NURSERY STOCK AND FIELD FERTILISER APPLICATION AFFECT EARLY PERFORMANCE OF *PINUS RADIATA* ON A PHOSPHORUS-DEFICIENT SITE IN NORTHLAND

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ABSTRACT

An experiment was established on a phosphorus-deficient site to determine the effects of nursery stock type and fertiliser application (after transplanting) on early growth and survival of 1/0 *Pinus radiata* D.Don seedlings. Three fertiliser treatments were compared: (1) slit-applied diammonium phosphate (DAP; 18 kg N and 20 kg P/ha) at 80 g/tree, (2) Christmas Is. 'A' grade rock phosphate (RP; 16% P) broadcast at 50 kg P/ha, and (3) partially acidulated rock phosphate (PARR; 17% P) broadcast at 50 kg P/ha. Tree stocks given DAP grew best over the first 2 years, but lost the early height advantage in the following 2-year period when stock on PARR- or RP-treated soil outgrew them by c. 0.5 m. After 4 years in the field, the trees with fertiliser were on average 1.8 to 2 times taller than stock without. Container stock maintained its initial 4 cm or so height advantage over bare-root stock for the 4 years of the trial, but cost three times as much to produce. Seedling survival was not affected by fertiliser application after planting, but survival was slightly lower for bare-root seedlings that were initially deficient in nitrogen. Inoculating the soil with freeze-dried spores of *Rhizopogon* spp. had no beneficial effects on seedling performance.

Keywords: nursery practice; seedling quality; diammonium phosphate; rock phosphate; mycorrhizas; nursery costs.

INTRODUCTION

On phosphorus-deficient soils in New Zealand, fertiliser treatment is required to obtain acceptable growth of *P. radiata* (Ballard 1987). Even with phosphorus applied, seedling growth is usually delayed somewhat after transplanting. This delay appears relatively short where diammonium phosphate (DAP) is applied but is distinctly longer where rock phosphate (RP) is used. With high rates of RP (around 1 tonne/ha ~ 120 to 150 kg P/ha) this lag may not necessarily be a problem. By 3 years after transplanting, trees treated with RP appear to "catch up" with DAP-treated trees that are not treated again. However, at lower rates of RP, this lag phase could be of critical importance. Some organisations now use a partly acidulated reactive phosphate rock (PARR) which combines a readily available fertiliser with a slow-reacting source of P (Smale 1991).

Although initial growth of certain conifer species can be related to nursery nutrition (van den Driessche 1991; Timmer & Munson 1991; Malik & Timmer 1996; Irwin *et al.* 1998), studies of *P. radiata* have shown no positive growth response to additional nursery fertiliser treatment (Benson & Shepherd 1977; Hunter 1991). This might be due to a lack of outplanting studies where seedling nutrition differs at time of transplanting. The majority of published studies concerning the effects of nitrogen fertiliser in the nursery on growth of *P. radiata* seedlings have involved hydroponic and pot studies (Will 1960, 1971; Knight & Will 1971; Knight 1973).

To date, only two published studies have tested for interactions between nursery treatments and field nutrition of *P. radiata* (Cellier *et al.* 1985; Hunter 1991). Therefore, this study was established in 1986 to test for potential interactions between five nursery stocks and five fertiliser treatments in the field.

METHODS

Nursery Stock

Planting stock used included three 1/0 (1 year in the seedbed) bare-root stocks and two container-grown stocks. All seedlings were produced at the Sweetwater Nursery at Awanui near Kaitaia. Various fertiliser treatments were applied to non-replicated plots in bare-root (BR) seedbeds and three plots were selected based on the nutritional status of shoots in mid-August (Table 1). One plot of seedlings (stock BR) was from normal nursery beds where shoots were not deficient in nitrogen (N). This population was produced using both pre-sowing applications of fertiliser (DAP at 250 kg/ha, sulphate of potash at 250 kg/ha, and agricultural lime at 1000 kg/ha) and five foliar applications of urea (5%) solution (amount applied not known).

