (Balneaves 1990), providing limitations of such a system are recognised (e.g., storage time should not exceed 48 hours unless modifications have been made to ensure that seedling roots are kept moist and that the crates of seedlings are kept "cool").

Three trials were carried out (two in Eyreton Nursery, North Canterbury, and one in the FRI Nursery, Rotorua) to study the impact of lifting conditions, and various methods to minimise drying of seedling roots in the carton, on seedling water potential and field growth after outplanting.

METHODS

Effect of Lifting Conditions at Eyreton Nursery, Canterbury

Over a 24-hour period, 1/0 *P. radiata* seedlings were lifted from one nursery bed at Eyreton Nursery at 0830, 0900, 1030, 1400, 1530, 1700, and 0830 hours on 12 and 13 June 1986. The period of time chosen was considered to be climatically representative of the conditions under which lifting is carried out. Weather conditions were noted at each lifting time.

At lifting, the seedling water potential of 15 seedlings in the nursery bed was taken, using a pressure bomb (Ritchie & Hinckley 1975). Eighty seedlings were lifted for immediate planting out in an adjacent cultivated site (five replicates of 16 trees in a fully randomised block design). A further 100 seedlings were lifted at each lifting time and root dipped in water, packed horizontally into "Aquapruf" planting boxes (Trewin & Cullen 1985) lined with a gusseted polythene bag. The polythene was folded over the root systems to fully enclose the roots, and the boxes of seedlings were placed in a cool store overnight. The cool store was maintained at +2°C and 90% R.H.

After overnight cool storage, seedling water potential was measured on 15 plants, and 80 seedlings were planted out alongside those planted immediately after lifting. Seedling height and ground-line diameter measurements were recorded 7 days after planting, and again 12 and 24 months later. In addition, further seedling water potential readings were made at lifting over the winter period to check that readings noted in the trial outlined above covered the range likely to be encountered in field practice.

Effects of Packaging Method

FRI Nursery, Rotorua

At Rotorua, 1/0 *P. radiata* seedlings were lifted and packed into cartons during the last week of August 1986. There were nine treatments, including waxed cardboard or plastic cartons (planting boxes), root wetting with water by spray nozzle or by dipping the roots of the seedlings in the top third of the boxes, and using a plastic flap to cover the roots in the waxed cartons. Each treatment involved one carton of 100 seedlings. The carton tops were stapled closed, and the cartons were placed in a container (Trewin & Cullen 1985) in the shade at FRI nursery. Stem water potentials were measured on a random sample of three seedlings from three positions in each carton (top, middle, and bottom) after 4 and 7 days' storage.

Eyreton Nursery, Canterbury

At Eyreton Nursery three options to keep roots moist after lifting were evaluated;

(1) Root dip all trees and pack into planting boxes;

(2) Root dip all trees and pack into polythene-lined planting boxes. Fold polythene over the root system and lower portion of foliage before stapling the planting box shut;

(3) Root dip all trees, pack into planting boxes, and tuck a water-soaked hessian "blanket" over the top and around the sides and end of the root system before stapling the planting box shut.

Packages of seedlings were then stored for 3 weeks in a cool store (+2°C, 95% R.H.) prior to planting out on a well-cultivated site. At time of planting, seedling water potential was measured on 15 seedlings. Of the remaining seedlings, 90 were planted out, in a randomised block design, in six blocks with 15 seedlings/block. Height and ground-line diameter measurements were made 7 days after planting and again 12 months later.

Analysis of Data

Tree survival, height, and diameter growth were analysed by analysis of variance for treatment and blocks. In the Rotorua trial, analysis was by 3-way analysis of variance with interactions.

RESULTS & DISCUSSION

Effect of Lifting Conditions on Performance of 1/0 Seedlings (Eyreton Nursery, Canterbury)

Conditions for lifting

Conditions for lifting varied considerably both throughout the winter and throughout any 1 day (Table 1). As could be expected, seedlings in dry crumbly soils showed more negative water potential readings than those in wet soils (Fig. 1). The prevalence of the north-westerly föhn wind (which has a major influence on temperature, relative humidity, and vapour pressure deficit (VPD)) could be expected to have an impact on seedling water potential. Seedling water potential was negatively correlated with VPD ($r^2 = 0.63$) (Fig. 2).

