Nursery Regimes Affect Seedling Size and Outplanting Performance of 1+0 Ponderosa Pine

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Sloan, John. 1994. Nursery Regimes Affect Seedling Size and Outplanting Performance of 1+0 Ponderosa Pine. In Landis, T.D.; Dumroese, R.K., technical coordinators. Proceedings, Forest and Conservation Nursery Associations. 1994, July 11-14; Williamsburg, VA. Gen. Tech. Rep. RM-GTR-257. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 169-181. Available at: http://www.fcnanet.org/proceedings/1994/sloan1.pdf

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INTRODUCTION

Ponderosa pine seedlings are successfully grown to outplanting specifications in two years at Lucky Peak Nursery in Boise, Idaho. Under favorable conditions, these bareroot seedling can grow very large shoots. However, the perception is that after just one year in the nursery, the trees have not grown large enough tops to meet specifications.

Nursery cultural practices can play a big part in seedling morphology and physiology. Fertilization and spacing both influence seedling nutrition. Soil fertility is very important to nursery stock production and, at Lucky Peak Nursery, nitrogen is the nutrient most limiting to growth. Many studies have shown that nitrogen fertilization can increase seedling size (Canham and McCavish 1981, Cochran 1972, Pharis and Kramer 1964, van den Driessche 1982). Other studies have documented that shoot/root ratios can be adversely affected by overfertilization with nitrogen (Steinbrenner and Rediske 1964, Vlamis and Evans 1957). Increased spacing in the seedbed up to an optimum, increases the size of 2+0 seedlings (Buse and Day 1989, Mexal 1980, Richards and others 1973, van den Driessche 1984).

It has been shown that undercutting seedlings in the nursery bed modifies the morphology of planting stock (Aldhous 1972, Buse and Day 1989, Cleary and others 1978, Duryea and Lavender 1982, Hobbs and others 1987, van den Driessche 1983).

The ability to produce 1+0 ponderosa pine would give Lucky Peak Nursery and their customers more flexibility. It would reduce the lead time required to produce trees for planting after a wild fire or harvesting. One-year-old seedlings cost less to grow, lift, grade, pack, store, ship, and plant. They take less water, fertilizer, weeding, and inventory. It would allow the nursery more frequent opportunities to fallow fields or conduct operations to maintain and improve drainage and soil aeration (Jenkinson and others 1993).

My goal was to produce 1+0 ponderosa pine seedings that could withstand the harsh conditions of Intermountain planting sites. I chose to modify the seedlings using three cultural practices: fertilization, density management, and root pruning. In this paper, I will compare the morphological characteristics and the outplanting performance of seedlings grown for one year in three regimes of nitrogen fertilization, at four density

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levels, and three regimes of root pruning.

The first objective was to determine the optimum cultural regime to maximize the height, caliper, and root mass of one-year-old ponderosa pine at Lucky Peak Nursery. A second objective was to compare outplanted 1+0 seedlings with 2+0 seedlings of the same seed source.

METHODS

The seed came from the upper portion of the ponderosa pine's elevation range (elevation 5500 feet or 1676 meters) on the Boise National Forest in central Idaho. The 1+0 test was sown in nursery beds in close proximity to where the same seedlot was growing as 2+0 stock. The 2+0 seedlings had a one-year head start at the time the 1+0 seedlings were sown. All trees were lifted at the same time.

Differences between treatments were determined using the analysis of variance technique and the Newman-Keuls comparison of means. All statistical differences were at the 95 percent level of confidence.

Nursery Treatments

The seed for the 1+0 stock was sown on May 8, 1990. Two experimental blocks were established, each containing three root pruning treatment sections randomly arranged. Within the root pruning sections were 12 randomly arranged fertilizer/ spacing plots, three feet (.9 m) long. This created 36 different cultural combinations, replicated twice.

