EFFECTS OF NURSERY PRACTICE ON *PINUS RADIATA* SEEDLING CHARACTERISTICS AND FIELD PERFORMANCE: II. NURSERY ROOT WRENCHING

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ABSTRACT

Seedlings were raised under routine nursery conditions and subjected to a variety of root wrenching and fertiliser treatments. Planting stock characteristics were determined at time of lifting using routine grading criteria. Increased wrenching frequency reduced seedling size, shoot moisture content and foliage concentrations of nitrogen and phosphorus but improved other aspects of seedling quality.

Field performance of planting stock was determined for two planting dates on a moderately severe site prepared for routine plantation establishment. Tree survival, size and form were improved by moderate wrenching treatments and these improvements were still evident in the fifth year after planting.

Mid-autumn planting produced the most distinct differences between unwrenched and wrenched stock. Differences were less marked for mid-winter plantings but wrenching still reduced the incidence of leader damage from 70 to 5%. Unwrenched stock displayed a high incidence of multileaders at two years as a result of initial leader deaths but rarely did this malformation persist at five years after planting.

INTRODUCTION

Undercutting and root wrenching are nursery techniques which have been used for many years to improve the survival potential of *P. radiata* seedling stock (Goudie, 1935). In recent years the development of suitable machinery has enabled these techniques to be applied in large nurseries. Van Dorsser and Rook (1972) have summarised the development of both the root wrenching technique and the machinery needed and have reviewed recent studies on the use of these practices in New Zealand. The techniques developed to suit New Zealand conditions have had to be modified to allow for much drier and hotter summer weather conditions and heavier soils in both the nursery and the forest in Australia.

New Zealand studies have shown that the physiology of *P. radiata* seedlings is altered significantly by root wrenching (Rook, 1969; van Dorsser and Rook, 1972). Undercutting and wrenching inhibit height growth but root growth is relatively unaffected on a dry weight basis (van Dorsser, 1969; Rook, 1971). Even though a substantial proportion of the tap root is severed in these operations, the soil is aerated

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and lateral root growth is stimulated. As a consequence, wrenched seedlings have a higher root : shoot ratio than unwrenched seedlings (Cameron, 1969). The stems are brown with little "soft" shoot growth and probably have cells with secondary thickening almost to the apex (Cameron and Rook, 1969; van Dorsser and Rook, 1972). Not only does the wrenched seedling have a more fibrous, compact root system than an unwrenched seedling when planted in the forest but also it seems to have a higher root regeneration capacity (Rook and Hobbs, 1972; Rook, 1973). Well wrenched plants are able to maintain better water relations than unwrenched seedlings when planted in hot dry conditions even though they transpire more rapidly (Rook, 1969). The wrenched plants also maintain higher rates of nett photosynthesis.

The quality of planting stock is measured ultimately by seedling survival and growth after planting in the forest. New Zealand experience suggests that wrenched seedling stock has better survival and more rapid early growth rates than unwrenched plants when planted on different sites, but the data are few (van Dorsser, 1967; 1969).

The present study examined the effect of manual wrenching practices in combination with fertilisation on 1-0 *P. radiata* seedlings, raised under otherwise normal nursery conditions. Survival in the forest and early growth were monitored for five years on a moderately severe site following planting either in late autumn or mid-winter.

METHODS

Nursery Study

The nursery experiment was conducted at the Forestry Commission of N.S.W. nursery at Canobolas State Forest near Orange during the 1969-70 growing season. Seed was size-graded before being sown in beds 1.5 m wide with "Stanhay" seeders at about 54 seed/m in each of six drills spaced 23 cm apart (nominal sowing density of 210 seed/m^2). Emergence and stocking counts were made at bimonthly intervals. Stocking density remained reasonably constant during the experimental period and close to the final counts given in Table 1.

Treatments were arranged in a randomised block layout with adjacent seedbeds used as blocks. Treatment plots within the beds were 3 m in length. Four treatments were established during the growing season (Table 1):

C control, no root wrenching or fertiliser
W2 root wrenched twice,
W5 root wrenched five times,
W5F root wrenched five times with two additions of fertiliser.

