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Lessons from Artificial Regeneration Studies in a Cutover Beetle-Killed Spruce Stand in Western Colorado

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Eleven specific lessons were learned about factors that affect seed germination, seedling establishment, and plantation success with Engelmann spruce and lodgepole pine.

This paper summarizes results from several separate but related studies of seeding and planting Engelmann spruce (Picea engelmannii Parry) and lodgepole pine (Pinus contorta Dougl.). The studies were made in a cutover stand of beetle-killed spruce on the White River National Forest in western Colorado. The 50-acre stand was at 10,500 feet elevation on a gentle northwest slope. A dense ground cover of forbs, grasses, and sedges developed after the area was salvaged logged in 1948.

Description of Studies

Seeding Studies

Seeding trials for spruce and pine were made in 1957, 1958, and 1959. Each trial contained 800 one-foot-square seed spots arranged in 5 blocks of 160 seed spots. Each block was subdivided into 4 treatments of 40 seed spots arranged in 4 equal rows. Spots in each row were 1 foot apart, and rows were 2 feet apart. There were 200 seed spots in each treatment.

All blocks were cleared to mineral soil before they were sown, and were weeded regularly to reduce vegetative competition. Seed spots were sown in late spring or early summer, with 15 seeds the first 2 years and 20 seeds the last year. The amount of viable seed sown, based on laboratory tests of treated seed, varied in each trial (see table 2). All seed was treated with an Endrin-Arasan-latex emulsion by the United States Fish and Wildlife Service.

Seeds were sown the same way in all treatments—soil was thoroughly loosened to a depth of about 1/8 inch, seed was mixed in, and the spot was packed lightly and uniformly. The following treatments (fig. 1) were applied to seed spots:

Shade—A cedar shingle 6-8 inches wide was placed on the south side of the seed spot.
Mulch—Seed spot was covered with a 1/2-inch layer of sawdust.
Shade-mulch—A combination of the above treatments.
No treatment—Used as a control.

Individual study objectives determined when treatments were applied. In 1957 it was desired to test treatment effect on survival only, whereas in 1958 and 1959 both germination and survival data were wanted. Treatments were applied in all trials when seed was sown, except in 1957, when seed spots were treated 3 weeks after they were sown, or 2 weeks after the first seedlings appeared.

The area between blocks and a 400-foot-wide buffer strip was baited with 1080-impregnated wheat on a 50- by 50-foot grid about 2 days before sowing. Seedling survival in each trial was checked biweekly during the first growing season. The 1957 pine trial was checked monthly in succeeding years.

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Figure 1.--Seed spots with shade treatment (left) and mulch treatment (above).

Treatment effect on germination was obtained from the 1958 pine and 1959 spruce seedings, while the 1957 pine seeding produced usable data on survival due to treatment. Spruce sown in 1957 and 1958 and pine sown in 1959 germinated so poorly that data were not analyzed.

Planting Studies

From 1957 through 1962, eight spruce and six pine planting studies were started to test the effect of different environmental factors on survival. Seedlings were hand planted in the spring by the deep-hole method on areas cleared to mineral soil and weeded at regular intervals. In those studies where shade treatment was applied, shingles were used as described in the seeding studies. Shingles were removed each fall to prevent snow from crushing them against the seedlings and causing possible injury.

Survival counts were made biweekly during the first growing season after planting. During succeeding years, survival was recorded in early spring and late fall.