Emerged seedlings were thinned to one of four spacing levels on June 15. The spacing levels included: **S1**) no thinning: average of 17.7 seedlings per ft^2 ($190.5/m^2$), **S2**) one seedling left where two or more seedlings came up in a clump (doubles): average of 15.1 seedlings per ft^2 ($162.5/m^2$), **S3**) seedlings thinned to 4cm spacing: average of 11.1 seedlings per ft^2 ($119.5/m^2$), and **S4**) seedling thinned to 6cm spacing: average of 8.3 seedlings per ft^2 ($89.3/m^2$).

The three fertilizer treatments were: **F1**) the normal fertilizer applications of presowing treble super phosphate (0-46-0) at 180 lbs/ac (202 kg/ha)(82.8 lb. of phosphorus/ac.) and ammonium nitrate (34-0-0) at 120 lbs/ac (136 kg/ha)(40.8 lb. of nitrogen/ ac) and top dressing of ammonium nitrate at 125 lbs/ac (140 kg/ha)(42.5 lb. of nitrogen/ac) twice, **F2**) normal presowing rates and twice the normal top dressing of ammonium nitrate (125 lbs/ac 4 times), and **F3**) normal presowing rates and three times the normal top dressing of ammonium nitrate (125 lbs/ac 6 times).

The three root pruning treatments were: **RP1)** no undercutting until the lifting date, **RP2)** seedlings undercut at 8 inches on August 9, and **RP3)** seedlings undercut at 8 inches on August 9 and undercut at 12 inches on September 25.

Other cultural practices were carried out by nursery personnel as usual. Each plot was lifted as soon as the ground thawed the next spring (March 8, 1991). A sample from the 2+0 nursery bed was lifted at the same time. Trees were stored in a cooler at 1° C until they were measured and again until planting.

Measurements

Seedlings were randomly selected for each test. From each 1+0 plot, 15 and 10 seedlings were used for outplanting and root growth capacity tests, respectively. Seedlings from the two blocks were combined to double the number of test trees. The 2+0 seedlings were divided into three groups based on the seedling caliper at the root collar: large(7-10 mm), medium(5-7 mm), and small (4-5 mm). This was to determine if size or age was responsible for any differences in performance between 1+0 and 2+0 seedlings. Height to the nearest cm and caliper to the nearest .01 mm was measured on all trees as was top and root volumes to the nearest .1 ml. Top and root volumes were measured by water displacement on a scale. Shoot/root ratios were based on these top and root volume measurements. I maintained the temperatures of air below 15° C and water below 10° C during sorting and measurements in order to minimize seedling stress. Only seedlings which were damaged in the lifting process or those which lacked a healthy green color were culled. Size was not a factor.

Root growth capacity tests were conducted with the root systems suspended in mist chambers for 14 days. The mist chamber temperatures were maintained at 23° C.

Outplanting test

The seedlings were planted April 22, 1991 in three different blocks on a site within the Boise National Forest. The second and third blocks were harsher and drier than the previous one because the soil was shallower. The first block was in a Douglas-fir/white spirea *(Pseudotsuga menziesii/Spirea betulifolia)* habitat type, the second and third blocks supported a Douglas-fir/elk sedge *(Pseudotsuga menziesii/Carex geyeri)* habitat type. Seedlings were rolled in wet burlap the day before planting and were acclimated at 50° for 18 hours.

Seedlings were spaced six feet apart within and between rows. Each planting spot was hand scalped to clear vegetation and debris in a 2-foot square area. The seedlings were side-hole planted in auger holes under good weather conditions for planting. Each block contained 390 randomly arranged seedlings, ten from each nursery cultural treatment combination and the three 2+0 seedling groups. Each tree planter planted an equal number of seedlings from each treatment.

RESULTS

1+0 Seedling Size

Root pruning in the nursery bed tended to reduce seedling height, top and root volume, caliper, shoot/root ratio, and increase root growth potential. Increased nitrogen fertilization in the nursery tended to increase height, caliper, shoot and root volume, and decrease root growth potential. Increased spacing increased height, caliper, shoot and root volume, and shoot/root ratio (Tables 1 and 2).

In figure 1 we see an example of the interaction affect of fertilizer and spacing on root volume. Under the 1x and 2x fertilizer regimes, the seedlings responded to each increase in spacing and fertilizer with a larger root volume. However, under the 3x fertilizer regime root volumes did not increase further and at the wide spacing the root volume began to decline.

