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Effects of Seeder Design and Seed Placement on Seedling Size and Cull Rates at Western Forest Nurseries

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RESEARCH SUMMARY

Nursery plots sown with the Summit Precision Seeder and the Oyjord Seeder were compared with plots oversown and hand thinned to desired spacings. We studied 26 seedlots of nine conifer species at five Forest Service, U.S. Department of Agriculture, nurseries. Seed placement by the two seeders varied with nursery, species, and seed characteristics. Neither

seeder placed seeds exactly, but this lack of precision provided a good comparison with the more exact hand-thinned treatment. Thinned plots showed less clumping and fewer gaps between seedlings, but the seedlings were not significantly bigger than in unthinned plots, nor did thinning increase the number of acceptable seedlings.

ACKNOWLEDGMENTS

I would like to express thanks and appreciation to Jim Lott (deceased) of the Missoula Technology and Development Center, Forest Service, U.S. Department of Agriculture, and Russ Ryker (retired) of the Forest Service's Intermountain Research Station who initiated this study. During their many years of dedicated service, they made valuable contributions to improve forest nursery stock production.

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Effects of Seeder Design and Seed Placement on Seedling Size and Cull Rates at Western Forest Nurseries

John P. Sloan

INTRODUCTION

Uniform spacing between seedlings is important to the efficient operation of forest tree nurseries. The value of western conifer seed continues to increase due to dwindling amounts of some seed sources, growth of genetically improved seed, and more costly, nondestructive seed collections from high-quality stands and trees. It is becoming more and more costly for nurseries to raise unacceptable seedlings that must later be discarded. Nursery managers would like to make better use of precious seed supplies, reduce the proportion of nonshippable trees, and produce more uniformly sized seedlings through more uniform spacing of trees. Seedlings raised in such conditions might perform better when planted in the field. However, we must place seed more precisely during sowing to obtain more uniform spacing between seedlings in the nursery bed.

In seedbed tests at five Forest Service, U.S. Department of Agriculture, nurseries during the spring of 1985, the Love/Oyjord seed sower and the Summit Precision Seeder differed in seed placement (Sloan 1990). In addition, seed placement using these two seeders and hand thinning were compared in extensive study plots to determine the effects on seedling spacing, seedling morphology, and cull rates. We studied 26 different seedlots, including nine species.

MATERIALS AND METHODS

The five Forest Service nurseries participating in this study were Coeur d'Alene Nursery, Coeur d'Alene, ID; Lucky Peak Nursery, Boise, ID; J. Herbert Stone Nursery, Central Point, OR; J. W. Toumey Nursery, Watersmeet, MI; and Wind River Nursery, Carson, WA. The study was a cooperative effort between the nurseries, the Forest Service's Missoula Technology and Development Center, and the Forest Service's Intermountain Research Station.

Both seeders were calibrated to sow at each nursery's target rate, based on species, seedlot germination rate, and a nursery loss factor. The nursery

loss factor came from production records. Seeds were covered with aluminum powder before sowing to make them readily visible and facilitate smooth flow through the seeders.

We ran the seeders using seed from nine conifer species. Douglas-fir (*Pseudotsuga menziesii* var. *menziesii* and var. *glauca* [Beissn.] Franco) (coastal and inland varieties) was sown at three nurseries. Both Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) and ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) were sown at two nurseries. White spruce (*Picea glauca* [Moench] Voss), noble fir (*Abies procera* Rehd.), jack pine (*Pinus banksiana* Lamb.), lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.), red pine (*Pinus resinosa* Ait.), and western larch (*Larix occidentalis* Nutt.) each were sown at one nursery (table 1).

Four species were sown at the Lucky Peak Nursery; three were sown at the Coeur d'Alene Nursery and the J. W. Toumey Nursery; two were sown at the J. Herbert Stone Nursery; and only noble fir was sown at the Wind River Nursery (table 1).

Each species at a nursery was treated as a separate test. Within each test, we sowed two seedlots. The first had about a 95 percent germination rate; the second had a 75 to 85 percent germination rate. Within each of three blocks, six plots were arranged randomly. Each of the six plots received one of the three treatments with one of the two seedlots. The treatments were: (1) seed sown using the Summit Precision Seeder calibrated to the target spacing, (2) seed sown using the Oyjord Seeder calibrated to the target spacing, and (3) seed oversown using the Oyjord Seeder and hand thinned to the target spacing after seedling emergence. Treatments were randomly arranged in blocks.