TABLE 1—Timing of treatments (weeks from sowing) and seedbed stocking density (seedlings/m^2; mean and s.e.) at final harvest H_2

Treatment	Operation			Stocking
	Wrenching	Fertilising	Lifting and Planting	
C	—	—	H_1 H_2	103 ± 7
W2	22, 26	—	H_1 H_2	93 ± 12
W5	20, 22, 24, 26, 28	— —	H_1 H_2	82 ± 9
W5F	20, 22, 24, 26, 28	0, 11	H_1 H_2	82 ± 8

Harvest H_1, 29 weeks; and H_2, 38 weeks from sowing. Stocking was unchanged between H_1 and H_2.

The wrenching was carried out manually using a spade to undercut the seedling taproot at about 13 cm depth on both sides and then heaving the soil and plants upwards about 6 cm. This treatment method also results in the lateral roots being severed parallel to the rows as the spade is driven into the soil at an angle. "Poplar special" fertiliser (6.2% N, 5.3% P, 4.6% K, 10.2% Ca, 0.4% Mg, 0.065% Zn, 0.032% B, 0.015% Mo and 0.13% Cu) was applied at the rate of 630 kg/ha either broadcast at sowing or as a dressing between drills at 11 weeks from sowing.

Seedlings were harvested from the middle four drills in each plot on the 29th and 38th week from sowing to provide a random sample for laboratory analysis and for forest plantings. At the first harvest the plot sample was five seedlings for analysis and 4 × 16 seedlings for planting while at the second harvest, 4 × 10 seedlings were harvested for analysis and again 4 × 16 seedlings for planting. Plant height, root collar diameter (r.c.d.), fresh weight, top and root dry weight were obtained. Foliage samples were analysed for N, P, K, Ca, Mg, Zn, Mn, Fe, Na and Al using published methods described fully by Benson (1974).

Field Study

Field performance of the four nursery stock types was evaluated in an experiment established in a routinely prepared plantation area. The site, near the top of an exposed hillside on Vulcan State Forest near Oberon, N.S.W., was one considered likely to provide severe test conditions for the plants. The planting area had been cleared of *Eucalyptus* forest and the debris bulldozed into windrows aligned parallel to the direction of slope (Stewart, 1970). The bay between the windrows was ploughed and eight blocks were laid out in pairs across the bay with successive pairs located at lower elevations down the slope. Plants lifted at 29 weeks after planting (21 April) and 38 weeks after planting (23 June) were planted into one or other of the paired blocks, this operation being repeated for each of the four block replicates. Within each block the nursery replications (4) were randomised and within each of the sub-blocks, the nursery treatments (4) were in turn randomised. Seedlings from each of the individual treatments were planted in straight line plots of 16 trees at a spacing of 1.2 × 1.2 m. The entire experiment occupied approximately 0.3 ha.

At each planting date, lots of 16 seedlings were lifted from the nursery treatments, packed, transported to the site and planted in their allotted place within the space of 18 hours to reduce the likelihood of damage due to moisture stress or exposure. Special care was taken to ensure that minor differences in planting techniques were spread randomly throughout the trial. Assessment for height, diameter and dry weight were the same as described earlier (Benson and Shepherd, 1976). Foliage samples from C and W2 were also collected at two and a half years from planting and analysed for the elements previously listed.

RESULTS

Nursery Study

Seedling size decreased with increased severity of root wrenching (Table 2). The plants wrenched five times were very small with a significant proportion of the lower needles "browning-off" or dead. These plants were about half the height of control seedlings and would not be considered acceptable planting stock according to current plant grading standards. Fertiliser additions to the frequently wrenched treatment resulted in less needle death and a slight increase in shoot height and dry weight.

Shoot development was curtailed more drastically than root development in root-wrenched seedlings. Mean shoot length remained the same; a slight decline between the April 21 and June 23 harvests is due to sampling error. The root weight increased significantly between the harvests, and for fertilised plants it was a five-fold increase. However at the week 39 harvest, there was no significant difference between treatments in root weight in spite of the substantial loss of roots due to root wrenching (evident from the harvest figures at week 29). There were qualitative differences between the root systems at the final harvest. Control plants had a thick tap root and only a few, very spare laterals. Wrenched seedlings had a much finer root system with many slender laterals and abundant mycorrhizae.

The moisture content of wrenched seedlings was significantly lower than that of control plants at the final harvest, reflecting no doubt the hard woody nature of the stem and the lack of soft apical tissues (Table 2).

