Factors affecting radiata pine seed germination

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Abstract

Many experiments have been carried out by the Forest Research Institute to investigate the germination of *Pinus radiata* D. Don (radiata pine) seed. These have shown that seed can be treated to germinate earlier and more evenly, producing a larger and more uniform final crop.

Seed size commonly ranges from 22,000 to 40,000 seeds per kilogram and this can affect germination and subsequent growth. Seed larger than 25,000 seed/kg had significantly better germination and produced significantly taller seedlings than smaller seed (33,000+ seed/kg) ($p = 0.05$). Seed is often soaked in cold water for 48 hours and stratified for three weeks in a coolstore before sowing. Results of experiments showed that seed should be stratified if it is to be sown into cold soil conditions, *i.e.*, early in the season or in nurseries in colder locations. Cold soaking seed at 10 to 15°C for 48 hours is sufficient if seed is to be sown in warmer soil conditions. The current practice of applying a fungicide (Thiram) before stratification or cold soaking was substantiated. If the fungicide is applied after stratification or soaking, seed germination is reduced, resulting in fewer and smaller seedlings at the end of the growing season.

Additional key words: Pinus radiata, *nursery, sowing, germination, seedling growth.*

Introduction

Rapid and uniform seed germination of radiata pine *(Pinus radiata* D. Don) is required in forest nurseries to make optimum use of limited quantities of genetically improved seed such as that from control-pollinated orchards. At present, the number of plantable seedlings raised in New Zealand nurseries amounts to only about half the seed sown (FRI, 1986).

Standard seed testing procedures for forestry species are well defined, and can include purity, weight, germination, moisture content, and vigour (Bonner, 1974). These germination tests are done under ideal laboratory conditions, and germination can be up to 95% (Baird, 1977). Such high germination success rarely occurs in the nursery because of less than optimal germination conditions including cold soil, fluctuating soil moisture, pathogenic fungi, and insect and bird damage. Attaining high germination success in the nursery requires considerable care in collecting, processing, and storing seeds and in applying appropriate pre-germination treatments (Barnett, 1985). Recommended methods for forest species have been widely published (Schopmeyer, 1974; Willan, 1985; Barnett, 1985) and techniques for radiata pine have been researched for many years (Bibby, 1953; Wilcox and Firth, 1980; Hedderwick, 1981; Menzies *et al.*, 1985; Rimbawanto *et al.*, 1988); as well, practical knowledge has been gained over many decades by nurserymen.

Hedderwick (1981) emphasised the importance of the factors of seed extraction (ripening of green cones, seed extraction, de-winging and drying), seed grading, and seed treatment with protective coating, including fungicide. Another important factor is seed pretreatment by soaking or stratification (Barnett, 1985). Current seed and nursery practices in New Zealand include seed extraction by machine grading seed into about four size grades (Baird, 1977), application of a fungicide and bird repellent (Hedderwick, 1981), and some form of seed pretreatment by soaking or stratification. This paper describes four experiments examining the effects of current radiata pine seed and nursery practice.

Methods

General experimental methods

These methods were followed for each experiment unless specified otherwise. Seed was given a 48 h cold soak, or soaked and then stratified for 3 weeks. For the 48 h soak, seed was placed in muslin bags and kept under water in a bucket for 48 h at room temperature (10-20°C). The water was changed after 24 h. For

stratification, the seed was soaked for 48 h as described, and then kept damp in the muslin bags at 4°C for 3 weeks.

Following surface air drying, the seed was hand sown at 12.5 cm x 6 cm spacing in three adjacent nursery beds. There were 6 replications, with the treatments randomly allocated across the 6 centre rows of each bed and the two outside rows sown as buffers. Two 2 m assessment plots were randomly allocated within each replication for assessment of germination, seedling health, and height growth.

All seedlings received normal conditioning (undercutting and wrenching) treatment. The following seedling traits were assessed:

- Germination was assessed weekly for up to 5 weeks.
- Seedling health was recorded monthly for 3 months.
- Seedling heights were measured 6 weeks after sowing and then monthly until the following winter.
- Final height assessment. In winter 1984, seedlings were lifted in the 2 m assessment plots and 30 seedlings per treatment per replication were sampled for dry weight distribution. The remaining seedlings in the trial were lifted and graded as acceptable trees or culls.