TABLE 1–Climatic conditions and seedling water potential at lifting

Date (day/month)	Time (h)	Temp (°C)	R.H. (%)	VPD (kPa)	Cloud	Wind dir. (km/h)	Seedbed condition (mean of 15 trees)	In-bed seedling water potential (kPa)
11/6	0830	6.5	92	0.08	8/8	NE-2	Dry	–430
	1330	15.0	34	1.12	0/8	NW-8	Dry	–1390
20/6	0830	7.3	53	0.48	0/8	NE-7	Dry	–680
	1530	9.7	80	0.24	7/8	W-8	Dry	–950
24/6	0830	9.1	56	0.51	0/8	W-8	Dry	–940
	1030	13.7	52	0.75	2/8	W-2	Dry	–1220
	1130	15.2	47	0.92	7/8	NW-2	Dry	–1320
	1330	13.0	41	0.88	7/8	NW-10	Dry	–1340
	1430	16.0	45	1.00	3/8	NW-3	Dry	–1300
	1530	14.0	52	0.77	1/8	NW-4	Dry	–1210
3/7	0830	3.0	94	0.04	7/8	SE-10	Wet	–420
	1030	5.0	88	0.10	5/8	SE-11	Wet	–700
	1130	6.0	85	0.14	7/8	SE-10	Wet	–1050
	1330	7.0	73	0.27	6/8	SE-13	Wet	–1140
	1430	7.0	79	0.21	7/8	SE-10	Wet	–1080
	1530	6.0	78	0.21	2/8	SE-5	Wet	–880
19/8	0915	10.0	66	0.42	7/8	NE-5	Moist	–760
	1030	14.0	45	0.88	8/8	NE-14	Moist	–1010
	1315	15.0	54	0.78	7/8	NE-11	Moist	–1100
	1530	14.0	57	0.69	5/8	NE-16	Moist	–1050

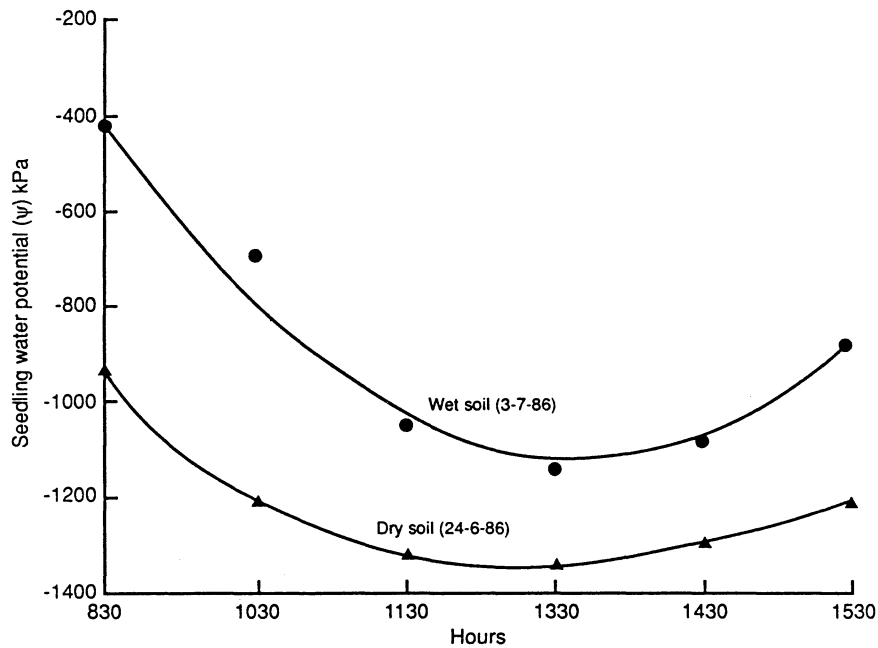

FIG. 1–Diurnal ψ readings for *Pinus radiata* seedlings at time of lifting on a dry and a wet nursery bed