TABLE 2—Seedling characteristics at each harvest. Data for H_1, from 5 seedlings per treatment, provide indications only. Data for H_2 are the means of 4 replicates, each consisting of 10 seedlings. Letters indicate values not significantly different at p, 0.05

Treatment	Shoot length (cm)		Dry weight (g) Shoot		Root		Shoot moisture content (% dry wt.)	
	H_1	H_2	H_1	H_2	H_1	H_2	H_1	H_2
C	24.6	23.9	1.80	2.61	1.96	2.89a	302	216
W2	20.6	17.9	1.32	1.82	1.12	2.73a	227	187a
W5	13.6	11.2a	0.90	0.85a	0.52	1.86a	193	176a
W5F	15.5	14.0a	0.96	1.20a	0.50	2.70a	217	176a

There was a very marked change in moisture content between the first and second harvest reflecting the natural processes of hardening-off in response to season but the change was most marked in the control.

In terms of two measures of plant type, shoot : rcd ratio and root : shoot dry weight ratio, there was a marked change due to treatment (Table 3). Root wrenching produced a much shorter, stockier seedling type with a significantly lower shoot : rcd. Root : shoot dry weight ratio was not altered significantly by two root wrenching treatments in spite of a reduced total dry weight due to wrenching (C 5.5 g; W2 4.5 g) but both W5 treatments were significantly different with very high ratios in excess of two.

Shoot tissue concentrations of N and P decreased with increased wrenching severity (Table 3). Fertilisation increased concentrations in the W5 plants to levels intermediate between those for W2 and W5 plants. Concentrations of other nutrients were not significantly affected by wrenching or fertilisation.

TABLE 3—Seedlings at final harvest: ratios of shoot length to root collar diameter (l/r.c.d.; X10) and root to shoot dry weight (r/s), together with concentrations of nutrient elements in shoot tissue. Results are means from 4 replicates of 10 seedlings (those for analysis, bulked). Letters indicate those not significantly different at p, 0.05

Treatment	r.c.d. (mm)	l/r.c.d.	r/s	N (%)	P (ppm)	K (ppm)
C	4.0	5.94	1.10a	1.92	1750	10290a
W2	3.6	4.99a	1.56a	1.39a	1320a	8240a
W5	2.8a	3.98	2.27b	1.21b	890b	7540a
W5F	3.1a	4.53a	2.31b	1.31ab	1120ab	7270a

Field Study

The most obvious difference between the seedlings after planting in the field was the extent of damage to the leader. Control seedlings, neither root wrenched nor fertilised, suffered severe leader damage in the winter and spring months following planting (Table 4). More than seventy percent of the unwrenched seedlings had damaged leading shoots whereas damage to root wrenched seedlings was insignificant. The weather during the first summer was relatively mild so that overall survival at two years was high. Only the early plantings on April 21 of unwrenched seedlings suffered any significant losses at establishment.

A direct result of the leader damage was a difference in growth habit of the young trees at two years. Trees originating from the control treatment were "bushy" and branched in appearance with frequent multiple leadering where competing laterals formed a "nest" of leaders around the original, dead leader. Root wrenched seedlings developed into trees with a more pronounced single leader with a slender, less branched appearance.

At two years from planting the trees from the early harvest planted in April were significantly shorter, with smaller stem diameter and at two and a half years had much

TABLE 4—Recorded damage to leading shoots of seedlings by treatments 5 months after planting out in the forest, and survival at 2 years. Means of four blocks consisting of samples of 16 planted seedlings (data after angular transformation)

Nursery treatment	Leader death (%)		Survival (%)	
	H_1	H_2	H_1	H_2
C	73.1	79.8	82.7	95.8
W2	4.1	2.2	97.9	96.6
W5	5.5	0.4	93.8	98.5
W5F	3.9	1.5	95.0	99.0

reduced shoot dry weight than seedlings harvested and planted in June (Table 5). However, at five years from planting this difference had largely disappeared, at least for height and diameter, dry weight not being recorded. The effects of nursery treatment were maintained throughout the five year period resulting in a decreasing order of performance: W2, C, W5F, W5 (Table 5), but again mean height and diameter differences had decreased. In contrast to the result for planting date, there were marked differences in stand stem volume by treatments at five years from planting.

Differences in foliage nutrient concentrations had also largely disappeared at 2.5 years. Wrenched stock planted in June had marginally higher N levels than stock planted in April or unwrenched stock planted at either date but the difference was not statistically significant.