All plots were 6 meters long with a 1-meter buffer separating the plots. Three 0.5-meter sample plots were placed within each plot. After sowing, a meterstick was laid alongside each row in a sample plot, and the position of every seed was recorded in millimeters. As soon as the measurements were made, the seed was covered with sand.

Table 1—Actual and target seed densities for the Summit and Oyjord Seeders using nine tree species at five nurseries

Species	Nursery ¹	Seeds per foot of row			Percent of target		
		Summit	Oyjord	Target	Summit	Oyjord	
Douglas-fir	CDA	19.8	18.9	20.6	96	92	ns ²
	LPN	14.5	25.8	22.9	63	113	**
	JHS	12.9	12.8	17.5	74	73	ns
Engelmann spruce	CDA	10.1	20.9	20.6	79	101	**
	LPN	18.0	23.3	21.9	82	106	**
White spruce	JWT	29.4	22.8	29.4	100	78	*
Noble fir	WRN	11.7	24.2	21.9	53	111	**
Jack pine	JWT	21.9	14.0	18.8	116	74	**
Lodgepole pine	LPN	14.4	18.0	19.9	72	90	**
Ponderosa pine	LPN	11.6	18.9	18.1	64	104	**
	JHS	11.4	11.6	16.2	70	72	ns
Red pine	JWT	20.4	14.3	17.9	114	80	**
Western larch	CDA	22.6	22.0	20.6	110	107	ns

¹Nursery code: Coeur d'Alene (CDA); J. Herbert Stone (JHS); J. W. Toumey (JWT); Lucky Peak (LPN); and Wind River (WRN).

²* 0.05 significance level; ** 0.01 significance level; ns not statistically different at the 0.05 significance level.

Five weeks after sowing, emerged seedlings in the oversown plots were hand thinned to the target spacing. The positions of the seedlings were measured on all sample plots using the same method as for mapping seed placement.

At the end of the first growing season, top height was measured on a sample of seedlings. Five seedlings in every half-meter sample row were randomly selected in each subplot and measured to the nearest centimeter. Also, seedlings were counted to verify that mortality during the growing season was minimal.

At three of the nurseries, more measurements were taken at lifting time. Each sample plot was measured separately. All seedlings were graded and counted by an experienced grader. Grading specifications, set by nursery personnel, were unique for each species and nursery. We measured total number of trees lifted, number of trees meeting specifications, and number of nonshippable trees for all sample plots. Also, 10 trees were randomly selected for morphological measurements: top height, stem caliper, top dry weight, and root dry weight.

RESULTS AND DISCUSSION

Data summaries and analyses are presented in tables 1 through 6. Some of the tests have mean values that appear to show obvious differences.

Table 2—Percentage of target seed densities obtained using the Summit Precision Seeder and the Oyjord Seeder

Nursery ¹	Species ²	Percent of target		
		Summit	Oyjord	
CDA	DF ³	96	92	ns ⁴
	ES	79	101	ns
	WL	110	107	ns
LPN	DF ³	63	113	**
	ES	82	106	**
	LP	72	90	**
	PP	64	104	**
JHS	DF	74	73	ns
	PP	70	72	ns
JWT	WS	100	78	*
	JP	116	74	**
	RP	114	80	**
WRN	NF	53	111	**

¹Nursery code: Coeur d'Alene (CDA); Lucky Peak (LPN); J. Herbert Stone (JHS); J. W. Toumey (JWT); and Wind River (WRN).

²Species code: Douglas-fir (DF); Englemann spruce (ES); western larch (WL); lodgepole pine (LP); ponderosa pine (PP); white spruce (WS); jack pine (JP); red pine (RP); and noble fir (NF).

³Inland variety of Douglas-fir.

⁴* 0.05 significance level; ** 0.01 significance level; ns not statistically different at the 0.05 significance level.