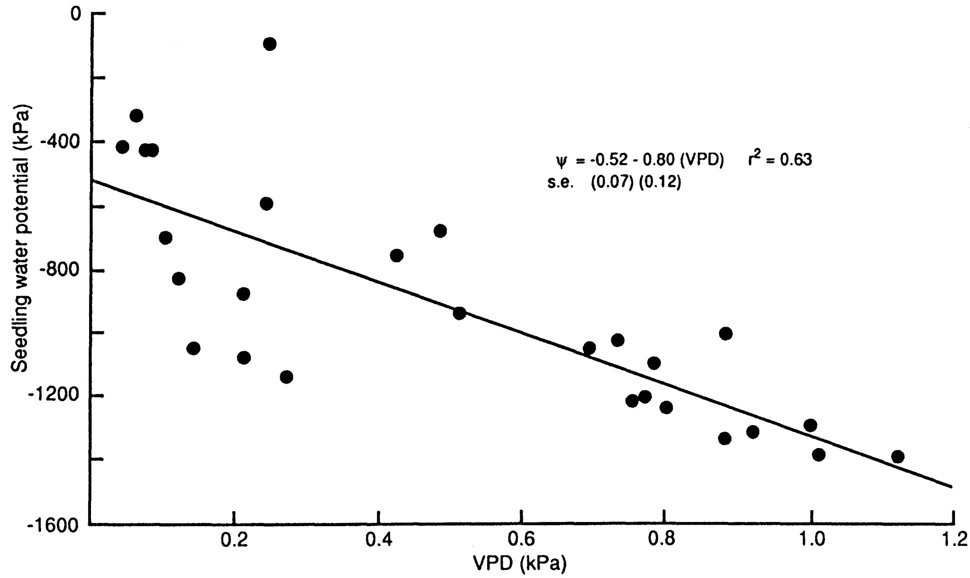

FIG. 2–Influence of vapour pressure deficit on seedling water potential

To explore what effect VPD has on seedlings lifted under these conditions of greater water potential deficit, a trial was established to observe diurnal patterns at lifting and the effects on field growth of seedlings after planting.

Seedlings were lifted on 12 and 13 June 1986 from a moist seedbed at set intervals to study diurnal patterns. Some seedlings were planted immediately while others were packaged into planting boxes and cool-stored overnight. A summary of climatic data and seedling water potential is given in Table 2.

In spite of root dipping in water, packaging, and overnight cool storage, seedling water potential did not fully recover in those lifted at 1400 h. These seedlings had the largest negative water potential at lifting. It was noted that even after overnight cool storage the

TABLE 2–Climatic conditions at lifting, and seedling water potential at time of lifting and after overnight cool storage

Time (h)	Temp (°C)	R.H. (%)	VPD (kPa)	Cloud	Wind dir. (km/h)	Seedling water potential at lifting (mean of 15 trees) (kPa)	Seedling water potential after overnight cool-storage (mean of 15 trees) (kPa)
0830	5.3	92	0.07	8/8	NE-2	–430	–230
0900	6.5	75	0.24	7/8	NE-4	–590	–270
1030	13.5	53	0.73	3/8	NE-7	–1030	–290
1400	14.0	37	1.01	0/8	NE-10	–1390	–510
1530	15.7	55	0.80	0/8	NE-3	–1240	–350
1700	6.3	87	0.12	0/8	NE-1	–830	–260
0830	5.9	93	0.06	0/8	NE-1	–320	–210

seedling shoots and needles were flaccid and lacked turgidity compared to seedlings lifted at other times, and at the outset they were not expected to perform well after planting.

Field growth response 12 and 24 months after planting

Survival was not affected by treatment and in all treatments was greater than 96%. However, tree height growth differed significantly ($p \leq 0.05$) between lifting times, and between the seedlings lifted, root dipped, and planted directly and those root dipped, packed, and cool-stored overnight (Table 3).