Lessons Learned

1. Sawdust mulch can improve germination

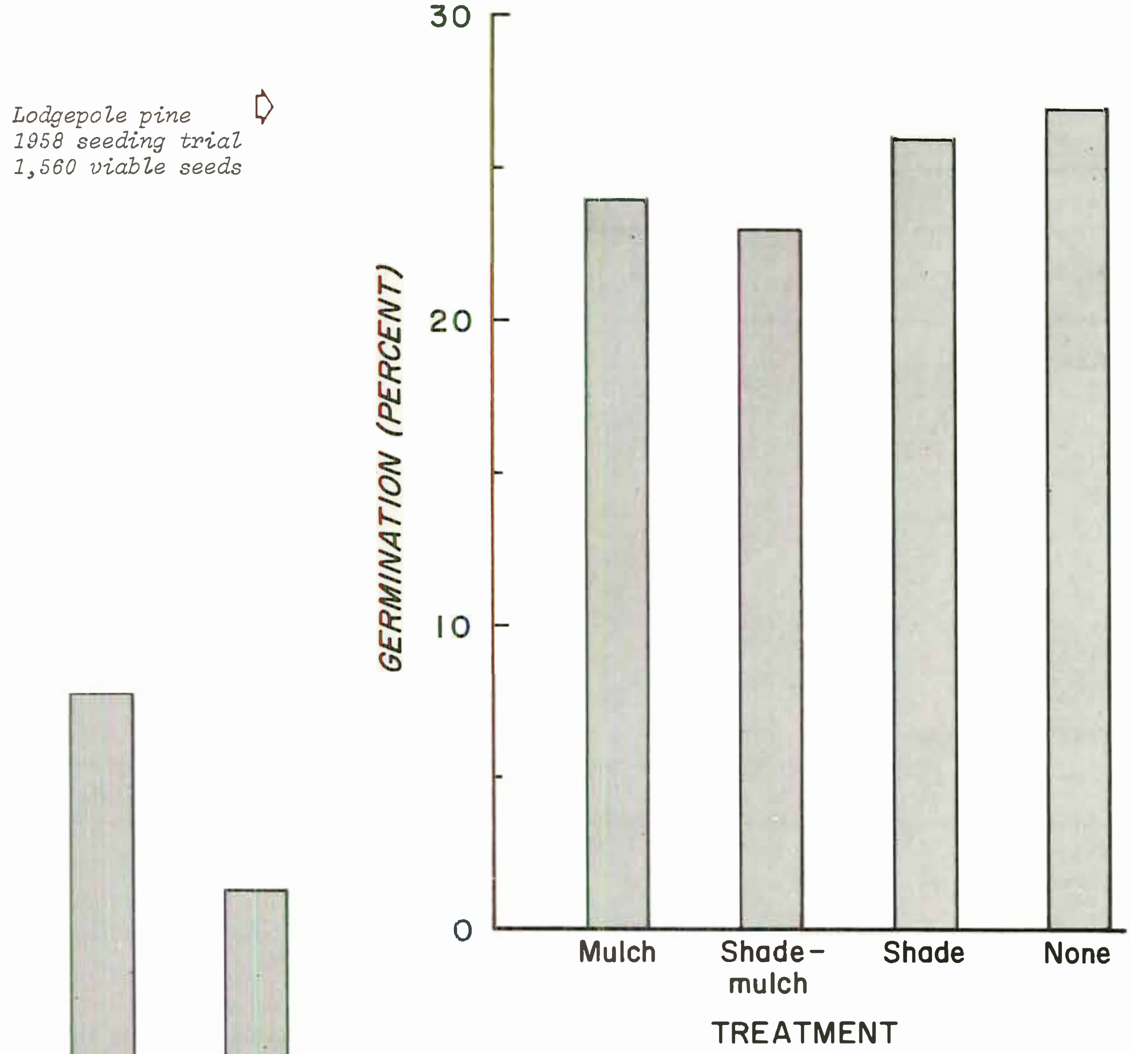
A sawdust mulch improved the germination of spruce seed, but germination of pine seed was not benefited by treatment (fig. 2). Since pine emergence did not begin until September 1 in 1958, soil and air temperatures during that period were probably below optimum for germination, regardless of treatment. The slightly higher initial germination in untreated seed spots, which would average warmer than mulched and shaded spots, tends to support that conclusion.