TABLE 1–Seasonal changes in nutrient concentrations (mg/g dry weight of shoots) of bare-root (BR) and container-grown (C) seedlings at the Sweetwater Nursery during the 1986 growing season.

Nursery stock	Nitrogen				Phosphorus			
	March	May	June	August	March	May	June	August
BR-N1	28	19	13	9	4.2	3.4	2.3	1.7
BR-N2	24	23	16	9	5.2	2.7	2.8	2.5
BR	—	—	19	22	—	—	3.3	2.7
C	28	17	17	—	3.0	3.0	3.0	—
C+RP	29	17	17	—	2.9	2.8	2.8	—

A second plot (stock BR-N1) was selected because seedling shoots were deficient in nitrogen. This stock was smaller than the other bare-root stocks. Seedlings from this plot were treated with 250 kg DAP/ha, 250 kg sulphate of potash/ha, and 1000 kg lime/ha. A third plot (stock BR-N2) was also deficient in nitrogen but these seedlings were approximately the same size as the BR stock. Seedlings from this treatment were treated with isobutylidene diurea (IBDU) at 500 kg/ha, 250 kg DAP/ha, 250 kg sulphate of potash/ha, and 1000 kg agricultural lime/ha.

Two populations of seedlings were grown in black polyethylene bags (approximately 9 × 9 × 10 cm) at approximately 111 bags/m^2. The potting medium in both populations contained the following products: 1.6 kg Osmocote®(3–4 month)/m^3; 1.6 kg Osmocote®(8–9 month)/m^3; 1.6 kg Osmocote®(12–14 month)/m^3; 3 kg dolomite/m^3; 0.5 kgMicromax®/m^3; 0.1 kg Terrazole® fungicide/m^3. The potting medium in half the containers (stock C) contained no RP. Potting medium in the other half (stock C+RP) received 2 kg RP/m^3.

Field Treatments

All fertilisers were applied after planting. The DAP treatment was applied in a spade slit next to the seedling (80 g/tree at planting); this amounted to c. 18 kg N/ha and 20 kg P/ha. A second treatment contained a granular, partially acidulated, reactive phosphate rock (PARR) from North Carolina, United States of America. PARR phosphate (17% P) is a well-granulated product with about half its phosphorus in the rock phosphate form. PARR was applied broadcast at a rate of 50 kg P/ha at planting. A third treatment contained RP from Christmas Island (Nauru A grade; 16% P) and was applied broadcast at a rate of 50 kg P/ha. A fourth treatment combined RP at 50 kg P/ha with a mycorrhizal treatment (RP+M). Fruiting bodies of *Rhizopogon rubescens* Tul. were collected in the autumn of 1986 and were freeze-dried. After the seedlings were planted, the soil under each was injected with 25 ml spore suspension (approximately 187 mg inoculum). The mycorrhizal suspension was prepared by adding 150 g powdered sporocarp material to 20 ℓ water. A fifth set of seedlings without fertiliser served as controls.

Plot Design

The study was a 5 × 5 factorial with four replications (100 plots total). Each plot contained 36 trees (four rows per plot and nine trees per row). The spacing was 1.66 × 4.87 m. The interior 14 trees served as measurement trees. Seedlings were planted out on 3 September and heights (H) and groundline diameters (GLD) were measured on 9 September 1986. Heights were subsequently recorded in March and August 1987, June 1988, and August 1990. GLD was recorded in August 1987 and June 1988. A volume index was calculated for each tree by the formula (GLD^2 × H). Foliage samples were collected from all plots in March 1987 and were sent to the Forest Research Institute at Rotorua for analysis. Foliage samples were dried to constant weight then ground. Foliage samples were digested using a sulphuric acid/lithium sulphate/selenium digest "brew" + hydrogen peroxide. Foliar nitrogen concentration was determined by the indophenol blue automated colorimetric method. Foliar phosphorus concentration was determined by the vanadomolybdate automated colorimetric method.

