EFFECT OF NURSERY PRACTICE ON *PINUS RADIATA* SEEDLING CHARACTERISTICS AND FIELD PERFORMANCE: I. NURSERY SEEDBED DENSITY

A. D. BENSON

Central Highlands Research Centre, Forestry Commission of NSW, Bathurst NSW

and

K. R. SHEPHERD

Department of Forestry, Australian National University, Canberra

(First received for publication 27 November 1975; in revised form 9 February 1976)

ABSTRACT

Pinus radiata D. Don seedlings were raised at a variety of seedbed densities under otherwise routine nursery conditions. Planting stock characteristics were determined at the time of lifting using routine grading criteria. Increasing seedbed density reduced seedling size and quality.

Field performance of the stock types was determined on a moderately severe site prepared for routine plantation establishment. Tree size and survival were significantly decreased for plants raised at higher seedbed densities. The effect persisted up to the fifth year after planting.

INTRODUCTION

Nursery costs for seedlings are lowered when they are raised at high density in the seedbed. However, tree seedling size decreases and form changes, with progressive increases in seedbed density. The number of seedlings rejected at planting time will increase due to poor growth. Height growth is affected less than diameter and root growth, so that plants are less sturdy, have lower root volumes and reduced root : shoot ratios when raised at higher densities (Bell, 1968; Burns and Brendemuehe, 1971; Richards, Leaf and Bickelhaupt, 1973).

Seedbed density influences seedling survival and early growth rate through competition-induced stress affecting seedling morphology and physiology. The seedlings most affected by high density in the nursery often do not survive planting out or grow less rapidly due mainly to small initial size (Shipman, 1964; Pawsey, 1972). In some instances the growth of seedlings from high density seedbeds indicates a lower relative growth rate (RGR) (Shoulders, 1961; Baron and Schubert, 1963).

The range of seedling size in *P. radiata* crops increases considerably with increasing seedbed density (van Dorsser, 1969) due partly to an exaggeration of initial size differences at the onset of competition, with diameter growth of smaller seedlings being suppressed more than that of larger seedlings. Pre-competition size variation can be reduced by careful sowing of good quality seed, graded and stratified, by the maintenance of moist conditions during germination and with a minimum of friable seed covering (Grose, 1958; Sweet and Wareing, 1966; Donald, 1968).

This study examined the effect of seedbed density on the planting stock characteristics of 1-0 *P. radiata* seedlings, raised under otherwise normal nursery conditions as well as growth of the stock after planting out in the forest.

METHODS

Nursery study

This was conducted at the NSW Forestry Commission nursery, Canobolas S.F. near Orange during the 1969-70 growing season. A previously uncropped area was used to eliminate any site variability due to past nursery management. Climate and site conditions during the period were reasonably representative for the nursery (Benson, 1974).

Size-graded seed was sown after stratification, in treatment plots measuring 3.0 m × 1.5 m. A randomized block layout was used with replicates sited on adjacent seedbeds. Sowing density treatments were established by varying both density within seed drills and distance between the drills which ran the length of the seedbed (Table 1). Seed was hand-sown evenly spaced within the drills, and covered with 5 mm-diameter washed river gravel. The beds were kept moist during emergence and subsequently sprayed with 'Captan' fungicide. They were weeded and cultivated at regular intervals to ensure that the only competition effects were those between tree seedlings.

Seedlings were harvested from the middle four drills in each plot in late June, 38 weeks after sowing. They were lifted carefully and allocated at random to four lots of 16 seedlings and one lot of 10 seedlings per plot. The four larger lots were planted out in separate blocks in the field study at Vulcan S.F. near Oberon. The remaining bundle in each case was used to obtain the following measurements:

For individual seedlings: shoot length; root collar diameter (r.c.d.).

For bulked plot sample: fresh weight of shoot and root; dry weight of shoot and root.

TABLE 1—Sowing density treatments and resulting plot stocking densities at harvest (38 weeks from sowing)

Treatment	Sowing Density Drills per bed	Drill spacing (cm)	Drill density seeds/m	Plot density seeds/m²	Stocking Seedlings/m² (mean & S.E.)
Low 'L'	6	23	26	103	101 ± 5
Medium 'M_1'	13	11	26	222	231 ± 4
Medium 'M_2'*	6	23	52	205	205 ± 4
High 'H'	13	11	52	445	420 ± 2

* Routine sowing density

Field study

The effect of seedbed density on the field performance of stock was evaluated in a routinely prepared plantation area which was likely to provide severe test conditions for the plants.