Volume index (a measure of tree productivity) at 24 months after planting clearly shows the differences in tree response to treatment (Table 3, Fig. 3). Further analysis of these data indicated a strong correlation ($r^2 = 0.81$) between seedling water potential at planting and volume index at age 2 (Fig. 4).

TABLE 3–Field growth response to lifting and cool storage effects for seedlings with an initial diameter of 0.5 cm and initial height of 26 ± 1 cm

Time	Treatment	12 months		24 months		
at lifting (h)		Diameter (cm)	Height (cm)	Diameter (cm)	Height (cm)	Vol. ind. ($d^2h/100$) $\frac{cm^3}{100}$
0830	Immediate planting	1.7	69 b	6.9	208 d	99 c
	Cool storage	1.6	79 a	7.3	244 a	130 a
0900	Immediate planting	1.2	62 cd	6.3	202 de	80 d
	Cool storage	1.4	71 b	7.0	228 b	106 b
1030	Immediate planting	1.4	60 cd	6.1	185 f	69 ef
	Cool storage	1.0	69 b	7.1	216 c	108 b
1400	Immediate planting	1.0	59 cd	5.8	185 f	62 f
	Cool storage	1.0	63 c	6.3	186 f	74 e
1530	Immediate planting	1.0	56 d	6.2	188 f	76 e
	Cool storage	1.1	64 c	6.8	204 d	94 c
1700	Immediate planting	1.2	63 c	6.3	197 e	78 de
	Cool storage	1.4	68 bc	6.7	226 b	101 bc
0830	Immediate planting	1.7	71 b	6.8	205 d	95 c
	Cool storage	1.7	80 a	7.2	241 a	125 a

Effects of Packaging and Root Wetting Treatments (Rotorua Trial)

Mean seedling water potentials at 4 and 7 days after lifting are given in Fig. 5. The main effects of sampling time, packaging and water treatment, and box sampling position were all significant ($p < 0.001$, < 0.001, and 0.029 respectively), and the interaction between packaging and water treatment and box sampling position was also significant ($p < 0.001$).

Seedlings became more stressed between 4 and 7 days after packing (Fig. 5) as water potentials became more negative. As a guideline, seedling water potential should be above –500 kPa (Menzies *et al.* 1985). Desiccation of seedlings in the top of cartons was apparent after even 4 days with normal packing (Treatment 1, Fig. 5). The trends were consistent between days 4 and 7 after packing, except for seedlings in the top of Treatment 8 carton which were more stressed than expected at day 7.