Experiment 1. Seed extraction

Seed from two seed sources, a Kaingaroa climbing select (seed collected from superior phenotypic but not progeny tested trees) and a bulk NZ Forest Products sample, were used in this trial. Cones from each seed collection were processed at either the Central Seed Store (now Proseed New Zealand, Private Bag 3020, Rotorua) (mechanical extraction) or by hand at the NZ FRI. Both seedlots were cleaned after extraction by a water absorption flotation method (Willan, 1985) to remove debris, and stratified for 6 weeks. This gave four treatments:

- Kaingaroa climbing select, mechanically extracted
- Kaingaroa climbing select, hand extracted
- NZ Forest Products, mechanically extracted
- NZ Forest Products, hand extracted.

The seed was sown into 3 nurseries on 3 consecutive days in mid-October 1983. The trial at Athol Nursery, Tokoroa (NZ Forest Products Ltd.) was hand sown at 12.5 cm x 8 cm spacing. That at Kaingaroa Nursery (NZ Forest Service) was sown with a vacuum drum precision sower at 12.5 cm x 7.5 cm spacing, and the one at NZ FRI Nursery (Rotorua) was hand sown at 12.5 cm x 6 cm spacing.

Experiment 2. Seed grading by size

Seed from Gwavas Seed Orchard (Seedlot 3/3/83/002/2&3) was hand-graded into three grades by weight and subsequently blended to give six treatments of pure grades and blends (Table 1). The seed grades 1-3 correspond to 20,000-25,000, 25,001-33,000, and 33,001-50,000 seed/kg respectively.

After a 48 h cold soak, the seed was coated with Thiram fungicide slurry. The seed was coloured with food colouring for identification after blending in treatments 4-6. The seed was hand sown in October 1983 at 12.5 cm x 6 cm spacing. Before the drills were covered, seed colour in each position was recorded for the blended grades to enable identification for future germination and height assessments. This would allow evaluation of whether seedlings from smaller seed were suppressed by seedlings from larger seed in blended grades.

Experiment 3. Seed pretreatment

(i) Effects of aeration during soaking, and soaking temperature: Seed orchard seed (Seedlot 2/3/83/002/3) was soaked at four temperatures (10, 15, 20 and 25°C), with and without aeration, to investigate the optimum temperature of the soak water, and whether aeration of the water improves the performance of the seed. This 4x2 factorial design gave 8 treatments. After 48 h, the seed was drained, coated with Thiram and air surface dried before hand sowing in October 1984.

(ii) Effect of stratification or 48 h soak: Seed orchard seed (Seedlot 2/3/83/002/3) was given one of three treatments before sowing, *i.e.*, after a 48 h soak or after three weeks stratification, or with no pretreatment at all. The seed was coated in Thiram fungicide before sowing. The trials were hand sown on 2 consecutive days: at Kaingaroa on 12 October 1983 at 12.5 cm x 8 cm spacing and at NZ FRI on 13 October 1983 at 12.5 cm x 6 m spacing.

Table 1. Treatments with their seed grades and weights.

Treatment	Seed weight (g)	Grade
1	0.04-0.049	1
2	0.03-0.039	2
3	0.02-0.029	3
4		Blend of 1 & 2
5		Blend of 2 & 3
6		Blend of 1, 2 & 3

Experiment 4. Application of fungicide

To evaluate whether applying the fungicide Thiram to the seeds after imbibition inhibits germination, seed orchard seed (Seedlot 2/3/83/002/2&3) was coated with Thiram both before and after a 3-week stratification period and before and after a 48 h cold soak. This 2x2 factorial design gave 4 treatments. The trial was hand sown in November 1983. Bird tape was strung above the trial to protect against bird predation.

Analysis

The data for all of the experiments were analyzed by analysis of variance with the least significant difference (LSD) test being using to determine significant differences between treatment means for all assessed variables.

Results

Experiment 1. Seed extraction

The germination trends were similar at all three nurseries (Table 2). The Kaingaroa climbing select seed had significantly better germination than the NZ Forest Products bulk seed. At NZ FRI, the machine-extracted climbing select seed had better germination than the hand-extracted seed, and the hand-extracted seed from the bulk lot had better germination than the machine-extracted seed. There were no differences in final germination as a result of method of extraction at the other two nurseries.