TABLE 5—Plant characteristics by planting date and nursery treatment at two years and five years from planting in the forest. Letters show means not significantly different at p, 0.05

	Shoot height (mm)	Stem diameter (mm)	Shoot dry weight (g)	Stand stem volume (m^3/ha)
for planting date				
(a) At 2 years			(2.5 years)	
April 21	452	91	38.8	—
June 23	492	114	62.4	—
(b) At 5 years				
April 21	1660	132	—	0.38
June 23	1715	135	—	0.41
for nursery treatment				
(a) At 2 years			(2.5 years)	
C	473a	105	57.2a	—
W2	518	117	60.3a	—
W5	452a	95a	41.4b	—
W5F	439a	99a	43.6b	—
(b) At 5 years				
C	1720bc	140b	—	0.40
W2	1760b	150b	—	0.51
W5	1670bc	130b	—	0.36
W5F	1600c	110b	—	0.25

DISCUSSION

Seedling size is a major factor determining early growth rate after planting in the forest (Pawsey, 1972; Benson and Shepherd, 1976).

An even more important criteria is the capacity of the planting stock to survive and incur little physiological damage when planted out. The nursery stock in the present experiment was raised at seedbed densities comparable with the "low density" treatment (Benson and Shepherd, 1976) which produced the best field performance of seedlings after transfer to the forest. But when planted in the forest the unwrenched stock suffered considerable leader damage and for the early harvest the survival was reduced (Table 4). This damage occurred despite having undergone a form of conditioning or "hardening off" with the onset of normal autumn weather, reflected in the decreased moisture content of the seedlings between the harvest of April 21 and the harvest of June 23 (Table 2). Rook (1973) noted similar seasonal changes in unwrenched *P. radiata* seedlings in New Zealand.

Root wrenching applied twice during the nursery period produced stock similar to that described in many New Zealand studies (van Dorsser and Rook, 1972). It caused a marked reduction in moisture content, similar to that of naturally hardened plants, but very much earlier in the season. This stock became established with little damage to the leading shoot, had a high percentage survival at two years and slightly improved growth at the end of five years. Stock root-wrenched five times was very reliable in field survival with little leader damage but growth at the end of five years was reduced. Additional fertiliser did not entirely offset this undesirable effect of the more frequent root wrenching. Thus the root wrenching applied only twice during the nursery phase of growth conditioned the plants well to the shock of lifting and transfer to the forest and conferred on them a capacity for rapid establishment and growth on these fertile soils.

Foliage nutrient concentrations have been used as an index of seedling quality (Armson and Sadreika, 1974).

Richards, Leaf and Bickelhaupt (1973) found ash concentrations decreased with increased seedbed density in 10 conifer species, an increase found in our previous work to reduce field growth in *P. radiata* (Benson and Shepherd, 1976). In this experiment wrenched seedlings had distinctly chlorotic foliage and concentrations of nitrogen and phosphorus were near or below the critical levels of 1.6% and 0.1% (Will, 1961). Added fertiliser partially improved foliage colour as well as N and P levels in the severely wrenched plants but the poor nutrient status of wrenched plants did not apparently limit the capacity for survival and subsequent growth.

The multileadered habit of the control stock resulting from leader death after planting did not persist for much more than three years, in keeping with the strong tendency of *P. radiata* seedlings to exert apical growth dominance (Burdon and Bannister, 1972). However, at five years W2 stock had produced 25% more stem volume per hectare than unwrenched stock and experience in Australia generally with the establishment and early growth of *P. radiata* would indicate that this early advantage will be retained (Waring, 1973).

The root-wrenching treatments which were applied in this experiment were relatively severe, resulting in a marked check to seedling growth in the nursery. Modern root-wrenching equipment, when used properly, can result in much more carefully controlled effects on seedling development (van Dorsser, 1969; van Dorsser and Rook, 1972). The depth of undercutting and the frequency of both horizontal and vertical root severance can be carefully controlled. These can be applied when soil moisture and weather conditions are such that the least damage to seedlings will result and very high quality stock can be produced.

It has been shown that root-wrenched nursery seedlings of *P. radiata* exhibit the same tendency for improved survival and rapid establishment when planted under Australian conditions as reported for New Zealand forests. In addition, under conditions of careful site preparation in the forest as is now commonly practised in Australia, the root-wrenched seedling has been shown to have an added growth rate at the end of the five years. The use of root-wrenched nursery stock should, therefore, be adopted along with soil cultivation, fertiliser application and weed control if maximum productivity is to be achieved in *P. radiata* plantations.

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