Table 3—Seed-spacing measurements (mean number per foot of row) on plots sown by the Summit Precision and the Oyjord Seeders

Species	Nursery ¹	Blank spaces ²		Double spaces		Single seeds	
		Summit	Oyjord	Summit	Oyjord	Summit	Oyjord
Douglas-fir	CDA	4.5	4.8	6.6	8.8	8.5	7.0
	LPN	3.0	6.9	5.2	9.9	6.1	9.7
	JHS	5.3	5.9	9.2	10.4	12.0	9.8
Engelmann spruce	CDA	2.4	5.4	4.7	8.2	4.4	8.2
	LPN	3.8	5.9	5.9	9.0	7.9	8.8
White spruce	JWT	7.3	6.0	11.3	9.2	11.8	8.4
Noble fir	WRN	3.0	7.0	5.0	11.5	4.7	7.6
Jack pine	JWT	5.3	3.3	7.1	5.6	9.4	5.1
Lodgepole pine	LPN	2.8	4.4	4.1	7.0	7.3	6.9
Ponderosa pine	LPN	2.2	4.7	3.1	7.0	5.9	7.5
	JHS	4.1	8.1	5.6	7.4	12.9	9.3
Red pine	JWT	4.7	3.4	6.5	5.7	9.0	5.3
Western larch	CDA	5.5	5.5	8.6	8.6	8.6	8.3

¹Nursery code: Coeur d'Alene (CDA); J. Herbert Stone (JHS); J. W. Toumey (JWT); Lucky Peak (LPN); and Wind River (WRN).

²Blank spaces are where seed spacing was greater than 1.5 times the average spacing. Doubles are where seeds were spaced closer than half the average spacing. Singles are where interseed spacing was 0.5 to 1.5 times the average spacing.

³* 0.05 significance level; ** 0.01 significance level; ns not statistically different at the 0.05 significance level.

Table 4—Seedling spacing measurements (mean number per foot of row) on plots sown by the Summit Precision Seeder, Oyjord Seeder, and hand-thinned

	Nursery ¹	Seedling density			Blank spaces ²			Double seedlings			Single seedlings						
		Summit	Oyjord	Thinned	Summit	Oyjord	Thinned	Summit	Oyjord	Thinned	Summit	Oyjord	Thinned				
Douglas-fir	CDA	15.0	16.7	9.9	** ³	3.0	3.9	1.1	**	5.3	7.0	0.5	**	6.5	6.2	7.8	**
	JHS	11.5	11.3	8.8	ns	4.7	5.6	2.2	**	8.7	9.0	.8	**	10.7	8.7	14.1	*
Engelmann spruce	CDA	12.4	17.1	9.7	ns	2.0	4.1	1.1	**	6.0	6.7	.4	**	4.3	6.8	8.0	*
	LPN	11.1	12.2	8.2	ns	2.0	3.4	.9	**	4.3	6.1	.3	**	4.6	5.3	6.5	*
White spruce	JWT	15.9	14.3	7.2	**	3.6	3.5	.9	**	7.5	6.8	.5	**	5.2	4.4	5.3	ns
Noble fir	WRN	5.4	12.7	6.8	**	.7	3.0	1.0	**	2.5	6.2	1.0	**	1.7	3.9	4.4	**
Jack pine	JWT	14.8	10.1	6.3	**	3.3	2.2	.9	**	5.5	4.4	1.1	**	6.2	3.4	3.8	**
Lodgepole pine	LPN	10.6	13.3	8.6	**	1.8	3.1	1.0	**	3.6	5.4	.4	**	4.9	4.9	6.6	*
Ponderosa pine	JHS	8.5	10.0	8.3	**	3.3	5.1	2.2	**	4.8	7.3	1.3	**	8.7	8.0	12.7	**
Red pine	JWT	14.1	10.9	6.8	**	3.5	2.5	.9	**	4.9	4.7	.7	**	5.9	3.7	4.8	**
Western larch	CDA	17.5	16.2	10.1	**	4.1	3.9	1.1	**	6.2	6.3	.4	**	7.2	6.2	8.1	**

¹Nursery code: Coeur d'Alene (CDA); J. Herbert Stone (JHS); J. W. Toumey (JWT); Lucky Peak (LPN); and Wind River (WRN).

²Blank spaces are where seedling spacing was greater than 1.5 times the average spacing. Doubles are where seedlings were spaced closer than half the average spacing. Singles are where interseedling spacing was 0.5 to 1.5 times the average spacing.

³* 0.05 significance level; ** 0.01 significance level; ns not statistically different at the 0.05 significance level.