Kaingaroa had the highest number of healthy seedlings, followed by Athol Nursery and then NZ FRI Nursery (Table 3). There were no significant differences between treatments at Athol Nursery for healthy seedlings. At Kaingaroa Nursery, NZ Forest Products bulk seed produced significantly fewer healthy seedlings than Kaingaroa climbing select seed, and machine-extracted seed produced significantly more seedlings than hand-extracted seed. At NZ FRI Nursery, bulk seed produced significantly fewer seedlings than climbing select. The greatest health problem was failure to germinate (or emerge), ranging from 1 to 15%, and this was reflected in the final number of healthy trees.

Other problems, e.g., bird damage and the number of dead seedlings, showed no significant differences and had little bearing on the final result. However, there was more seedling death at NZ FRI because of early damping-off problems.

At NZ FRI Nursery and at Kaingaroa Nursery, the hand-extracted climbing select seedlings were significantly shorter than the other three treatments (Table 4). At Kaingaroa Nursery the machine-extracted seedlings were tallest. At Athol Nursery, climbing select

Table 2. Cumulative percentage germination for machine- or hand-extracted seed of two seed origins, sown in three nurseries.

	Cumulative Percentage Germination			
	Kaingaroa climbing select seed		NZ Forest Products bulk seed	
Nursery	Hand extracted	Machine extracted	Hand extracted	Machine extracted
NZ FRI	96 b[1]	99 a	90 c	85 d
Kaingaroa	95 a	98 a	88 b	86 b
Athol	91 a	92 a	85 b	85 b

[1] Means with the same alphabetical letter for a given nursery are not significantly different (LSD test, P = 0.05).

Table 3. Seedling health 3 months after sowing, for seedlings raised from hand-extracted or machine-extracted seed of 2 seedlots sown in 3 nurseries.

	% of Seedlings in each Health Category[1]			
	Kaingaroa climbing select seed		NZ Forest Products bulk seed	
Nursery/ Health category	Hand extracted	Machine extracted	Hand extracted	Machine extracted
NZ FRI				
Healthy	87 a	88 a	81 b	78 b
Not germinated	4 b	1 a	10 c	15 b
Unhealthy	2 a	0 a	1 a	1 a
Damaged/dead	8 a	10 a	8 a	7 a
Kaingaroa				
Healthy	91 b	95 a	85 c	83 c
Not germinated	5 b	2 a	12 c	14 c
Unhealthy	1 a	1 a	1 a	1 a
Damaged/dead	3 a	3 a	1 a	2 a
Athol				
Healthy	87 a	85 a	82 a	82 a
Not germinated	9 a	8 a	15 b	15 b
Unhealthy	1 a	3 a	2 a	1 a
Damaged/dead	3 a	4 a	2 a	2 a

[1] Means with the same alphabetical letter for a given nursery and health category are not significantly different (LSD test, P = 0.05).

seedlings were significantly taller than bulk seedlings, until they were topped, but there were no significant differences between the two extraction methods.

There were no significant differences in dry weight distribution between treatments at Athol and NZ FRI Nurseries (Table 5). At Kaingaroa Nursery, climbing select machine- extracted seed produced significantly larger seedling tops. There was no significant difference between hand or machine extraction for the number of plantable seedlings produced at all 3 nurseries, although at Athol Nursery, climbing select seed produced significantly more plantable seedlings than bulk seed.

Experiment 2. Seed grading by size

Differences in the mean cumulative germination percentages between the seed grades were not significant until day 30, although most germination was completed by day 25, and there were no great changes after this. Grade 1 seed had the best germination (82%) and Grade 3 seed the worst (69%), irrespective of whether the seed was blended into mixed grades or not. There was no significant difference between Grade 1 and Grade 2 final seed germination (82% and 75% respectively) but the final germination of seed from Grade 3 was significantly lower than the seed from Grade 1.

There was a general trend for larger seed to produce more healthy seedlings irrespective of whether the seed was blended into mixed grades or not. Failure to germinate or emerge caused the greatest loss of plants, particularly with the smaller seed. The average percentages for failure to emerge were 17.5% for Grade 1, 24.5% for Grade 2, and 30.7% for Grade 3 seed. A small percentage of seedlings were unhealthy, although there were no consistent differences between treatments. Most unhealthy seedlings stayed in that category or died. Only a small percentage of seedlings were damaged by birds. Seedlings from the largest seed were significantly taller than those from the smaller seed 42 d after sowing (average height 2.3 cm), and this pattern was consistent

Table 4. Seedling height growth for seedlings raised from hand-extracted or machine-extracted seed of 2 seedlots sown in 3 nurseries.