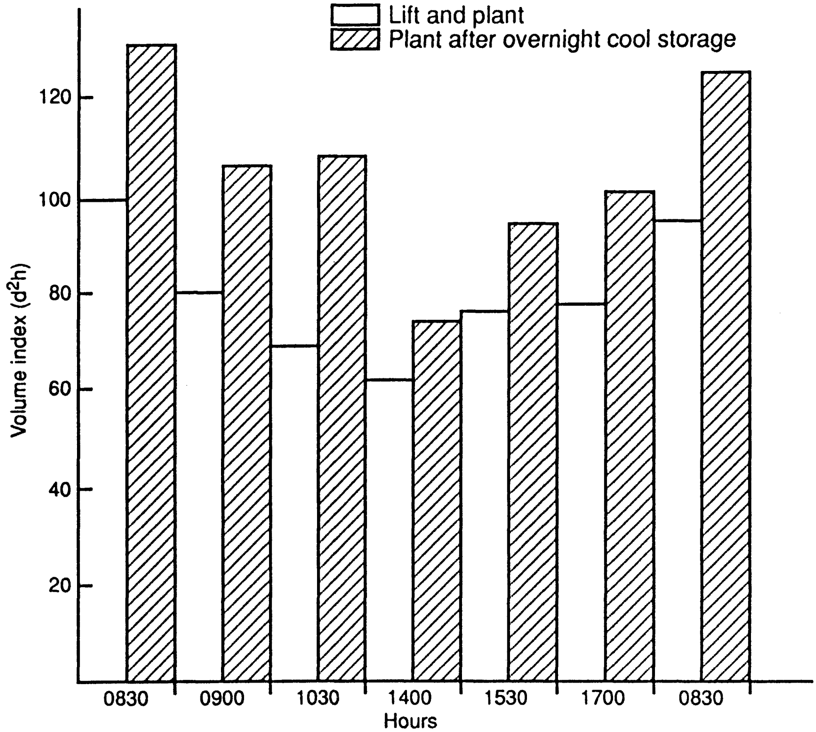

FIG. 3–Influence of lifting time and overnight cool-storage on volume index (D^2H) of *Pinus radiata* 2 years after planting

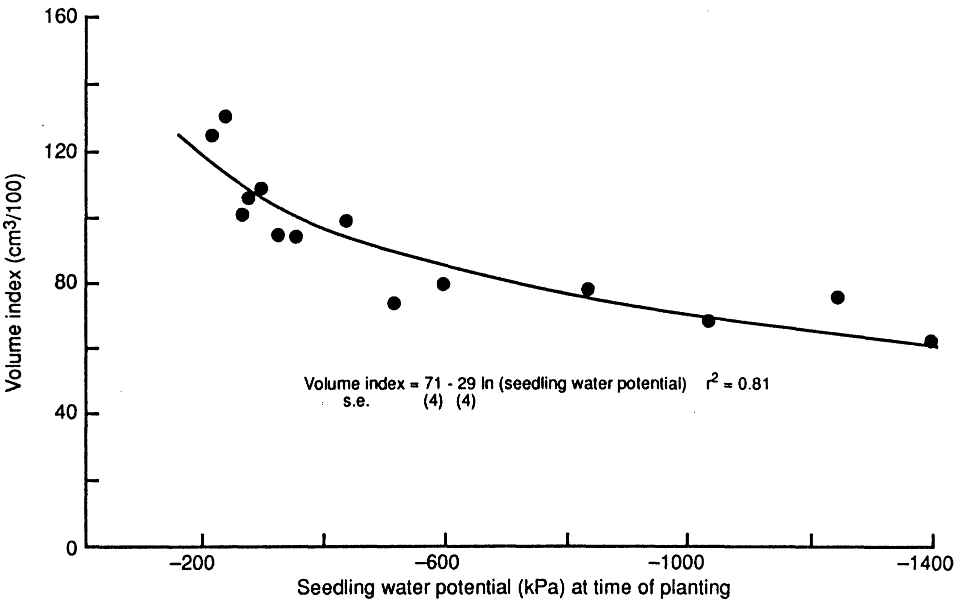

FIG. 4–Relationship between seedling water potential at time of planting and tree productivity (volume index) 2 years after planting