Table 5—Seedling heights and calipers for Summit Precision Seeder, Oyjord Seeder, and hand-thinned plots

Species	Nursery ¹	Mean seedling heights-1st year			Mean seedling heights-2d year			Mean seedling caliper					
		Summit	Oyjord	Thinned	Summit	Oyjord	Thinned	Summit	Oyjord	Thinned			
		----- Centimeters -----			----- Centimeters -----			----- Millimeters -----					
Douglas-fir	CDA	6.4	6.3	5.4	*	17.9	16.6	16.0	ns	3.4	3.4	3.6	ns
	LPN	—	—	—		—	—	—		2.8	2.8	3.0	ns
	JHS	14.6	13.1	15.2	*	29.5	29.9	30.8	ns	6.6	6.3	6.5	ns
Engelmann spruce	CDA	3.8	4.1	3.9	ns	18.6	18.9	19.0	ns	3.8	3.4	4.1	ns
	LPN	2.7	2.2	2.5	*	5.9	5.2	5.4	ns	3.4	3.1	3.5	*
Lodgepole pine	LPN	4.7	4.8	4.7	ns	19.3	18.9	19.0	ns	5.4	4.7	5.6	**
Ponderosa pine	JHS	9.4	8.7	9.0	ns	22.2	22.6	22.5	ns	6.9	6.5	7.1	ns
Western larch	CDA	12.2	11.6	11.0	ns	38.3	37.0	36.1	ns	4.0	3.9	4.2	ns

¹Nursery code: Coeur d'Alene (CDA); J. Herbert Stone (JHS); J. W. Toumey (JWT); Lucky Peak (LPN); and Wind River (WRN).
²* 0.05 significance level; ** 0.01 significance level; ns not statistically different at the 0.05 significance level.

Table 6—Seedling dry weights and grades for Summit Precision Seeder, Oyjord Seeder, and hand-thinned plots

Species	Nursery ¹	Total seedling dry weight			Shippable seedlings			Mean number of shippable trees					
		Summit	Oyjord	Thinned	Summit	Oyjord	Thinned	Summit	Oyjord	Thinned			
		----- Grams -----			----- Percent of total -----			----- No./ft -----					
Douglas-fir	CDA	4.12	4.16	4.52	ns ²	74	72	74	ns	54	51	33	**
	LPN	1.35	1.33	1.41	ns	64	56	55	ns	6	10	7	—
	JHS	16.53	14.07	14.75	ns	47	65	85	ns	35	43	46	—
Engelmann spruce	CDA	5.42	4.15	6.34	ns	72	79	78	*	38	60	33	*
	LPN	1.89	1.49	1.76	*	59	64	64	ns	12	14	7	*
Lodgepole pine	LPN	10.81	7.52	11.30	**	69	76	79	**	15	24	15	**
Ponderosa pine	JHS	13.24	11.65	13.93	ns	37	45	40	ns	11	15	11	—
Western larch	CDA	3.62	4.03	4.58	ns	73	75	81	ns	35	35	24	**

¹ Nursery code: Coeur d'Alene (CDA); J. Herbert Stone (JHS); J. W. Toumey (JWT); Lucky Peak (LPN); and Wind River (WRN).
²* 0.05 significance level; ** 0.01 significance level; ns not statistically different at the 0.05 significance level.

However, in a few cases the variation in the data is so great that mean values may be visually different, but not statistically different. For a more indepth comparison of the two seeders and a discussion of their performance, see Sloan (1990).

Seed Mapping

Overall, both machines sowed less seed than the target rates (table 1). Mean seed densities were inconsistent within species and for both seeders. In fact, table 2 shows more consistency within nurseries than within species. At each nursery different persons calculated seed requirements and weighed seed, and different tractor operators ran different tractors with varying speed, precision, and consistency. The hand-thinned plots were not mapped at this stage because they were oversown. The seed densities were not important so long as the seed was distributed evenly over the entire plots.

The average number of seeds can be misleading, since spacing as well as density determines the seedlings' ability to compete for moisture, nutrients, and light. Table 3 summarizes the seed spacing. Plots sown with the Oyjord Seeder had more doubles (seeds closer than half the average spacing) in seven out of 13 tests. In two of the three tests at the J. W. Toumey nursery, however, we found opposite results. Doubles did not differ between seeders at the J. Herbert Stone Nursery and in one test each at the J. W. Toumey and Coeur d'Alene Nurseries.

Blank spaces were defined as any interseed space greater than 1.5 times the average spacing. The blank space results were similar to those for doubles (table 3).