Six individual treatments produced seedlings with average heights above 8 cm. These all came from the plots which were not root pruned. Seven treatment

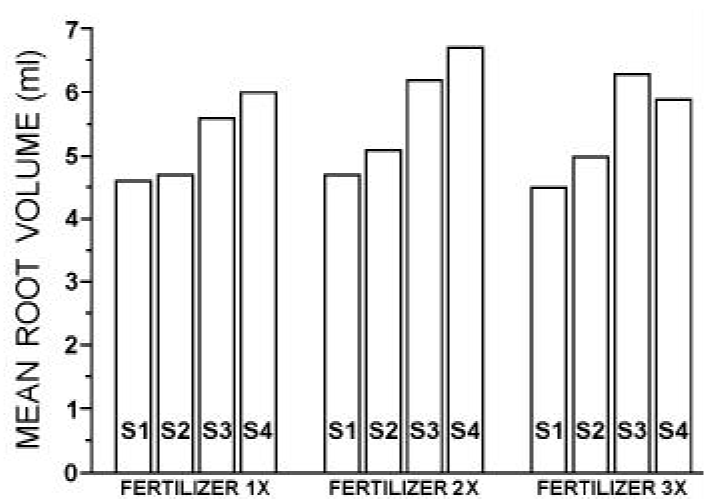

Figure 1. An example of how fertilizer and space affected size (in this case, root volume) of 1+0 ponderosa pine seedlings. 1X indicates normal rates of application of ammonium nitrate, 2X indicates twice the normal application of ammonium nitrate, and 3X indicates tree time the rate of ammonium nitrate. S1 plots were unthinned. Successive plots were less dense up to S4 where the seedlings were spaced 6 cm apart within the rows.

Table 1. Size and root growth capacity for ponderosa pine seedlings. The 1+0 seedlings are divided by treatment; the 2+0 seedlings are divided by size class. Values followed by different letters are significantly different at the 95 percent level of confidence. Values followed by the same letter or no letter are not significantly different.

Treatment	Mean Height (cm)	Mean Caliper (mm)	Shoot Volume (ml)	Root Volume (ml)	Total Volume (ml)	Mean >no. Roots >1.5 cm	Length of 3 Longest Roots (cm)	Short Root Class
F1	7.3ab	3.9a	5.3a	5.2a	10.5s	7.4b	13.0c	4.1a
F2	7.7b	4.1b	6.2b	5.9b	12.1b	6.8b	10.9b	4.4b
F3	7.2a	4.2b	5.9b	5.9b	11.8b	4.1a	7.2a	4.3ab
S1	7.2	3.6a	4.5a	4.6a	5.1a	5.7	10.5	4.2
S2	7.4	3.9b	5.4b	5.3b	10.7b	6.3	10.8	4.3
S3	7.7	4.3c	6.5c	6.2c	12.7c	5.7	10.2	4.3
S4	7.3	4.4d	6.7c	6.5c	13.2c	6.7	10.0	4.3
RP1	8.3c	4.4a	6.6c	6.2b	12.8c	4.0a	8.6a	3.8a
RP2	6.5a	3.8b	4.9a	5.3a	10.2a	5.5b	9.8a	4.5b
RP3	7.4b	4.0c	5.8b	5.5a	11.3b	8.7c	12.7b	4.4b
1+0 AVE	7.4	4.0	5.8	5.7	11.5	6.1	10.4	4.3
2+0								
Small	9.2a	3.9a	8.7a	5.3a	14.0a	15.1a	17.1	4.6
Medium	11.7b	5.3b	15.9b	8.9b	24.8b	22.6b	18.3	4.9
Large	16.0c	7.7c	31.4c	16.9c	48.3c	21.0b	18.6	4.8

combinations produced average calipers above 4 mm. All but one came from plots which were not root pruned. Only four treatment combinations grew seedlings with calipers above 4 mm and heights above 8 cm. None of the treatments included root pruning; two received 2x nitrogen and two received 3x; spacings included all but the densest one (Table 3).