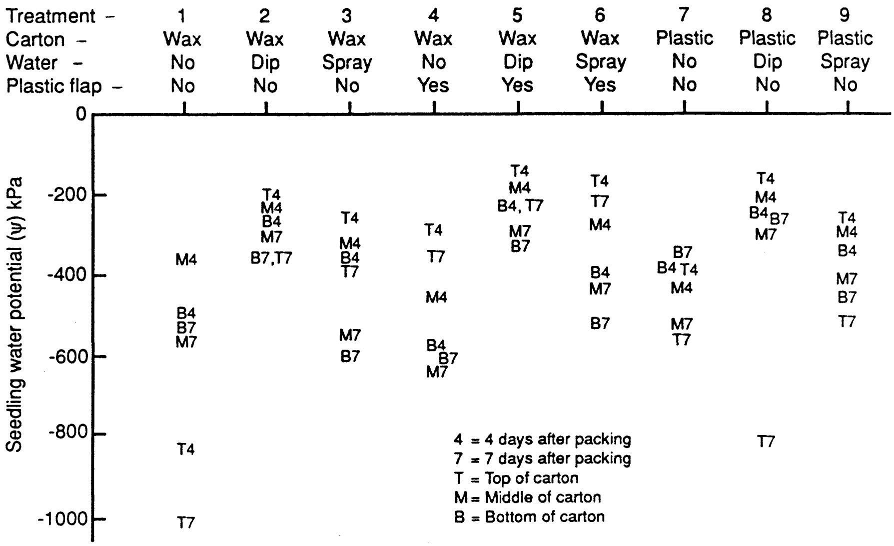

FIG. 5–Mean seedling water potentials at 4 and 7 days after lifting for nine packing treatments sampled at three positions in each carton (FRI, Rotorua trial)

The best treatment overall (Table 4) was Treatment 5 (waxed carton, dipped seedlings, and a plastic flap) although the use of a plastic flap did not give a significant improvement (Treatment 5 *v*. Treatment 2). The comparison between dipping and spraying can be seen in Treatment 2 *v*. Treatment 3, and Treatment 5 *v*. Treatment 6. Dipping the roots of seedlings in the top third of a carton was significantly better than spraying the roots, especially in the bottom and middle of the cartons. Presumably more water from the dipped seedlings reached seedlings lower in the cartons than from spraying. However, dipping all the seedlings would add too much weight of water, and also leave too much free water which could cause

TABLE 4–Mean seedling water potentials for the trial at FRI Nursery, Rotorua (nine treatments sampled at three box positions)

Treatment			Box position		
Carton type	Watering*	Plastic flap	Top (kPa)	Middle (kPa)	Bottom (kPa)
Wax	No	No	–0.92 e†	–0.46 def	–0.52 ef
Wax	Dip	No	–0.30 ab	–0.28 ab	–0.31 abc
Wax	Spray	No	–0.32 ab	–0.44 cdef	–0.48 def
Wax	No	Yes	–0.34 abc	–0.55 f	–0.59 f
Wax	Dip	Yes	–0.19 a	–0.26 ab	–0.28 ab
Wax	Spray	Yes	–0.20 a	–0.37 bcde	–0.46 cdef
Plastic	No	No	–0.48 cd	–0.48 ef	–0.38 bcde
Plastic	Dip	No	–0.51 d	–0.26 ab	–0.26 ab
Plastic	Spray	No	–0.39 bcd	–0.35 bcde	–0.40 bcde

* Dip = dipping roots of the top third of the seedlings in water, letting them drain briefly without shaking, and putting them in the carton.
Spray = one short spray with a fine nozzle over the top of the seedling roots before closing the carton.

† Means with the same alphabetical letter within a given box position are not significantly different (LSD Test, $p = 0.05$).

deterioration of the cartons. Lack of spraying or dipping caused unacceptable desiccation (Treatments 1 and 4). Plastic cartons gave results similar to those with waxed cardboard cartons.

Maintaining Root Moisture in Planting Boxes after Packaging

Survival of tree stocks was 100% in all treatments and therefore will not be considered further.

Seedling water potential measurements and the growth parameters 12 months after planting are summarised in Fig. 6. There were significant differences ($p \leq 0.05$) between the three packaging treatments, with Treatment 3 (roots covered with a wet hessian "blanket") giving consistently better results. Seedlings from this treatment had higher xylem water potential, and this was coupled with better growth response after planting out. There was no