The effect of microsite variation was minimised by using a split plot design and close spacing, line plots running parallel with likely site-quality gradients. This design allowed the segregation of variance due to differences in forest site, nursery replicates and nursery treatments. The experiment consisted of four blocks of four plots each with 16 line sub-plots of 16 seedlings. Site preparation methods were similar to those described by Stewart (1971). Weather conditions were representative for the area with annual rainfall during the first three years being 969, 998 and 831 mm. These figures are comparable with the 17-year mean rainfall of 1000 mm (Commonwealth Bureau of Meteorology, 1967).

The four samples of 16 seedlings from each nursery treatment plot were packed, transported and planted in their allotted lines. This operation was completed within 18 hours of lifting to reduce the likelihood of damage due to moisture stress or exposure. Special care was taken to ensure that any minor differences in planting technique were spread randomly throughout the trial.

The trial was assessed for initial establishment in early summer, about five months after planting, when tree height and the incidence of leader damage were also measured. Height measurements were subsequently taken annually in winter for the next five years. Every second plant in each sub-plot was harvested at ground level in October-November, 1972, some two and a half years after planting, for shoot dry weight measurement and also to thin the stand.

RESULTS

Nursery study

Seedling size at harvest varied inversely with seedbed density (Table 2). However, within-drill density had a greater influence on seedling size than did drill spacing or overall seedbed density.

Seedlings became more spindly at increasing drill densities with height and diameter being much less sensitive than dry weight to seedbed density variation (Table 2). This change in seedling character was best defined by the shoot length/shoot dry weight ratio which was significantly lower for plants raised under low seedbed densities. Shoot length/r.c.d. ratio did not reflect this change in character, nor did the seedling moisture content or root/shoot ratio.

Field study

Plant survival at two years was significantly lower for stock raised at high within-drill densities, although overall survival was very high throughout the experiment (Table 3).

Conspicuous growth differences, especially in shoot dry weight, were evident in different field blocks due to site factors. Nevertheless, this did not mask the effect of seedbed density and plants raised at higher densities lagged in shoot height and dry weight at two years. Marked differences in growth habit were evident at two years

TABLE 2—Measurements at harvest (38 weeks) for seedlings raised at various seedbed densities

Treatment and Density†	Shoot length (cm)	R.C.D. (mm)	Dry weights (g)				Ratios of shoot measurements	
			Seedling	Root	Shoot	Root/Shoot	Length/Dry weight	Length/R.C.D.
L 101 ± 5	29.5	4.3	5.40	2.36	3.04	0.78	10.01	7.06
M_1 231 ± 4	25.3	3.6	4.00	1.89	2.11	0.89	12.29	6.95
M_2 205 ± 4	22.9	3.4	3.22	1.52	1.70	0.95	13.84	6.70
H 445 ± 2	21.4	2.9	2.27	1.11	1.16	0.96	18.47	7.37
Significance level	***	***	***	**	***	n.s.d.	***	n.s.d.
L.S.D. ($P_{0\cdot05}$)	2.3	0.4	1.19	0.60	0.61		2.69	

Bracketed values not significantly different at $P_{0\cdot05}$

† Seedlings/m²; mean and S.E.

TABLE 3—Survival, height and weight after 2 growing seasons on forest site of seedlings raised under different densities

Treatment	Survival (%)	Shoot height (cm)	Shoot dry weight (g)	Height/ Dry weight
L	99.3	67.4	211	0.36
M_1	98.1	60.3	185	0.42
M_2	92.6	58.7	161	0.47
H	96.9	54.4	128	0.56
Mean for all plots	96.7	60.2	171	0.45

Bracketed means not significantly different at $P_{0.05}$

Survival values have been subject to angular transformation

with plants raised at lower seedbed densities having considerably more lateral branches and foliage. This trend can be discerned from the shoot height : weight ratios (Table 3).

Five years after planting, highly significant differences in tree height and diameter at breast height could be attributed to seedbed density. Stem volume was 70 percent larger on plots planted with seedlings from the low density seedbeds than on plots planted with seedlings from the high density seedbeds (Table 4). Tree height differences

TABLE 4—Stand parameters, 5 years from planting, for trees grown from seedlings raised at different seedbed densities

Treatment	Tree height (m)	D.b.h. (cm)	Stem volume (m^3/ha)
L	2.52	3.8	4.77
M_1	2.34	3.3	3.65
M_2	2.44	3.4	3.45
H	2.28	3.1	2.80
Significance level	***	***	

Bracketed means not significantly different at $P_{0.05}$

became more pronounced with time after planting (Fig. 1). The data suggest that seedling height at planting may have been the most critical factor in determining height differences up to five years.