Comparison of 1+0 and 2+0 seedlings

The average caliper and root volume for the small 2+0 size class was very close to the average 1+0 caliper. The average height and shoot volume of the small 2+0s were similar to the very largest 1+0 seedlings. This made the shoot/root ratio of the small 2+0 seedlings about 50 percent larger than 1+0s. The trees in the medium and large 2+0 size classes were larger than those of the small class and the 1+0 seedlings in every morphological characteristic. Between the three 2+0 size classes, there was very little difference in shoot/root ratio (Table 2). The root growth capacity was higher for the 2+0 seedlings but differed little between the size classes (Table 1).

Outplanting

The overall first-year outplanting survival of the 1+0 seedlings was 57 percent, compared to 68 percent for the 2+0 seedlings after one growing season. The 1+0 survival ranged from 33 to 80 percent for different treatments. For 2+0 seedlings, the range was from 47 percent (medium size class) up to 83 percent (small size class).

Seedling survival dropped from the first block to the second and fell still more in the third block. The differences were due to shallower soils (Figure 2). At first glance, none of the nursery

Table 2. Measured means for morphological characteristics of ponderosa pine seedlings planted on the Boise National Forest. The 1+0 seedlings are divided by treatment; the 2+0 seedlings are divided by size class. Values followed by different letters are statistically different at the 95 percent level of confidence.

Treatment	Shoot Volume (ml)	Root Volume (ml)	Shoot/ Root Ratio	Mean Height (cm)	Mean Caliper (mm)	First-year Survival	First-year Height (cm)	Mean Growth
F1	5.4a	5.2a	1.05a	7.0a	3.5a	61	11.6a	66
F2	6.3c	5.7c	1.10b	7.4b	3.7b	58	12.4b	68
F3	5.8b	5.5b	1.05a	7.2ab	3.7b	53	11.5a	60
S1	4.6a	4.6a	1.00a	6.9a	3.4a	58	11.3a	64
S2	5.3b	5.0b	1.07b	7.3bc	3.3a	57	12.3b	68
S3	6.5c	6.0c	1.08bc	7.5c	3.8b	56	12.3b	64
S4	7.0d	6.2c	1.12c	7.2b	4.0c	56	11.5ab	60
RP1	7.1c	6.1b	1.15c	8.0c	4.0c	57	12.8c	60
RP2	4.8a	5.0a	0.95a	6.5a	3.4a	54	11.0a	69
RP3	5.7b	5.2a	1.09b	7.2b	3.5b	60	11.7b	63
1+0 AVE	5.8	5.5	1.07	7.2	3.6	57	11.9	65
2+0								
Small	7.8a	5.1a	1.59	9.3a	3.5a	83a	15.3a	65c
Medium	16.7b	10.4b	1.63	12.4b	5.7b	47b	19.2a	55b
Large	29.7c	17.1c	1.75	16.3c	7.7c	73a	25.2b	42a

treatments seem to have affected the outplanting survival (Table 2). However, in figure 3 we see how the increased root growth potential that came from the root pruning treatments did increase the survival in block III, the harshest one. It appears that the root growth capacity is not a limiting factor in the first two blocks but new root growth was especially important as the site conditions became drier.

Figure 4 shows how the best 1+0 treatments survival compared to 2+0 seedling survival. In each of the three blocks the 1+0 seedlings performed about