The site was located in the Te Kao region of the Aupouri Peninsula, Northland. The soil type was a Rangiuru clay (grey-brown granular clay on a light-brown strongly granular clay). The soil also contained some greenish sticky granular clay. The pH of the surface (0–20 cm depth) was 5.0 and the soil contained no available phosphorus (Bray II). The parent material was andesite. Prior to planting, the site had been ripped and bedded.

Statistical Analysis

The trial was assessed using analysis of variance (ANOVA). Duncan's New Multiple Range Test was used to compare the effect of experimental treatments on seedling performance. Linear regression analyses (SAS 1988) were used to examine relationships between seedling growth and two independent variables (RCD and nitrogen concentration). Analyses were performed on plot means using SAS software.

Since early growth is often related to initial seedling diameter and height (Albert *et al.* 1980; Mason *et al.* 1996; Richardson *et al.* 1996; Zwolinski *et al.* 1996), relationships between groundline diameter (GLD) and growth were examined. Using means for five nursery stocks (n=5), the regression of initial GLD and fourth-year height (H) was: H = 192 + 14.8*GLD ($r^2 = 0.75$). Therefore, a covariance analysis was performed (using initial tree diameter as a covariate) to examine the nature of the treatment effects (Snedecor & Cochran 1967). In previous trials, it has proved useful to see whether treatment differences remain, or whether they become insignificant, after adjusting for seedling size (South *et al.* 1989).

RESULTS

There were initial differences in seedling morphology among the five nursery stocks (Table 2). On average, BR-N1 seedlings were smaller in height and ground-line diameter than other seedlings. In addition, seedlings grown in containers were initially 3 to 9 cm taller than bare-root seedlings (Table 3).

Seedling survival after 4 years was lower for seedling stocks that were deficient in nitrogen (Table 3). Fertiliser application after planting and mycorrhizal inoculation after planting did not affect survival. By March (approximately 6 months after planting out), foliar nutrition was similar for four nursery stocks (Table 4). Only the BR stock differed significantly from the other four stock types, with slightly lower shoot concentrations of nitrogen and phosphorus. Overall, seedling shoots contained 16 mg N/g dry weight and 1.2 mg P/g dry weight. The levels of phosphorus in the foliage indicated seedling roots had formed mycorrhizas.

Initial growth differed among the five nursery stocks. Diameter and height growth during the first 2 years after transplanting were lowest for bare-root seedlings that were nitrogen deficient at time of planting out. Overall, the container-grown stock grew more in diameter than the bare-root stock. Adding RP to the growing media did not affect the size or early field performance of container-grown seedlings (Table 3).

Application of phosphorus fertiliser in the field had a strong effect on seedling nutrition and growth. Seedlings treated with DAP or PARR had higher phosphorus concentrations than those treated with RP (Table 4). Although early growth was greater with DAP (likely due to increased nitrogen concentrations), the effect was ephemeral. Growth after the second year was less for seedlings receiving DAP than for seedlings growing in plots treated with RP or PARR. After 4 years in the field, seedlings in control plots were about half as tall as seedlings treated with phosphorus.

Interactions between nursery stock and field treatments occurred for first-year diameter growth and for stem volume after two growing seasons (Table 2). These interactions appeared to be due to changes in scale as opposed to changes in rank (Fig. 1). Overall, both

TABLE 2–Analysis of variance (Anova) and analysis of covariance (Covar) for various performance attributes.