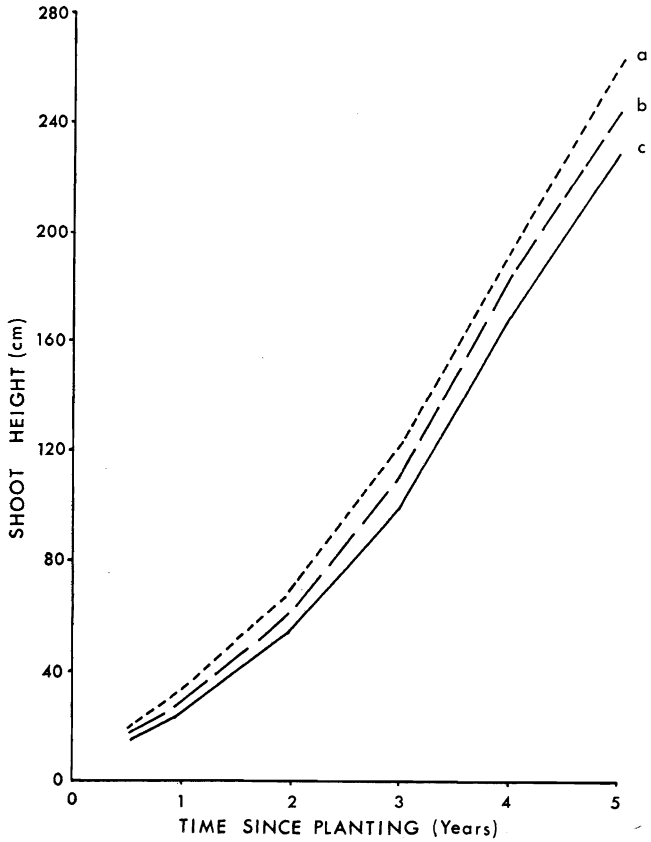

FIG. 1—Height growth in the field of seedlings raised in the nursery at seedbed densities of: a, 103; b, 205; c, 445 seedlings/m^2.

DISCUSSION

Planting stock quality is controlled to some extent through grading and culling practices based on seedling characteristics at time of lifting. Morphological characteristics of size, 'sturdiness' and 'balance' are frequently used (e.g. Wakeley, 1954; Anstey 1971; Williston, 1974; Schmidt-Vogt, 1975). More recently developed systems are based on characters that may infer superior drought or cold resistance (Stone and Jenkinson, 1971). However, planting stock quality is ultimately measured by seedling survival and early growth (Aldhous, 1972) and will vary with the conditions under which seedlings are established and required to grow (Donald, 1965, 1968; Schmidt-Vogt, 1975).

In this experiment stock quality, as measured by field performance, decreased with increasing nursery seedbed density and especially with within-drill densities. Planting stock size decreased and seedlings became more spindly when raised at higher seedbed densities. The shoot length: shoot dry weight ratio was a more sensitive grading criteria in this experiment than the more often recommended shoot length: r.c.d. ratio (Schmidt-Vogt, 1975). However, the former index requires destructive sampling and more complex equipment, and hence is less useful in practice.

Even in a relatively mild year, seedling survival was lower for plants raised at high within-drill densities. The initial differences in tree size became more pronounced with time from planting for stock raised at different densities and were especially conspicuous in terms of shoot dry weight and r.c.d./d.b.h. The height growth curves indicate that growth rate of all stock types was similar over the period examined and that the differences at five years were due mainly to differences in stock size after planting.

Variation in seedbed sowing density may produce only small differences in seedling size but these small differences in height and diameter may represent differences in seedling size of practical importance once these seedlings are planted out in the forest. A seedbed density increase of 77 percent resulted in percentage differences of 28, 33 and 58 percent in planting stock height, r.c.d. and shoot dry weight at lifting and a 70 percent difference in stand volume per hectare at five years.

Seedbed density may also influence the early growth of plantations due to variability of planting stock. In this experiment .planting stock variability was higher for high density seedbeds than for low density seedbeds, a difference which was still evident after two years in the field, despite further effects of differences in site quality (Table 5). This variability in tree height will lead to uneven canopy closure and accentuate between-tree competition effects at this stage of plantation development.

Seedbed densities must be carefully controlled to produce planting stock of uniform size and quality. Within-drill densities affected seedling size more than between-drill spacing in this experiment. Competition will start earlier on an intra-row than on an inter-row basis and therefore within-drill spacing is a major factor in determining plant stock size, quality and variability.