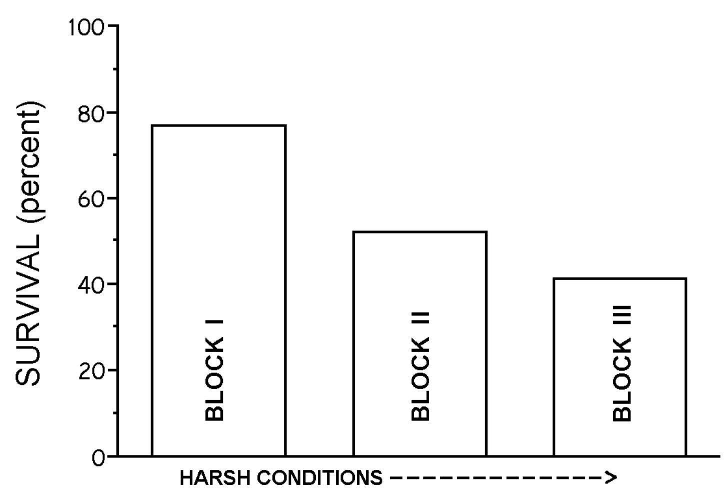

Figure 2. The ponderosa pine seedlings were planted in three blocks on the Boise National Forest. Each successive block was harsher and drier. Figure shows the survival rate of 1+0 seedlings on the three blocks.

as well as the 2+0. Seedling survival reflected the tough conditions of the outplanting site. The spring was wetter than normal but the summer was droughty. At Idaho City, May precipitation was 124 percent of normal. June, July and August precipitation were 72, 53, and 4 percent of normal. A wild fire two years earlier left the site black and the shrubs sprouting vigorously. Ten percent seedling mortality was attributed to pocket gophers.

First-year mean seedling heights showed average height gains for 1+0 seedlings in the range of 60 to 70 percent of initial heights. The average height gain for the 2+0 seedlings after the first growing season ranged from 42 percent for the large size class, to 65 percent for the small size class (Table 2).

Table 3. First year survival and height means for 36 treatment combinations of 1+0 ponderosa pine planted on the Boise National Forest.

Treatment	Times Root Pruned	Rate of Fertilizer (ml)	Seedlings Spaced	First-Year Survival (%)	First-Year Height (cm)
111	0	1X	no	63	11.9
112	0	1X	yes	47	12.4
113	0	1X	4cm	33	12.5
114	0	1X	6cm	57	10.5
121	0	2X	no	60	13.0
122	0	2X	yes	69	12.9
123	0	2X	4cm	72	14.0
124	0	2X	6cm	61	13.8
131	0	3X	no	52	13.1
132	0	3X	yes	47	15.8
133	0	3X	4cm	59	14.1
134	0	3X	6cm	63	10.2
211	1	1X	no	63	11.3
212	1	1X	yes	66	12.6
213	1	1X	4cm	50	11.0
214	1	1X	6cm	69	10.9
221	1	2X	no	53	10.7
222	1	2X	yes	43	10.6
223	1	2X	4cm	52	11.8
224	1	2X	6cm	66	12.5
231	1	3X	no	55	9.6
232	1	3X	yes	43	11.4
233	1	3X	4cm	55	10.3
234	1	3X	6cm	38	8.4
311	2	1X	no	67	11.6
312	2	1X	yes	80	11.3
313	2	1X	4cm	70	11.4
314	2	1X	6cm	63	12.6
321	2	2X	no	48	9.1
322	2	2X	yes	63	12.4
323	2	2X	4cm	55	13.6
324	2	2X	6cm	52	12.6
331	2	3X	no	62	11.1
332	2	3X	yes	55	11.7
333	2	3X	4cm	62	11.6
334	2	3X	6cm	40	11.1

DISCUSSION

Nursery treatments effect on seedling size

Similar to my findings, Pharis and Kramer (1964) saw the root weights of 1+0 loblolly pine increase with nitrogen fertilization but then decreased when nitrogen was increased further. Others have reported increased seedling caliper and biomass from fertilization but only slight increases in height growth for other conifers (Armson and Sadrieka 1979, Switzer and Nelson 1963, van den Driessche 1982).

The increase in seedling size with increased spacing and the slight decrease in height with the widest spacing is consistent with other studies (Baron and Schubert 1963, Edgren 1977, Mullin and Bowdery 1977, Richards and others 1973, Sloan 1992, van den Driessche 1984).