The most important measurement is the mean number of seeds that met the target spacing. A seed with adequate spacing (a "single seed") is defined as any seed that has a distance to seeds on either side of 0.5 to 1.5 times the average spacing (Boyer and others 1985). Neither the Summit Precision Seeder nor the Oyjord Seeder was consistently more accurate in placing seeds in these tests (table 3).

Some of the seed placement performance by the two seeders can be explained by seed characteristics. The Summit Precision Seeder seemed to perform better than the Oyjord when large, symmetrical, and rounded seeds were sown. When small or angled seed was used, however, the Summit sower had problems placing one seed at a time.

Of the seeds tested in this study, the spruces were the smallest. White spruce was smaller than Engelmann spruce. Black spruce seed at the J. W. Toumey Nursery was so small that it could not be successfully sown by the Summit Precision Seeder. The western larch seed was also small. Ponderosa pine

seed was the largest. For that reason it produced the best spacing. Lodgepole pine seed was smaller than the ponderosa, and red pine was smaller yet. Jack pine had the smallest of the pine seeds. Douglas-fir seed was large, but it was variable in shape. The coastal variety planted at the J. Herbert Stone Nursery was more triangular, while the inland variety seed at Coeur d'Alene and Lucky Peak was more rounded. The Oyjord performed better than the Summit with angularly shaped seed. Noble fir seed was large, but it was also very resinous and sticky. It often had pieces of wing still attached. This created clumping problems in both seeders, especially the Summit.

Seedling Mapping

Overall, the hand-thinned plots showed a lower seedling density than both the Summit and the Oyjord seeder plots (table 4) and, therefore, a greater mean distance between seedlings. The exceptions came in the Engelmann spruce plots at the Coeur d'Alene and Lucky Peak Nurseries, and in the Douglas-fir plots at the J. Herbert Stone Nursery where differences were not significant. In the noble fir test at Wind River the Summit Seeder produced a lower density and wider average spacing than the hand-thinned treatment because of the resin problem discussed earlier.

Two tests were not included in the analysis of seedling location, both at Lucky Peak: (1) the ponderosa pine seedbed was established next to a shelter-belt harboring seed-eating birds, which conducted their own taste analysis during germination, and (2) the Douglas-fir seedlot with an expected 95 percent germination rate simply failed to germinate at an adequate level.

The hand-thinned treatment produced fewer blank spaces and fewer double seedlings than the Summit and Oyjord seeders. However, the hand-thinned plots had a few blank spaces where seeds were not sown or did not germinate. This shows that not even the hand thinning was precise, putting precision seeding in perspective.

The thinned plots had more well-spaced seedlings (singles) in eight tests. In three tests at the J. W. Toumey Nursery, however, the Summit Precision Seeder matched or exceeded the number of singles produced by hand thinning. With jack and red pine the Summit Precision Seeder produced more singles. With white spruce the difference was not significant. The seedling maps showed even fewer differences between the number of blanks, doubles, and single seedlings than the seed maps. This demonstrates that precision seeding can be totally effective only when sowing seedlots with very high germination

rates. Even with truly precise seed placement, the more seeds that fail to germinate, the less uniformity in seedling spacing.

Figures 1 through 5 compare seed and seedling spacing distribution for the high-germination (95 percent) seedlots. Each seedling location histogram in each of the bottom rows looks very similar to the one for seed placement above it. Because some seeds didn't germinate, the seedling distribution is slightly to the right of seed distribution along the spacing scale. The poorer the germination for any seedlot, the greater the displacement in the histogram. Ideally, the seedling location histograms should have only a few bars grouped around the target spacing, much like the hand-thinned seedling histograms.

In no case did the seedling spacing by the seeders approach the even seedling distribution of the hand-thinned plots (fig. 5).

Histograms of three tests show the Summit Precision Seeder gave better seed and seedling distribution than the Oyjord Seeder: ponderosa pine at J. Herbert Stone Nursery (fig. 3b), lodgepole pine at Lucky Peak Nursery (fig. 2b), and noble fir at Wind River Nursery (fig. 5). Histograms for other tests show little difference between the two seeders.

Figures 6 and 7 compare the distribution of seed spacing with the distribution of the resulting seedling spacing for the high- and low-germination lots of Engelmann spruce at Lucky Peak and Coeur d'Alene Nurseries. It is difficult to see a difference between the seed and seedling distribution in any of the comparisons. The spacing of the high-germination seedlots is only slightly better. Results were similar for other species.