	Seedlings Height (cm)			
	Kaingaroa climbing select seed		NZ Forest Products bulk seed	
Days from Sowing	Hand extracted	Machine extracted	Hand extracted	Machine extracted
NZ FRI				
48	3.1 b	3.2 a	3.0 b	3.0 b
97	8.4 b	8.9 a	8.3 b	8.2 b
153	24.2 b	26.2 a	25.4 a	25.6 a
241	31.7 b	34.5 a	33.9 a	33.9 a
Kaingaroa				
56	3.4 b	3.6 a	3.3 b	3.2 c
98	7.2 b	7.7 a	7.2 b	6.9 c
154	22.7 b	24.6 a	23.5 b	23.3 b
219	29.0 c	32.0 a	30.6 b	30.0 bc
Athol				
49	3.5 b[1]	3.6 a	3.3 c	3.2 c
105	11.3 a	11.3 a	10.5 b	10.5 b
160	28.2 a	28.4 a	26.7 b	27.2 b
216	33.4 a	33.7 a	30.3 a	31.4 a

[1] Means with the same letter for a given nursery and date are not significantly different (LSD test, P = 0.05).

Table 5. Dry weights (g) of tops, roots and whole seedling, root/shoot (R:S) ratios and number of plantable seedlings for seedlings raised from hand-extracted or machine-extracted seed of two seedlots sown in 3 nurseries.

	Kaingaroa climbing select seed		NZ Forest Products bulk seed	
	Hand extracted	Machine extracted	Hand extracted	Machine extracted
NZ FRI				
Top	7.05 a	7.47 a	7.47 a	7.62 a
Root	1.24 a	1.38 a	1.41 a	1.50 a
Seedling	8.28 a	8.85 a	8.88 a	9.12 a
R:S ratio	0.177 a	0.184 a	0.188 a	0.196 a
Plantable No.	579 a	583 a	547 a	536 a
Kaingaroa				
Top	5.70 b	6.62 a	5.69 b	5.86 b
Root	0.97 a	1.04 a	0.92 a	0.94 a
Seedling	6.67 b	7.66 a	6.61 b	6.80 b
R:S ratio	0.170 a	0.158 a	0.163 a	0.161 a
Plantable No.	647 a	661 a	607 a	608 a
Athol				
Top	6.48 a[1]	6.05 a	5.93 a	5.91 a
Root	1.13 a	1.11 a	1.15 a	1.07 a
Seedling	7.61 a	7.16 a	7.08 a	6.98 a
R:S ratio	0.175 a	0.183 a	0.196 a	0.183 a
Plantable No.	646 a	634 a	604 b	605 b

[1] Means with the same letter for a given nursery and variable are not significantly different (LSD test, P = 0.05).

for all subsequent measurements (Fig. 1). Seed from Grade 1 was consistently taller whether the seed was blended or not.

There was no consistent trend in dry weight distribution, although larger seed usually produced heavier seedlings. However, none of the differences were statistically significant.

There were significantly more plantable seedlings from treatments with the larger seed as a component of the blends, and least from treatments with the smallest seed (Table 6).

Experiment 3. Seed pretreatment

i) Effects of aeration during soaking, and soaking temperature: There was no significant interaction between imbibing temperature and aeration. There was a consistent trend for poorer germination following higher imbibition temperatures (Table 7). This trend became apparent 22 d after sowing, and germination following imbibition at 25°C was significantly worse than imbibition at lower temperatures.

Aeration of the water during imbibition speeded up germination and resulted in better final germination, although the difference was not significant after 29 d from sowing (Table 7).

Table 6. Number of plantable seedlings as a function of seed size for treatments in each replication.

Treatment	No. of plantable seedlings
Grade 1	150 a[1]
Grade 2	148 a
Grade 3	127 c
Grades 1 & 2	149 a
Grades 2 & 3	134 bc
Grades 1, 2 & 3	141 ab

[1] Means followed by the same letter are not significantly different (LSD test, P = 0.05).