Root pruning reduced the size of the seedlings here as has been documented for conifers in the literature (Bacon and Bachelard 1978, Benson and Shepherd 1977, Hobbs and others 1987, Kainer and Duryea 1990, Venator and Mexal 1981). Although the first root pruning

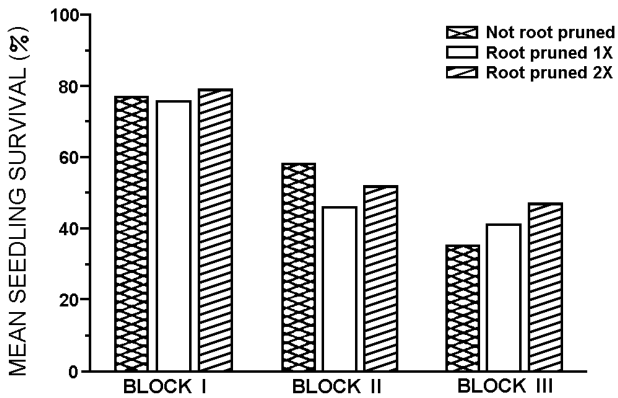

Figure 3. Effect of root pruning treatments on survival in three blocks of 1+0 ponderosa pine seedlings planted on the Boise National Forest. In the nursery bed, seedlings were root pruned twice, once, or not at all.

treatment in early August was effective in slowing seedling growth and lowering shoot/root ratios, it did not cause the seedlings to set buds. Budset did not occur for all treatments until late September. What is puzzling is the fact that root pruning just once, reduced the seedling size more than root pruning twice (Table 2). Some researchers have recommended that root pruning will be more effective when it is done in conjunction with other cultural treatments including density regulation because root pruning will not be as effective at higher densities (Racey and Racey 1988, O'Neill and others 1988, Edgren 1977, Mullin and Bowdery 1978). I found that even in the densest plots, root pruning improved root growth potential.

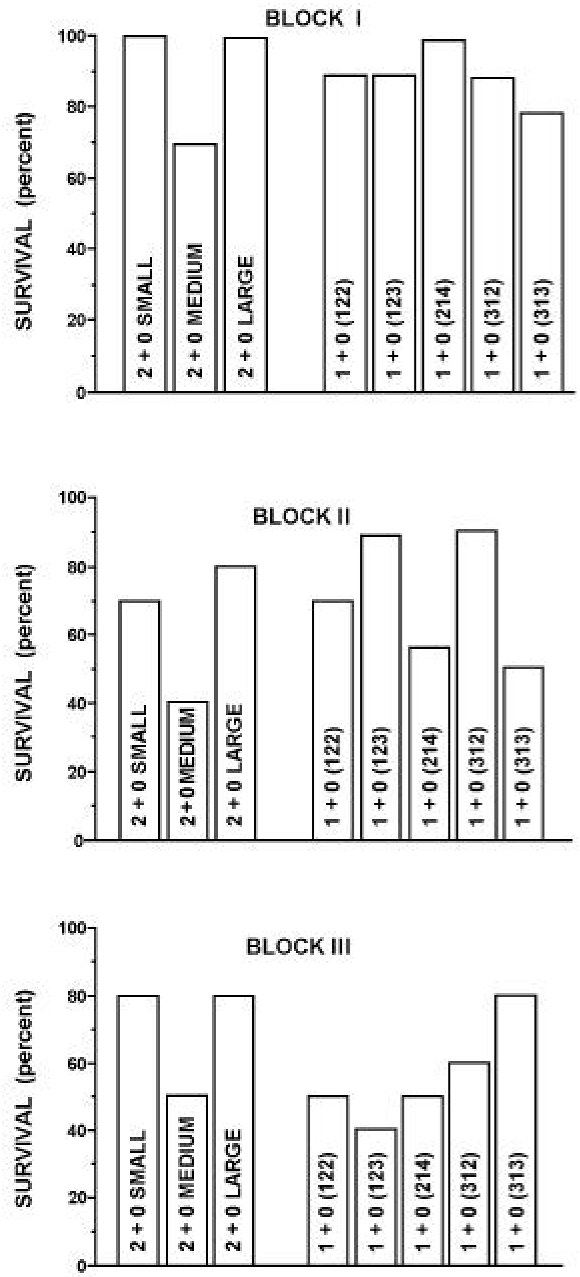

Figure 4. Average heights for ponderosa pine seedlings planted on the Boise National Forest. The first three represent 2+0 size classes and the last five bars represent selected 1+0 treatment combinations. See table 3 for interpretation of 1+0 seedling identification numbers: root pruning treatment, fertilizer treatment, spacing treatment.