Seedling Grade and Morphology

After 2 years in the nursery, seedlings from eight of the 13 tests were lifted and graded. Seedling heights were not different for any of the sowing treatments (table 5). In only two cases out of eight did mean seedling caliper (table 5) and total dry weight (table 6) differ between treatments: Engelmann spruce and lodgepole pine, both at Lucky Peak Nursery. In both instances, mean seedling caliper and total dry weight were less on plots sown by the Oyjord Seeder than on plots sown by the Summit Precision Seeder and hand-thinned plots. In the case of lodgepole, seedlings grew larger from the treatments that produced lower seedling densities. The initial seedling density was not different between treatments for Engelmann spruce, but the Oyjord treatment had more doubles and blank spaces. This is consistent with other studies where decreased density increased seedling calipers (Boyer

and South 1987; Brissette and Carlson 1987; Mullin and Bowdery 1977; Richards and others 1973; Scarborough and Allen 1954; van den Driessche 1984). Although the differences in seedling spacing in the other species and seedlots were all significant, evidently they were not great enough to significantly affect seedling size.

Cull rates and number of shippable trees don't show an overall trend. Plots sown with the Oyjord Seeder, however, produced as many or more trees that met grading specifications as the Summit Precision Seeder and the hand-thinned plots (table 6). In figure 8 we see how the average numbers decline for each treatment from seeds sown, to seedling density, to shippable seedlings. The first three charts show fairly consistent relationships. Mostly, more seed was sown using the seedlots with 75 to 85 percent germination than those with 95 percent. Often the difference in germination rates and sowing rates cancelled each other producing about the same number of established seedlings for the two seedlots in each test. Hand-thinned plots generally produced fewer seedlings in the shippable category than plots sown with either seeder. Cull rates were often similar for hand-thinned plots and plots sown with either seeder, but initial seedling densities were lower on the hand-thinned plots. Several studies on southern pines have shown an increase in the proportion of shippable seedlings with a decrease in seedbed density (Boyer and South 1986, 1987; Burns and Brendemuehl 1971; Caulfield and others 1987; Shoulders 1961). The hand-thinned treatment in this study did not lower cull rates because wider seedling spacing was not sufficient in most cases to increase seedling size. Grading specifications are based on size and other morphological characteristics, health, and lifting damage.

Two tests had very high cull rates: Engelmann spruce at Lucky Peak and ponderosa pine at J. Herbert Stone. Seedling grading specifications were different at each nursery and for each species. Slight differences in specifications could greatly increase or decrease the number of shippable seedlings.

CONCLUSIONS

Neither of the two seeders exactly placed seed in any of the tests described here. As a result, seedling spacing was not uniform. However, even with oversowing and hand thinning to the desired spacing, no more seedlings met specifications. Hand thinning was not successful in increasing seedling heights. It increased mean caliper and total dry weight in only two of eight tests.

Placement of seed by the two seeders varied with each species and nursery. Seed size and shape also

Figure 1a—Spacing distribution histograms for Douglas-fir seeds and seedlings from 95 percent germination seedlots at the Coeur d'Alene Nursery.

Figure 1b—Spacing distribution histograms for Engelmann spruce seeds and seedlings from 95 percent germination seedlots at the Coeur d'Alene Nursery.

Figure 1c—Spacing distribution histograms for western larch seeds and seedlings from 95 percent germination seedlots at the Coeur d'Alene Nursery.

Figure 2a—Spacing distribution histograms for Engelmann spruce seeds and seedlings from 95 percent germination seedlots at the Lucky Peak Nursery.

Figure 2b—Spacing distribution histograms lodgepole pine seeds and seedlings from 95 percent germination seedlots at the Lucky Peak Nursery.

Figure 3a—Spacing distribution histograms for Douglas-fir seeds and seedlings from 95 percent germination seedlots at the J. Herbert Stone Nursery.

Figure 3b—Spacing distribution histograms for ponderosa pine seeds and seedlings from 95 percent germination seedlots at the J. Herbert Stone Nursery.

Figure 4a—Spacing distribution histograms for jack pine seeds and seedlings from 95 percent germination seedlots at the J. W. Toumey Nursery.

Figure 4b—Spacing distribution histograms for red pine seeds and seedlings from 95 percent germination seedlots at the J. W. Toumey Nursery.