2. Time of germination of spring-sown seed is geared to summer precipitation

Although total rainfall was nearly the same during different trial years, its distribution markedly influenced the onset of germination (table 1). In 1957, rainfall was adequate and well distributed from 1 week before to 6 weeks after sowing. As a result, germination began the second week after sowing and was mostly completed by the end of the third week. Precipitation was less favorably distributed in 1958 and 1959, however, and as a consequence, germination was delayed for 7 or more weeks. In both those years, the start of germination was preceded by a period of about 2 weeks when weekly rainfall was about 1.5 inches.

3. A substantial portion of sown seeds may remain dormant for 1 year

Average total germination of sound seed was satisfactory in four out of six seeding trials, but the proportion of initial to holdover germination varied considerably (table 2). As soils remained dry through the summers of 1958 and 1959 until about September 1, after which temperatures were low, poor first-year germination probably resulted from adverse conditions rather than from embryonic dormancy.



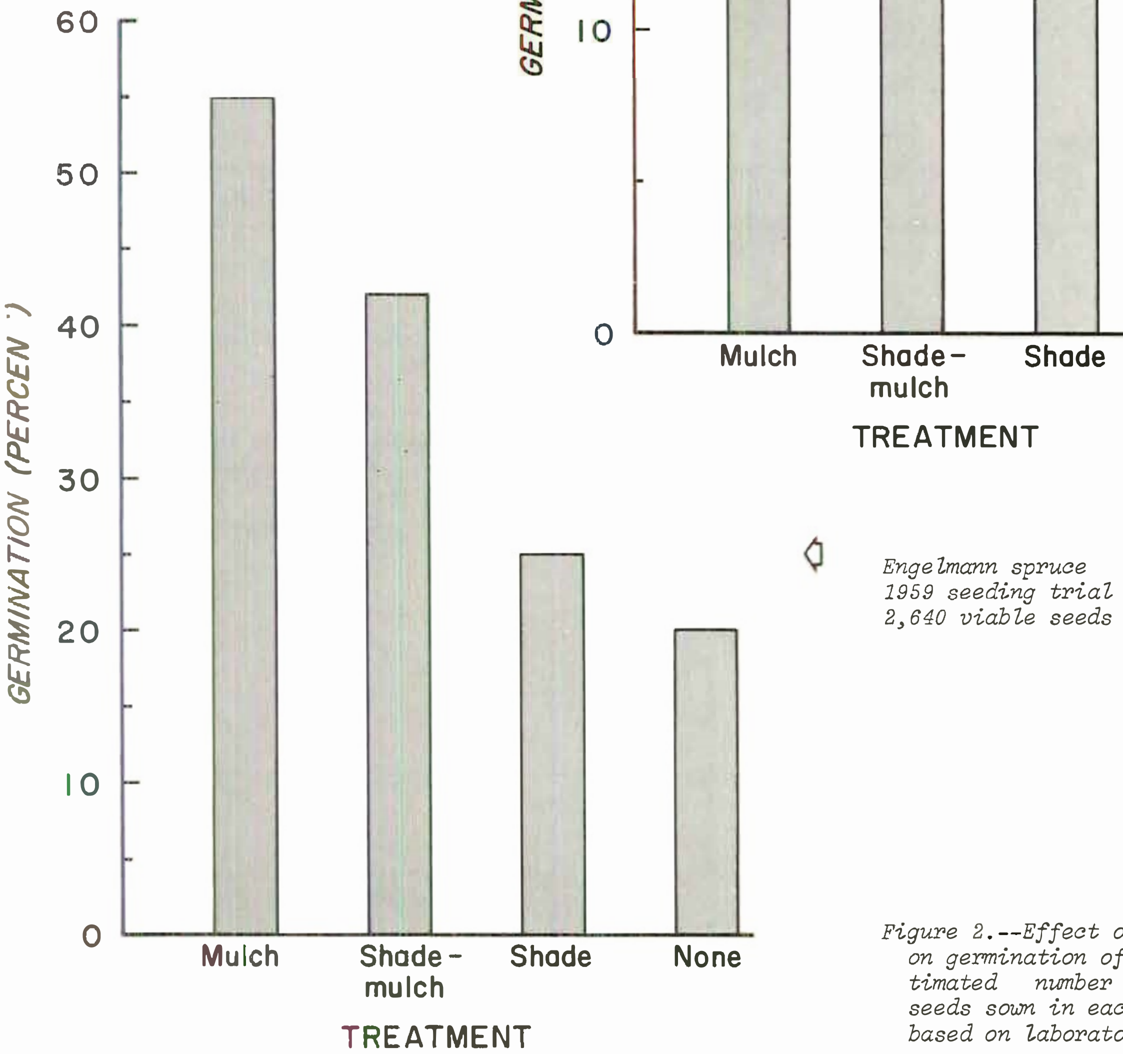


Figure 2.--Effect of treatment on germination of seeds (estimated number of viable seeds sown in each treatment based on laboratory tests).

Table 1.--Relationship of precipitation to proportion of germinated seeds that emerged at weekly intervals following sowing

Weekly periods before and after sowing date	Rain			Germinated seeds			
	1957	1958	1959	1957 Pine	1958 Pine	1959 Pine	1959 Spruce
	- - - Inches - - -			- - - - - - Percent - - - - - -			
Before sowing:							
2	0.24	([1])	0.74				
1	.78	0.36	1.10				
After sowing:							
1	1.46	.04	.20				
2	.44	.02	.07	([2])			
3	.62	0	.09	86			
4	.27	.38	.13	--			