Treatments which increased seedling size tended to also increase shoot/root ratios because they promoted more top growth than root system growth. The reverse is true for treatments which reduced seedling size. This was also shown by Duryea (1984), Duryea and Lavender (1982), Tanaka and others (1976), Stein (1984), and van den Driessche (1983). Racey and others (1983) consider shoot/root ratio to be of little value as an indicator of seedling potential. Shoot/root ratio within a size class is a good indicator of survival potential, especially on droughty sites (Thompson 1985).

The root pruning treatments which reduced seedling growth in the nursery increased root growth potential by allocating some of the energy into storage which would otherwise have gone into growth. Bacon and Bachelard (1978) saw similar results. The opposite was true of the fertilizer treatments: increase in fertilizer increased seedling size and reduced root growth potential. Root growth potential did not change much at the wider spacings even though space increased seedling caliper and shoot and root volumes (Table 2). This agrees with van den Driessche (1984). Wider spacing may provide a possible way to increase seedling size and still maintain root growth potential.

Outplanting test

As we planted the seedlings into the field, it appeared that the 2+0 trees would have an advantage over the 1+0 trees because of their larger size and larger root growth potential. Many of the 1+0 calipers and heights seemed to be meager, especially for this tough site. However, the 1+0 seedlings were superior in their even balance between shoots and roots. Although the 2+0 seedlings had a better average survival rate than the 1+0 seedlings, some of the 1+0 treatments had survivals as good or better than the 2+0 treatments. This agrees with Rose and others (1992) who found that 1+0 ponderosa pine could perform as well as 2+0.

I found that root growth potential produced a noticeable influence on field survival only on the harshest block. Much research has examined the relationship between RGP and outplanting performance. Richie and Dunlap (1980) found that 85 percent of the literature reported positive correlations while Richie and Tanaka (1990) found 75 percent.

The larger the 2+0 size class, the smaller the relative first-year height growth in the field. This was because the root systems of the larger seedlings were not as well balanced to the shoots resulting in more planting stress. The relative height growth of the 1+0 seedlings was similar to the small 2+0 size class.

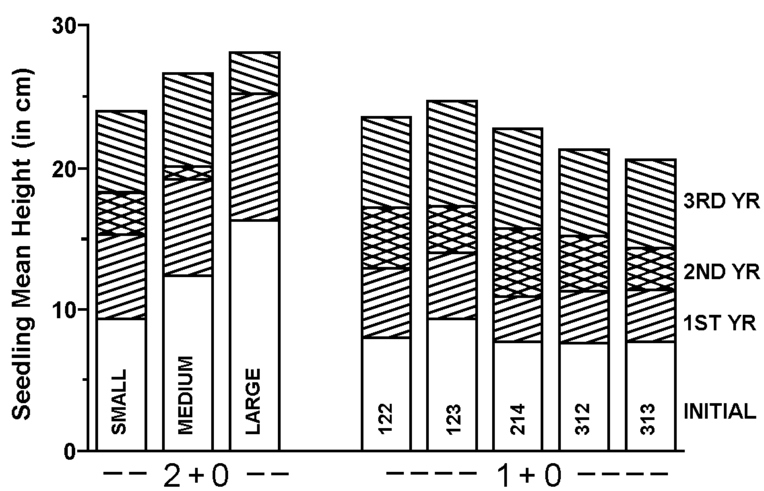

Figure 5. Comparison of survival for ponderosa pine seedlings planted on three blocks in the Boise National Forest. The 2+0 seedlings are divided into three size classes. The five best 1+0 treatments are identified in parentheses. The three numbers refer to root pruning, fertilizer, and spacing respectively. See table 3 for interpretation of the treatment codes.