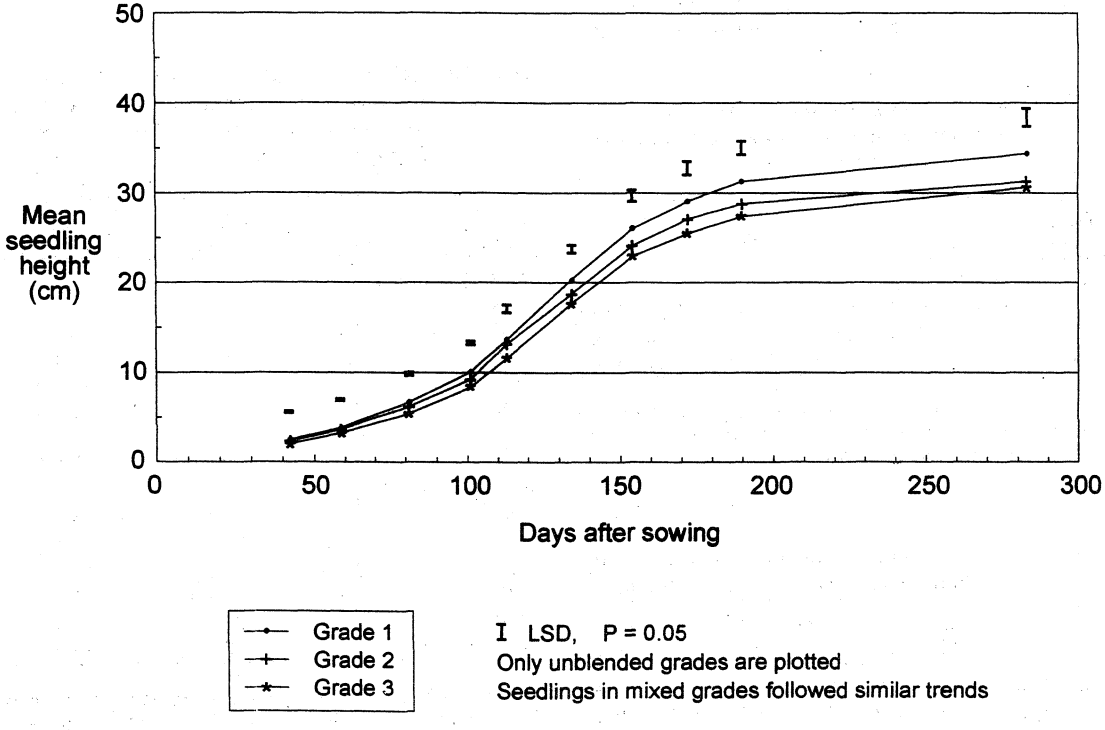

Figure 1. Effect of seed grading by weight on subsequent height growth at NZ FRI Nursery.

Height was measured 5 weeks after sowing and again before conditioning in March. Neither seed imbibition temperature nor aeration had any significant effect on subsequent growth (Table 8).

ii) Effects of stratification or 48 h soak: In both nurseries, stratified seed germinated significantly faster, and seed that had not been pre-treated germinated significantly slower than seed that had been given a 48 h soak (Table 9). Differences in germination became significant 25 d after sowing at the NZ FRI Nursery and after 34 d at Kaingaroa Nursery. Germination was slower at Kaingaroa Nursery, presumably because of cooler soil temperatures (mean air temperature at 0900 hours is 1.8°C cooler at Kaingaroa in October).

Seedlings growing from stratified seed were significantly taller, initially, at both nurseries, because of faster germination (Table 10). The significant differences between treatments disappeared by 89 d after sowing at NZ FRI Nursery and 124 d after sowing at Kaingaroa Nursery, before conditioning had commenced in March.

Seedling top dry weights followed the pattern of seedling heights, with control seedlings being lightest

Table 7. Effect of imbibing temperature and aeration during imbibition on cumulative seed germination.