5	.42	1.20	.62	9			
6	.66	.06	1.71	--	([2])		
7	.25	.27	.26	3	47	([2])	([2])
8	([1])	.03	.54		--	11	56
9	.40	1.18	.17		--	--	--
10	([1])	1.25	([1])		23	10	13
11	--	--	.06		--	--	--
Holdover germination				2	30	79	31
Total	5.54	4.79	5.69	100	100	100	100

[1] Trace.
[2] Limited.

Table 2.--Summary of seed sown and germination for all treatments in lodgepole pine and Engelmann spruce seeding trials

Species and year sown	Seed sown		Germination of viable seeds		
	Total	Viable[1]	Initial	Holdover	Total
	Number		- - - Percent - - -		
Lodgepole pine:					
1957	12,000	9,240	56	1	57
1958	12,000	6,240	44	19	63
1959	16,000	5,280	16	58	74
Engelmann spruce:					
1959	16,000	10,560	35	16	51

[1] Based on laboratory germination tests of treated seed.

4. Most seedling mortality is caused by frost heaving, mice, and damping-off fungi

In addition to the large number of seedlings killed by mice (table 3), many living seedlings were partially defoliated when rodents clipped seedcoats from cotyledons to which they were still attached.

5. Sawdust mulch and shade increase both survival and stocking of seeded lodgepole pines

After 3 years, average stocking in treated seed spots was nearly three times more than in untreated spots, even though percent survival was relatively low (table 4).

Table 3.--Causes of mortality in lodgepole pine and Engelmann spruce seedings during the first growing season after spring sowing

Causal agent	Germinated seeds			
	1957--Pine	1958--Pine	1959--Spruce	Average[1]
	- - - - - - - - - Percent - - - - - - - - - -			
Damping off	13.9	13.4	17.2	14.8
Unidentified	18.1	7.8	12.0	13.7
Mice	3.1	4.6	18.2	8.2
Frost heave	5.7	23.3	0	8.1
Heat	2.4	2.5	1.4	2.1
Trampled	3.5	.6	0	1.7
Leafhoppers	1.3	0	0	.6
Man	.2	.7	.4	.4
Gophers	.7	0	0	.3
Hail	.1	0	0	.1
Total	49.0	52.9	49.2	50.0

[1] Based on totals for both species and 3 years.