Source	Initial height	Height increment Yr 1	Height increment Yr 2	Height increment Yr 3+4	Height Yr 4	Initial dia.	Dia. increment Yr 1	Dia. increment Yr 2	Dia. Yr 2	Vol index	Survival
	Probability of a greater F-value										
Anova											
Block	0.0001	0.1660	0.3113	0.0335	0.025	0.042	0.1594	0.0001	0.0001	0.0004	0.0041
Nursery stock	0.0001	0.0001	0.0001	0.8757	0.235	0.001	0.0001	0.0001	0.0001	0.0001	0.0001
Field treat	0.5709	0.0001	0.0001	0.0001	0.001	0.104	0.0001	0.0001	0.0001	0.0001	0.4139
Nursery × field	0.8308	0.5585	0.4708	0.3512	0.385	0.487	0.0172	0.3343	0.3110	0.0328	0.7498
Covar											
Block	0.0001	0.1690	0.3109	0.0353	0.0265	—	0.1642	0.0001	0.0001	0.0001	0.0044
Initial GLD	0.0001	0.0001	0.0002	0.9845	0.0498	—	0.0001	0.0001	0.0001	0.0001	0.0005
Nursery stock	0.0001	0.0001	0.0506	0.8869	0.6916	—	0.0001	0.0001	0.0001	0.0001	0.0057
Field treat	0.7040	0.0001	0.0001	0.0001	0.0001	—	0.0001	0.0001	0.0001	0.0001	0.3975
Nursery × field	0.9162	0.5480	0.4539	0.3619	0.4015	—	0.0263	0.3297	0.2400	0.0066	0.8192

TABLE 3–Effect of *P. radiata* nursery stock and field fertiliser treatment on initial height and diameter, height growth, diameter growth, height (age 4), diameter (age 2), volume index (age 2), and survival (age 4).

Treatment	Initial height (cm)	Height increment Yr 1 (cm)	Height increment Yr 2 (cm)	Height increment Yr 3+4 (cm)	Height Yr 4 (cm)	Initial dia. (mm)	Dia. increment Yr 1 (mm)	Dia. increment Yr 2 (mm)	Dia. Yr 2 (mm)	Vol index (m^3/ha)	Survival (%)
Nursery stock											
BR-N1	25 c	22 c	42 c	180	269	5.2 c	7.0 d	15.7 c	28.0 c	1.2 d	87 b
BR-N2	31 b	24 c	47 bc	179	281	6.6 ab	8.6 c	17.0 bc	32.3 b	1.7 c	88 b
BR	30 b	29 b	52 ab	183	294	6.4 b	10.3 b	18.4 b	35.2 b	2.3 b	94 a
C	34 a	33 a	55 a	176	298	6.8 a	12.5 a	21.8 a	41.2 a	3.0 a	99 a
C+RP	34 a	31 ab	53 ab	171	289	6.6 ab	13.1 a	21.9 a	41.5 a	3.1 a	96 a
Field treatments											
Control	31	18 c	26 c	88 c	164 b	6.3	6.7 c	10.4 d	23.4 d	0.7 c	91
Rock	31	26 b	54 b	213 a	324 a	6.2	9.2 b	20.0 bc	35.4 bc	2.0 b	95
PARR	31	28 b	52 b	217 a	328 a	6.5	9.6 b	21.8 ab	38.0 b	2.3 b	95
DAP	31	41 a	65 a	165 b	301 a	6.2	17.0 a	23.3 a	46.7 a	4.3 a	92
Rock + M	31	26 b	51 b	205 a	313 a	6.3	9.0 b	19.3 c	34.7 c	1.9 b	92

Values within a column/group combination followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's New Multiple Range Test. Note: when a treatment effect was not significant, the multiple comparison test was not conducted.

TABLE 4–Nutrient status of seedlings 6 months after planting out (samples collected in March 1987).

Treatment	Nitrogen	Phosphorus
	------------- mg/g dry	foliage ---------------
Stock types		
BR-N1	16.2 a	1.17 b
BR-N2	16.3 a	1.19 ab
BR	15.5 b	1.10 c
C	16.0 a	1.25 a
C + RP	16.4 a	1.21 ab
Field treatments		
Control	15.8 b	0.98 c
Rock phosphate	15.5 b	1.16 b
PARR	15.7 b	1.30 a
DAP	17.6 a	1.29 a
Rock phosphate + M	15.8 b	1.16 b

Analysis of variance indicates significant replication (p=0.0001), stock type (p=0.0078), and fertiliser (p=0.0001) effects. The nursery × field interaction term was not significant (p=0.31). Values within a column/group combination followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's New Multiple Range Test.