Days after sowing	Imbibition Temperature (°C)				Aeration	
	10	15	20	25	Yes	No
18	4.8ab[1]	8.8a	5.5ab	3.4b	7.9a	3.4b
22	60.2a	58.0a	52.5a	40.4b	59.5a	46.1b
29	75.0a	72.5a	69.5a	55.5b	71.3a	65.0a
41	76.0a	73.6a	69.5a	56.1b	71.8a	65.8a

[1] Means for a given day from sowing for imbibition temperature or aeration with the same lletter are not significantly different (LSD test, P = 0.05).

Table 8. Effect of seed imbibition temperature and aeration on seedling height growth (cm).

	Imbibition temperature (°C)				Aeration	
	10	15	20	25	Yes	No
Initial height	2.6	2.7	2.6	2.5	2.7	2.6
Final height	27.1	26.7	27.5	26.9	26.7	26.7
Increment	24.5	23.9	24.8	23.5	24.2	24.1

Table 9. Cumulative percentage germination of seed pretreated by 48 h cold soak, stratification, or no pretreatment, sown in two nurseries, NZ FRI and Kaingaroa.

Days from sowing	Cumulative Percentage Germination		
	Control	48 h cold soak	3-week stratification
NZ FRI Nursery			
20	16.1 c[1]	42.0 b	77.8 a
22	49.2 c	66.3 b	82.3 a
25	79.7 a	79.4 a	82.9 a
34	81.8 a	80.5 a	83.1 a
Kaingaroa Nursery			
20	0.0 c	35.8 b	62.6 a
27	36.8 b	80.8 a	82.4 a
34	81.8 a	85.1 a	82.8 a
55	82.2 a	85.5 a	83.1 a

[1] Means with the same letter for a given nursery and sampling day are not significantly different (LSD test, P = 0.05).

Table 10. Effect of seed stratification, 48 h cold soak, or no pre-treatment on subsequent seedling height growth at NZ FRI and Kaingaroa nurseries.

Days from sowing	Cumulative Percentage Germination		
	Control	48 h cold soak	3-week stratification
NZ FRI Nursery			
48	2.6 b[1]	2.6 b	3.0 a
67	3.7 b	3.7 b	4.3 a
89	5.7 a	5.8 a	6.4 a
123	13.2 a	13.5 a	14.2 a
153	22.2 a	22.7 a	23.5 a
193	28.4 a	28.4 a	29.2 a
230	30.0 a	30.0 a	30.8 a
Kaingaroa Nursery			
55	2.9 b	3.0 b	3.3 a
97	6.0 b	6.6 a	6.9 a
124	12.3 b	12.9 a	13.3 a
152	20.6 a	21.3 a	22.3 a
180	26.0 a	27.1 a	27.0 a
217	26.7 a	28.2 a	28.0 a

[1] Means with the same letter for a given nursery and days from sowing are not significantly different (LSD test, P = 0.05).

(Table 11). This was significant only at Kaingaroa Nursery. Control seedlings also had lighter root systems than those from stratified or 48 h soaked seeds. Seedlings from stratified seed were not significantly heavier than those from seed soaked for 48 h at both nurseries.

There was no significant difference in the number of plantable seedlings between treatments within each nursery, but NZ FRI Nursery produced more than Kaingaroa Nursery (172 and 152 seedlings per bed respectively).

Experiment 4. Application of fungicide

Stratified seed germinated significantly faster than seed soaked for 48 h. There was an interaction between seed pretreatment and timing of Thiram application (Table 12). There was no significant difference in final germination if Thiram was applied before or after seed stratification. However, there was a significant effect with 48 h cold soaking, with final germination being higher when Thiram was applied before soaking.

The greatest problem with seedling health was failure to germinate (or emerge). Thiram coating of seed before 48 h cold soaking was the best treatment. There was some bird damage to emerging seedlings, although this did not exceed 6% for any treatment. A small percentage of seedlings were unhealthy or died, but there were no large differences between treatments. Overall, 66.5% of the trees were healthy. The most healthy seedlings were from the treatments coated before stratification or cold soaking.

Seedlings from stratified seed were significantly taller, since they germinated earlier. However, by the end of May, when measurement ceased, the differences were no longer significant. There was no significant differences in dry weight distribution and number of plantable seedlings between any of the treatments.

Table 11. Dry weight distribution of seedlings from NZ FRI and Kaingaroa nurseries.