Table 4.--Yearly survival and 3-year stocking percentages in the 1957 pine seeding trial

Treatment	Germinated seeds	Survival[1]			Stocked seed spots,[2] 1959
		1957	1958	1959	
	No.	- - - - - - Percent - - - - - -			
Shade	1,286	56	14	11	30
Mulch	1,342	48	15	9	28
Shade-mulch	1,408	59	19	13	45
None	1,243	40	5	3	11
Average or total	5,279	51	13	9	28

[1] Based on number of seeds that germinated.
[2] Based on 200 seed spots sown in each treatment.

6. Successful seeding establishment cannot be expected when germination occurs late in the growing season

None of the seeds that germinated in the 1958 and 1959 pine trials, or the 1959 spruce trial, survived overwinter. Seedlings apparently did not harden off sufficiently to withstand the adverse fall and winter weather. In 1959, for example, peak germination occurred about September 1, but seedlings were still emerging when snow covered the area 2 weeks later. Late-germinating seedlings have little resistance to frost heaving (see table 3, 1958 pine trial).

7. Pocket gophers can destroy established plantations

Although mountain pocket gophers (Thomomys talpoides) destroyed some seedlings each year, losses were highest during a population peak the third and fourth winters when other environmental factors were no longer causing serious seedling mortality (fig. 3).

Nearly all seedlings destroyed by gophers were clipped just above ground level, but a few died from root destruction by burrowing animals. The higher proportion of total spruce mortality caused by gophers during winter as compared to summer may have been