Maximum within-row spacing of seedlings is obtained for a given density when drills are closely spaced. However, there are practical limitations to drill spacing in a mechanized nursery. Plant survival in this experiment was in excess of 90 percent which compares very favourably with the 40-50 percent commonly obtained in New South Wales nurseries. This experiment emphasises the desirability of devising techniques and machinery to obtain designed within-drill spacings in closely spaced drills.

TABLE 5—Variability in height, as coefficient of variation (%), of seedlings at time of lifting and at two years after planting

Treatment	At lifting	At 2 years
L	11.5	21.9
M_1	13.7	24.3
M_2	19.0	24.0
H	17.6	25.0
Experimental mean	15.4	23.8

ACKNOWLEDGMENTS

We would like to thank the Forestry Commission of NSW for financial assistance and permission to use the data obtained in this study. We are particularly grateful to Mr Geoffrey Bulkeley and Mr Don Sheather for help in the field and in the preparation of diagrams.

REFERENCES

ALDHOUS, J. R. 1972: Nursery practice. **Forestry Commission, London, Bull. 43.**

ANSTEY, C. 1971: Survival and growth of 1-0 radiata pine seedlings. **N.Z. J. For. 16:** 77-81.

BARON, F. J. and SCHUBERT, G. H. 1963: Seedbed density and pine seedling grade in California nurseries. **U.S. For. Serv., Res. Note PSW-31.**

BELL, T. I. W. 1968: Effect of fertilizer and density pre-treatment on spruce seedling survival and growth. **Forestry Commission, London, For. Rec. 67.**

BENSON, A. D. 1974: Some effects of nursery practice on **Pinus radiata** D. Don seedlings and early plantation establishment. M.Sc. thesis, Australian National University, Canberra.

BURNS, R. M. and BRENDEMUEHE, R. H. 1971: Nursery bed density affects slash pine seedling grade and grade indicates field performance. **U.S. For. Ser., Res. Pap. SE-77.**

COMMONWEALTH BUREAU OF METEOROLOGY 1967: Climatic survey, Region 10, Mitchell. **Meteorology summary.**

DONALD, D. G. M. 1965: A study of the history, practice and economics of forest nurseries in South Africa. **Universiteit of Stellenbosch Annale 40A(1).**

——— 1968: Fundamental studies to improve nursery production of **Pinus radiata** and other pines. **Universiteit of Stellenbosch Annale 43A(1).**

GROSE, R. J. 1958: Notes on the influence of stratification at constant temperature on germination of **Pinus radiata** D. Don. **Forests Commission of Victoria, Plantation Technical Paper 5.**

PAWSEY, C. K. 1972: Survival and early development of **Pinus radiata** as influenced by size of planting stock. **Aust. For. Res. 5:** 13-24.

RICHARDS, N. A., LEAF, A. L. and BICKELHAUPT, D. H. 1973: Growth and nutrient uptake of coniferous seedlings: comparison of 10 species at various seedbed densities. **Plant & Soil 38:** 125-43.

SCHMIDT-VOGT, H. 1975: Planting material. **In** 'Symposium on Stand Establishment' **IUFRO Joint Meeting, Division 1 & 3, Wageningen, The Netherlands,** October 15-19, 1974. Pp 70-86.

SHIPMAN, R. D. 1964: Low seedbed densities can improve early height growth of planted slash and loblolly seedlings. **J. For. 62:** 814-7.

SHOULDERS, E. 1961: Effect of nursery bed density on loblolly and slash pine seedlings. **J. For. 59:** 576-9.

STEWART, J. P. 1971: Site preparation. **In** 'Radiata Pine' **Symposium Volume 1, Australian National University, Canberra, 1970.** Paper 20.

STONE, E. C., and JENKINSON, J. L. 1971: Physiological grading of ponderosa pine nursery stock. **J. For. 69:** 31-3.

SWEET, G. B. and WAREING, P. F. 1966: The relative growth rates of large and small seedlings in forest tree species. **Forestry 39 (Supplement):** 110-7.

VAN DORSSER, J. C. 1969: Seedling density. **In** 'Forest nursery and establishment practice in New Zealand' (C. R. G. Chavasse & G. C. Weston, Eds.). **N.Z. For. Serv., For. Res. Inst., Symposium 9, Rotorua, 1967.** Pp 62-4.

WAKELEY, P. C. 1954: Planting the southern pines. **U.S. Dep. Agriculture, Agriculture Monograph 18.**

WILLISTON, H. L. 1974: The optimum loblolly, shortleaf and slash pine seedling. **U.S. Dep. Agriculture, Treeplanters Notes 25(4):** 11-3.