By the end of the second growing season, nearly all of the differences in height between the 1+0 treatments had disappeared. Likewise for the 2+0 seedlings, after two growing seasons there are no longer significant differences in top heights between the three size classes (Figure 6). Because of the dry conditions, many of the large 2+0 seedlings died back or did not grow much in the second and third seasons. In both cases, many of the smaller seedlings have caught up. Hobbs (and others 1987) also found that morphological differences in ponderosa pine seedlings seen at planting, disappeared four years later.

Several of the treatment combinations produced seedlings that survived better than the 1+0 average. Of the treatments with the best survival rates, most were root pruned twice. The root pruning and fertilizer treatments had the biggest impacts. The spacing treatment did not seem to matter. This suggests that root growth potential and the balance between top and roots are important to seedling survival. I did not find 1+0 seedling size to be very important to survival.

Many factors affect seedling survival and growth. As is stated by Mexal and Landis (1990), shoot height is often highly correlated with growth. I found that seedling height after the first growing season was highly correlated to initial shoot length, caliper, shoot volume, and shoot volume. I did not see high correlations between survival and any of the morphological characteristics: shoot volume, root volume, shoot/root ratio, shoot length, or caliper. That does not mean that these characteristics are not important. All must be considered in relation to each other and to the planting site.

Caliper is considered by some to be the best indicator of survival (Cleary and others 1978, Long and Carrier 1993, South and others 1993). Others have shown that root volume is important (Haase and Rose 1993, Long and Carrier 1993, Lopushinsky and Beebe 1976). Rose and others (1991) found that 1+0 ponderosa pine seedlings with larger root volumes survived better in the field.

The harsh planting site was hard on both the 1+0 and 2+0 seedlings. The performance of the small 2+0 seedlings compared to the large showed that the biggest trees are not the best on tough sites. Although the 1+0 seedlings had better shoot/root balance, they soon lost their primary needles, leaving them with just one years needles to carry on photosynthesis. The 2+0 seedlings were sturdier and maintained their previous year's foliage. Short seedlings seem to have an advantage on droughty sites (Hermann 1964, Lopushinsky and Beebe 1976, Tuttle and others 1988, van den Driessche 1991). Taller seedlings have a greater surface for both photosynthesis and for water loss by transpiration (Carlson and Miller 1990).

Lucky Peak Nursery can produce one year old ponderosa pine with the capability to be successful on Intermountain planting sites. We could possibly improve the size of the 1+0 seedlings if we sowed the seed earlier in the spring. There was not any one treatment combination that produced seedlings superior to all others.

In the field, survival and growth would have been greater with normal rain during the first growing season or on a more moderate site. A more moderate site would be better for 1+0 ponderosa pine seedlings of the quality here. For harsh planting sites like this one, I would recommend planting 2+0 stock tailored to the dry conditions: large root volume, large caliper, high root growth potential, and short top.

SUMMARY

We grew 1+0 ponderosa pine seedlings under regimes of three root pruning options, three fertilizer options, and four different spacings in the nursery beds. All three of the cultural practices influenced the seedling

size at lifting. The largest 1+0 seedlings were not root pruned, received the medium fertilizer treatment, and grew at 6 cm apart (8 seedlings/ft^2 or 89 seedlings/m^2), the widest spacing. The largest did not have the highest survival in the field. Treatments which slowed seedling growth in the nursery bed, such as root pruning, tended to increase root growth potential. In the harshest outplanting block, root pruning appeared to improve seedling survival as well.

Overall survival rates were 68 percent for 2+0 seedlings and 57 percent for 1+0 on a harsh planting site with shallow soil and a dry first growing season. In a typical year survival would probably have been in the 80 to 90 percent range. However, some of the 1+0 treatments survived as well or better than the 2+0.

The 1+0 seedlings with the greatest initial heights were still the tallest at the end of the first growing season but after three seasons since outplanting, the differences are small.

In order to grow 1+0 seedings with the best chance of surviving on a harsh site, I would recommend root pruning twice, increasing the target spacing to 4cm (11 seedlings/ft^2 or 119/m^2), and leaving the nitrogen fertilization rates at the current (1X) levels.

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