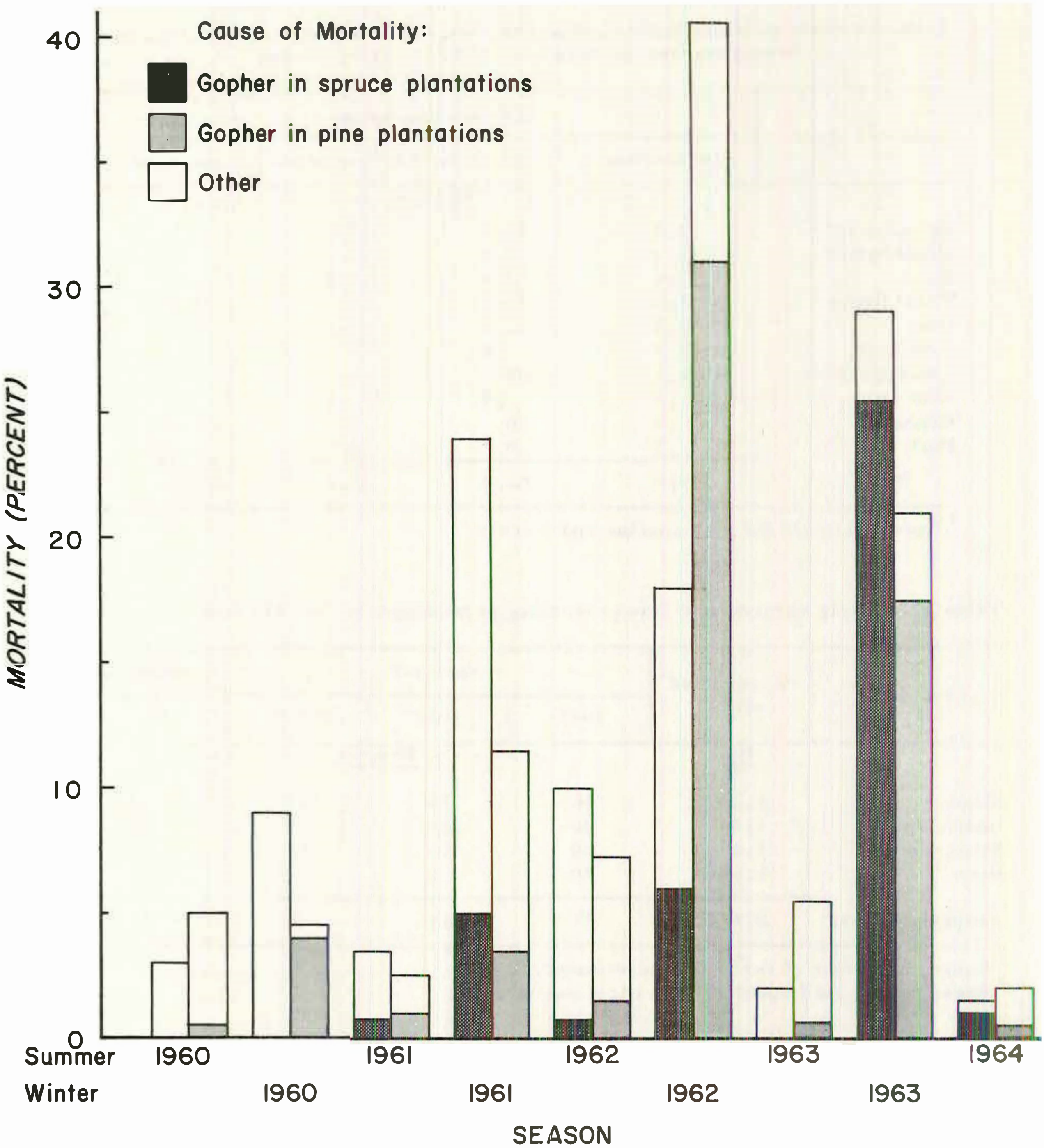


Figure 3.--Percent of total mortality by seasons caused by gophers and other factors after planting Engelmann spruce and lodgepole pine seedlings.

the result of woody plants becoming more important as food during the winter when green herbaceous vegetation was less abundant.[2] [3]

Plantations can be lost if gophers are not controlled, but the timing of control measures should be based on animal population surveys; population peaks are irregular, and planting sites vary in their capacity to support gophers. Gopher populations can be controlled indirectly by using herbicides to reduce forage plants[4] or directly by trapping or poisoning with strychnine or 1080-treated grain.[2] [5] [6]

8. New growth on planted spruces is extremely sensitive to frost

Low temperatures during the growing season killed new growth, even after it had fully expanded and set terminal buds. Injury was limited to current plantings in light frost years, but in 1962 and 1964, heavy frosts caused damage in plantations that were several years old (table 5). Regardless of plantation age, shaded seedlings suffered less damage than those grown in the open. Shade was more effective in reducing the number of injured seedlings in older than in current plantations.

Table 5, which shows only the percentage of injured seedlings, does not appraise total damage. All new shoots were generally killed on open-grown seedlings, while shaded seedlings, in contrast, rarely had more than one dead shoot (fig. 4).

Frost damage appeared to be inversely proportional to the amount of protection. In a study at the Fraser Experimental Forest it was found that open-grown seedlings had an average of eight frost-killed shoots, whereas the average on seedlings grown under shingles was less than one; seedlings grown under a canopy of cheesecloth suffered no damage.

Frost damage may have greater consequences than just loss of foliage. Until planted seedlings establish new roots and recover from planting shock, photosynthesis and subsequent food production are limited. Since reserve food, already depleted by preplanting storage, is used to form new shoots, the net result of frost damage is to reduce stored foods and the capability of the plant to replace those reserves. When summer foliage losses from frost are preceded or followed by winterkilling of branches by snow mold, a large percentage of the photosynthetic mechanism of a seedling may be lost.

Although frost injury occurs when nighttime temperatures drop below freezing, lethal temperatures in tissue are probably due to foliage becoming even colder than ambient air as it loses heat by radiation to clear skies. Frost damage can be greatly reduced or eliminated by planting seedlings against stumps or logs, which not only reduce radiation from the seedling to the sky, but also warm them by reradiating heat absorbed from the sun, and from the soil as it cools at night. Crowns of trees and shrubs also offer good protection.