Figure 4c—Spacing distribution histograms for white spruce seeds and seedlings from 95 percent germination seedlots at the J. W. Toumey Nursery.

Figure 5—Spacing distribution histograms for noble fir seeds and seedlings from 95 percent germination seedlots at the Wind River Nursery.

Figure 6a—Englemann spruce seed spacing at the Lucky Peak Nursery using the Oyjord Seeder and the Summit Precision Seeder. The histograms on the left represent 95 percent germination seedlots (95), while the histograms on the right represent 75 to 85 percent germination seedlots (75-85).

Figure 6b—Distribution of Englemann spruce seedlings at the Lucky Peak Nursery using hand thinning, the Oyjord Seeder, and the Summit Precision Seeder. The histograms on the left represent 95 percent germination seedlots (95), while the histograms on the right represent 75 to 85 percent germination seedlots (75-85).

Figure 7a—Englemann spruce seed spacing at the Coeur d'Alene Nursery using the Oyjord Seeder and the Summit Precision Seeder. The histograms on the left represent 95 percent germination seedlots (95), while the histograms on the right represent 75 to 85 percent germination seedlots (75-85).

Figure 7b—Distribution of Englemann spruce seedlings at the Coeur d'Alene Nursery using hand thinning, the Oyjord Seeder, and the Summit Precision Seeder. The histograms on the left represent 95 percent germination seedlots (95), while the histograms on the right represent 75 to 85 percent germination seedlots (75-85).

Figure 8—Comparison of the average seed density, the average seedling density, and the average shippable seedlings from seven tests at Coeur d'Alene Nursery (CDA), J. Herbert Stone Nursery (JHS), and Lucky Peak Nursery (LPN). Each histogram represents one test, including two seed-lots of the same species: a 95 percent germination lot (95) and a 75 to 85 percent germination lot (75-85). Treatments include (1) sowing with the Summit Precision Seeder, (2) sowing with the Oyjord Seeder, and (3) hand thinning to a desired spacing.

influenced the seed placement. The large, rounded seeds were more evenly spaced by the Summit Seeder. The Oyjord plots tended to have more blank spaces and more clumping of seeds. This was not the case at the J. W. Toumey Nursery where the seeds were smaller and the Summit Seeder placed seeds inconsistently.

When seed was small like white spruce, or angled on one end like coastal Douglas-fir, the Summit Seeder's vacuum system had problems picking up and placing just one seed at a time. This explains why several species showed little difference between the two seeders. The Summit Seeder also had difficulty sowing the resinous and sticky noble fir seed at Wind River Nursery. The plots that were oversown and hand thinned produced fewer seedlings per unit area, fewer blank spaces, less clumping of seedlings, and generally, more well-spaced seedlings than the other two treatments.

Seedbed density and spacing did not affect the percentage of total trees that met grading specifications. In fact, Oyjord plots, which often had the poorest seedling spacing, produced as many or more shippable seedlings per unit area as the other two treatments in all of the tests lifted. Since the Oyjord and hand-thinned cull rates were only slightly different and had more total seedlings, the Oyjord plots surpassed the hand-thinned plots in shippable seedling production.

Seedling spacing is a function of seed placement and seedlot germination. This complex problem and the way it influences seedling growth and morphology depends on many factors. Many of these factors were not measured in this study. It appears that the differences in seedling spacings were not great enough to change the seedling morphology. Even when we hand-thinned plots to specified seedling spacings, we did not greatly reduce the cull rates or increase the total shippable seedling production per unit area.

The results of this study emphasize some of the major underlying problems which must be solved if we desire evenly spaced and morphologically consistent seedlings. A machine that can place seed exactly loses its value very quickly if the germination rate of our seed goes down. Even a very precise and consistent seeder using a high germination seedlot is of little value if we have not determined the optimum morphological characteristics of the seedlings we want to grow and the spacing and culture that will produce those results.

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Nursery plots sown with the Summit Precision Seeder and the Oyjord Seeder were compared with plots oversown and hand thinned to desired spacings. We studied 26 seedlots of nine conifer species at five Forest Service, U.S. Department of Agriculture, nurseries. Results varied with nursery, species, and seed characteristics. Thinned plots produced less clumping and fewer gaps between seedlings, but showed little or no difference in seedling size, nor in the number of acceptable seedlings.

KEYWORDS: conifers, spacing, seed sower, seedling morphology

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