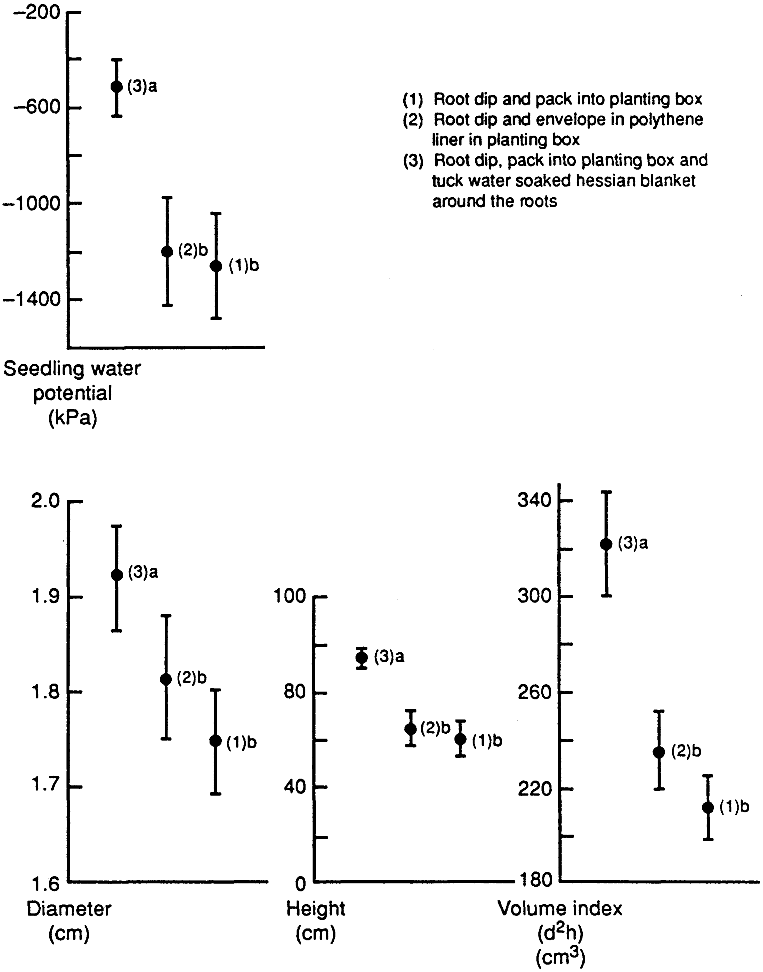

FIG. 6–Comparison of methods to maintain root moistness and these effects on seedling water potential at time of planting and on field growth after 12 months

advantage (in this trial) in lining the planting boxes with a polythene liner which enveloped the roots and lower portion of the stems.

Management Implications

Seedlings go through a natural diurnal cycle of water potential, with a minimum water deficit before dawn and a maximum deficit from about noon to mid-afternoon as seedling water absorption from the soil lags behind transpiration (Kramer & Kozlowski 1979; Larcher 1975). Within normal daytime working hours, the bulk of the lifting is carried out during this period of maximum water deficit.

In the trials described in this paper, several features are worth highlighting:

- Lifting seedlings during dry soil conditions or high daytime VPD places undue stress on seedlings, resulting in reduced growth after planting in the field. Seedling water potential declined to levels greater than –1200 kPa, especially under dry soil conditions. To minimise this effect nursery beds should be irrigated in the late afternoon/evening prior to the day of lifting.
- Root dipping in water coupled with overnight cool storage can alleviate seedling water stress. For longer-term storage it appears to be advantageous to envelop seedling roots with a water-soaked hessian blanket, thereby ensuring high water potentials are maintained.
- Root dipping of seedlings in the top third of the planting boxes appeared to maintain seedlings in good condition. This was more effective than spraying the roots with water using a mist applicator.

The direct packing system is not designed for long-term storage of tree stocks. Rather, the emphasis (correctly so) is on rapid turnover of stock on the planting site. Nevertheless, inclement weather can hold up planting for considerable periods of time and stock then need to be held over either at the nursery or on the planting site until access to sites is possible and planting can resume. It has been noted that tree stocks root-dipped and packed in planting boxes are (according to the officer in charge of Eyreton Nursery) "lifeless" within 2 days, even with cool storage. However, to maintain a steady outflow of seedlings from Eyreton Nursery to planting sites all over the South Island (and occasionally to North Island sites too) it is necessary for seedlings to be lifted on a Friday and held in the cool store over the weekend for despatch early Monday morning. It is essential, therefore, to maintain a moist root system and the "hessian blanket" is one way in which this may be achieved.

The use of root dip products to alleviate desiccation has been evaluated (Menzies, unpubl. data) and these data will be available soon.

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