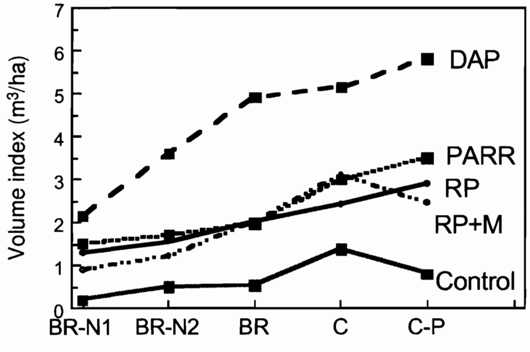

FIG. 1–Effect of nursery stock type and field fertiliser treatment on volume index of *Pinus radiata* after 2 years in the field. This interaction (p=0.03) appears to be of scale rather than rank. Fertiliser treatments are: control = no fertiliser after transplanting; PARR = partially acidulated reactive phosphate rock; DAP = diammonium phosphate; RP = rock phosphate; RP+M = rock phosphate plus mycorrhizal spores. Nursery stocks are: BR-N1 = bare root seedlings deficient in nitrogen: BR-N2 = bare root seedlings treated with IBDU and deficient in nitrogen; BR = bare root seedlings not deficient in nitrogen; C = container stock; CP = container stock with rock phosphate in the potting media.

container stocks and the BR stock responded more to the DAP treatment than stocks that were deficient in nitrogen.

DISCUSSION

Nursery Stocks

Initial GLD accounted for a significant amount of variation for almost all variables (Table 2) but it did not appreciably change the conclusions. These analyses suggest differences in performance of nursery stocks were not due solely to differences in initial GLD. Some of the performance differences might be explained by seedling nutrition at lifting.

Seedlings of *P. radiata* with less than 12 mg N/g dry shoot are considered nitrogen deficient (Knight 1978; Will 1985). For the Te Kao study, seedlings with 9 mg N/g dry shoot had 6% to 7% less survival than seedlings with 22 mg N/g dry shoot (Table 3). Similar results have been reported by others. Hunter (1991) found that *P. radiata* seedlings treated with fertiliser while being conditioned in the nursery had higher survival and higher nutrient concentrations at lifting (18 mg N/g and 1.6 mg P/g) than seedlings not receiving fertiliser during conditioning (13 mg N/g and 1.1 mg P/g). One study with *P. sylvestris* L. (Rikala & Repo 1997) indicated that needles with the highest nutrient concentration (> 12 mg N/g) had the least damage in an artificially produced frost. Although Menzies *et al.* (1981) found no correlation between nitrogen concentration and frost tolerance, Knight (1991) suggested that light applications of nitrogen made late in the season might reduce susceptibility to autumn frosts.

Research trials often exhibit high initial survival and this could mask differences in survival potential between nursery stocks. For example, high first-year survival (97%) of seedlings with only 10 mg N/g shoot has been reported (P.J.Knight unpubl. data). Therefore, under some conditions, seedlings that are deficient in nitrogen can survive well. After 6 months in the field, their nitrogen concentration may be no different from that of seedlings that received adequate fertiliser (Table 4). However, results from the Te Kao study suggest that in some years nitrogen nutrition of *P. radiata* seedlings in the nursery can affect survival. Higher survival might result if (1) root-growth potential was increased by additional application of fertiliser in the nursery (Hunter 1991; Williams & South 1995), and (2) seedlings were planted out at a time when initial survival depends on rapid initial root growth.