Days from sowing	Cumulative Percentage Germination		
	Control	48 h cold soak	3-week stratification
NZ FRI Nursery			
Seedling top (g)	8.21 a[1]	8.55 a	8.89 a
Seedling root (g)	1.45 b	1.69 a	1.58 ab
Seedling total (g)	9.67 a	10.24 a	10.47 a
Root/shoot ratio	0.177 b	0.196 a	0.178 b
Kaingaroa Nursery			
Seedling top (g)	5.92 b	7.30 a	7.30 a
Seedling root (g)	1.21 b	1.36 a	1.37 a
Seedling total (g)	7.13 b	8.66 a	8.67 a
Root/shoot ratio	0.204 a	0.187 a	0.188 a

[1] Means with the same letter for a given nursery and variable are not significantly different (LSD test, P = 0.05).

Table 12. Effect of Thiram fungicide applied before or after stratification or 48 h cold soaking on final germination percentage.

Thiram applied	Germination Percentage	
	Stratified seed	48 h cold-soaked seed
before	77 ab[1]	81 a
after	73 bc	72 c

[1] Means followed by the same letter are not significantly different (LSD test, P = 0.05).

Discussion

There was no consistent difference in nursery performance between hand-extracted and machine-extracted seed sown in three nurseries, indicating that current seed extraction methods are not causing significant seed damage.

The results of grading seed have clearly demonstrated that heavier seed gave better seedlings. Grade 1 seed had better germination, and produced much healthier and taller seedlings than Grade 3 seed. The results from Grade 2 seed were intermediate between Grades 1 and 3. When these grades of seed were blended, the same trends occurred, with the results intermediate between the individual grades. Therefore there would be a wider range of seedling heights from blended grades. When germination and percentage of healthy seedlings are considered, most Grade 2 treatments were not significantly worse than Grade 1 treatments. The performance of Grade 3 seed (more than 33,000 seeds/kg) was poor, and use of this seed should be avoided wherever possible.

The significant differences in the performance of different seed grades also support the use of seed grading to obtain more uniform seedlings. Radiata pine seed in New Zealand is graded into several grades at present, and where possible only larger seed should be used for optimum performance. However, the boundary in the number of seeds per kilogram between grades varies each year, depending on the season. Cone size, and therefore

seed size, can vary depending on the growing climate during cone maturation. Poorer germination and height growth can be expected from smaller seed, resulting in fewer plantable seedlings at the nursery gate.

Water temperature for 48 h soaking before sowing should be kept cool. The best results were obtained from soaking at 10°C. Soaking at higher temperatures gave poorer germination results. Water aeration gave faster initial germination, and better final germination, although the differences were not significant for final germination. Aeration could be done by keeping the seed under running water rather than left in a plastic bag or bucket. Running water would also keep imbibition temperatures low (10-14°C in Rotorua).

The main difference between stratification, 48 h soak, and no pretreatment (sowing dry seed) was the speed of germination. This effect was more noticeable at Kaingaroa with its colder climate. Here the times to reach 75% of final germination were 20, 27, and 34 d respectively and 18, 22, and 23 d respectively at NZ FRI Nursery where the difference between the treatments was not so great. Faster germination gives taller seedlings, and also, if the germination period is shorter, more even seedlings. Bird predation should also be less if the germination period is reduced. Treatment differences were not significant by the end of the growing season. The implication from this experiment is that seed should be stratified for cooler soil conditions (either early spring sowing or higher altitude nurseries). Cold soaking is adequate for warmer soil conditions, and no seed pretreatment should be necessary in mild climates. However, since seed does germinate faster and produce larger seedlings when given a 48 h cold soak before sowing, then this should be done as a standard practice.

Germination was improved if Thiram was applied before stratification or cold soaking. Three weeks' stratification speeded up germination, but had a lower overall germination at the end of the assessment time. The seedlings were taller in treatments where the Thiram was applied before either stratification or cold soaking. Seedling health followed the same trends. It is possible that Thiram may have entered the imbibed seed through opened or damaged seed coats and inhibited germination when it was applied after stratification or cold soaking, resulting in smaller seedlings.

Acknowledgments

The authors would like to thank Dr P. Coolbear, Seed Technology Centre, Massey University; Dr D.W. Fountain, School of Biological Sciences, Massey University; and Dr S.O. Hong and Dr C.J.A. Shelbourne, NZ Forest Research Institute, for their very helpful comments and suggestions on this paper.

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