Benson & Shepherd (1977) and Hunter (1991) reported that extra nursery applications of fertiliser did not increase initial growth after planting. We are aware of only one report that shows a relationship between nitrogen status of *P. radiata* at lifting and growth after outplanting (Knight unpubl. data). Results from Te Kao support the observations by Knight and suggest that growth of nitrogen-deficient seedlings during the first year can be 5 to 7 cm less than that of seedlings with 22 mg N/g. These findings are consistent with those for other pine species (Larsen *et al.* 1988, 1989; van den Driessche 1991; Irwin *et al.* 1998).

Currently, the recommended range in nitrogen concentration for an acceptable *P. radiata* seedling is quite narrow. Foliage with less than 14 mg N/g is considered to be deficient and levels exceeding 18 mg N/g are believed to be undesirable (Knight 1978). However, this study casts some doubt on the belief that 22 mg N/g is too high. In fact, at planting, the BR N/P ratio of this stock was only 8 (as opposed to a N/P ratio of 14 in March of 1987). If a quotient of about 10 is "normal" for *P. radiata* seedlings, this suggests the BR seedlings were not excessively high in nitrogen at planting. Perhaps future nursery research should re-evaluate the current nutritional standards for nursery stock to see if the range for acceptable nitrogen concentration should be widened.

Relationship between Nitrogen Concentration and Early Growth

Simple linear regressions were made to determine relationships between diameter at planting, nitrogen concentration 6 months after planting, and early field growth. The effect of foliar nitrogen concentration on growth appears to be ephemeral. Although height growth during the first 2 years was positively related to nitrogen concentration in the field, it was negatively related to nitrogen concentration in the third and fourth years (Table 5). However, the results from these regressions were influenced by the treatments. The DAP treatment initially increased nitrogen concentrations (sampled in March 1987) but height growth was less from DAP during the third and fourth years. For this reason, the equations in Table 5 should not be used for predictive purposes.

TABLE 5–Relationship between growth and initial groundline diameter (GLD) and foliar nitrogen concentration (N) in March of 1987 for seedlings that received phosphorus fertiliser after planting out (n=80).

Equation		Intercept	GLD	Nitrogen	Adj r^2
		------------	P > |T|	----------	
Diameter increment—Year 1 (mm)	= –31 +1.7GLD +2.0N	0.0001	0.004	0.0001	0.40
Diameter increment—Year 2 (mm)	= –21 +2.6GLD +1.6N	0.001	0.0001	0.0001	0.35
Height increment—Year 1 (cm)	= –44 +3.6GLD +3.2N	0.0003	0.004	0.0001	0.33
Height increment—Year 2 (cm)	= –12 +3.4GLD +2.9N	0.43	0.02	0.0003	0.19
Height increment—Years 3 + 4 (cm)	= 340 –2.5GLD –7.7N	0.0001	0.69	0.02	0.04

Nitrogen concentrations ranged from 14 to 19 mg/g foliage (mean 16.2). GLD ranged from 4.4 to 8.3 mm (mean 6.3).

Source of Phosphorus

The rapid growth response observed from DAP may have been due partly to the application of about 18 kg N/ha. However, the extra height growth from DAP was observed only during the first 2 years in the field. In fact, seedlings treated with DAP grew less in height during the third and fourth growing seasons than those in the PARR or RP treatments. After 4 years in the field, seedlings treated with RP were as tall as or taller than DAP-treated seedlings. There was no significant difference in growth between the PARR and the untreated RP seedlings. Other researchers have also reported no significant differences in response to different types of RP (Hunter & Graham 1983).

Mycorrhizal Treatment

Successful inoculations of pine seed with *Rhizopogon* spp. spores have been achieved in the field (Davis *et al.* 1996) as well as in the nursery (Donald 1975; Theodorou & Benson 1983; Castellano & Trappe 1985). In contrast, attempts to improve seedling performance by applying mycorrhizal spores to tree roots at time of outplanting have failed. Alvarez & Trappe (1983) found that dusting roots of conifers with mycorrhizal spores reduced seedling survival in some cases (possibly through desiccation of roots). Treating roots with a slurry containing spores improved neither survival nor growth (Pilz & Znerold 1986). The authors concluded the application of "...spores to a seedling's roots immediately preceding outplanting appears to be ineffective."

There could be several reasons for the lack of response of transplants to spore inoculations at Te Kao. Seedlings produced at the Sweetwater Nursery were likely infected with *Rhizopogon rubescens* and *Thelephora terrestris* Ehrh. ex Fr. (Chu-Chou & Grace 1990). As seedling roots at planting are invariably mycorrhizal, adding more spores to the rhizosphere in the hope of improving seedling performance might prove futile. It is possible the injected spores were simply outnumbered by resident fungi in the soil. When background levels of naturally occurring mycorrhizal fungi are abundant in the soil, a high rate of spore inoculation will likely be required to achieve infection with *R. rubescens* (Theodorou & Skinner 1976; Castellano & Trappe 1985). Thus far, researchers have not been able to demonstrate any positive effect with spore inoculation at time of transplanting seedlings. Alternatively, freeze-drying of fruiting bodies and storage at room temperature might have reduced spore viability (Theodorou & Bowen 1973).

Costs

Costs are often the deciding factor when choosing a treatment. Typically, costs associated with producing seedlings in black polyethylene bags are higher than for bare-root seedlings. In New Zealand, 1/0 bare-root seedlings that average 6 mm at the root collar can be produced for about $0.20/seedling while similar seedlings produced in polyethylene bags (PB 1.5) may cost $0.60/seedling. Although the container-grown seedlings in this study (C) started out 4 cm taller than bare-root seedlings with adequate fertiliser (BR), the difference in height (4 cm) remained the same after four growing seasons in the field. Such a difference in height would hardly be worth spending an additional $492/ha (1230 × $0.40).

At time of writing, the cost of DAP at 98 kg/ha (@ $500/tonne) is about $49/ha. In comparison, 294 kg PARR/ha would cost about $88/ha (@ $300/tonne), and 294 kg RP/ha (@ $180/tonne) would cost about $53/ha. The DAP treatment provides 30 kg/ha less phosphorus than the other treatments but the DAP provides more nitrogen (18 kg/ha).

Some managers of bare-root nurseries have considered using slow-release fertilisers. The release of nitrogen from IBDU is slower than from urea or DAP. However, slower is not necessarily better in comparison with periodic applications of soluble fertilisers. In some bare-root nurseries, a slow-release fertiliser may be less effective than readily soluble sources of nitrogen (van den Driessche 1988). IBDU is certainly more costly than urea or ammonium nitrate. On a weight basis, IBDU costs about $4/kg N while urea costs about $0.80/kg N. Therefore, 155 kg N/ha, applied as IBDU, would cost $620/ha in comparison to $124/ha for urea. At the Sweetwater Nursery, seedlings treated with conventional fertilisers had higher nitrogen status at lifting and were just as large as seedlings treated with IBDU. A disadvantage of slow-release fertilisers for bare-root nurseries is that the nursery manager loses control over the timing of nitrogen release. The release rate of IBDU also depends on the media (Goh 1979). Although some claim that IBDU is ideal for bare-root nursery beds, the cost and results from the Sweetwater Nursery cast some doubt on the validity of this statement.

The cost of inoculation with mycorrhizal spores at time of planting can be estimated using commercial products currently sold for this purpose in the United States. The cost is estimated at $0.07 /seedling. Where 1230 seedlings are established per hectare, this would amount to about $86/ha. For this study, this additional expense would not be justified.

In summary, the most cost-effective treatment combination for this study was adding RP at planting to bare-root seedlings that had 22 mg N/g dry shoot. This combination produced seedlings that achieved 93% survival with an average fourth-year height of 326 cm. Although performance of this stock treated with PARR was just as good (95% survival:

326 cm), the cost of this fertiliser is higher than RP ($35/ha more). However, PARR is a well-granulated product and is easier to spread than finely ground RP.

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