[2] *Colorado Cooperative Pocket Gopher Project. Pocket gophers in Colorado. Colo. Agr. Exp. Sta. Bull. 508-S, 26 pp., illus. 1960.*

[3] *Ward, A. Lorin, and Keith, James O. Feeding habits of pocket gophers in mountain grasslands, Black Mesa, Colorado. Ecology 43: 744-749, illus. 1962.*

[4] *Keith, James O., Hansen, Richard M., and Ward, A. Lorin. Effect of 2,4-D on abundance and foods of pocket gophers. J. Wildlife Manage. 23: 137-145, illus. 1959.*

[5] *Hansen, Richard M. New dispenser aids gopher control. Colo. Agr. Exp. Sta. Pam. 1-S, 8 pp. 1959.*

[6] *Ward, A. Lorin, and Hansen, Richard M. The burrow-builder and its use for control of pocket gophers. U. S. Fish and Wildlife Serv. Spec. Sci. Rep.: Wildlife No. 47, 7 pp. 1960.*

Table 5.--Percentage of live Engelmann spruce seedlings injured by frost (injury recorded when a seedling had one or more dead current shoots)

Year injury recorded	Open-grown seedlings		Shade-grown seedlings	
	Older[1] plantations	Current plantations	Older[1] plantations	Current plantations
	Percent			
1957	--	0	--	0
1958	0	0	0	--
1959	0	57	0	27
1960	0	33	0	23
1961	0	72	0	8
1962	100	100	8	54
1963	0	--	0	--
1964	20	--	0	--

[1] Includes all plantations established in years prior to the year frost injury was recorded.

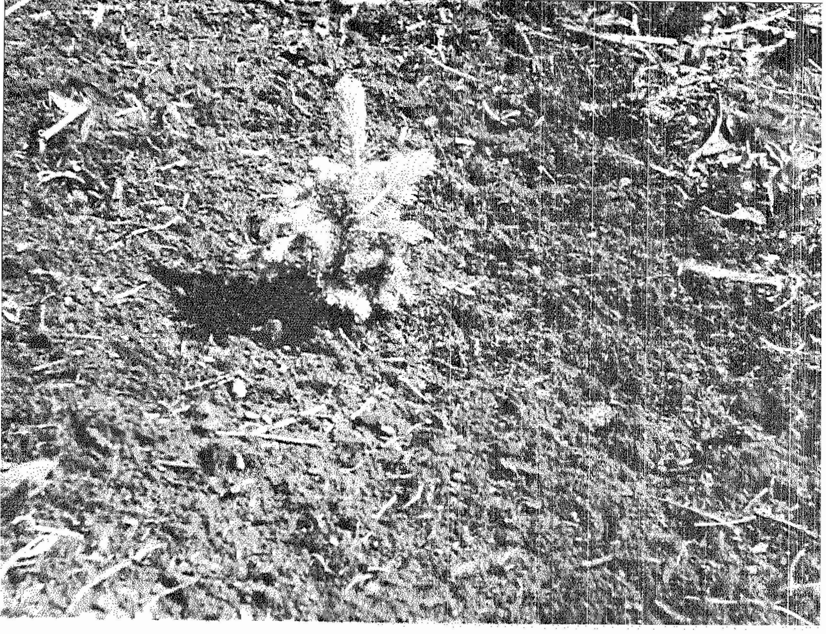


Figure 4.--Mid-August frost injury to an open-grown spruce seedling planted in June. All new growth was dead, and appears as lighter foliage in the photograph.

9. Planted pines are not injured by frost

Even though pines were grown adjacent to spruce plantations, neither shaded nor open-grown seedlings suffered frost damage.

10. Shade reduces incidence of snow mold

Open-grown spruces suffered more injury from snow mold than shade-grown spruces (table 6), but treatment had no effect on incidence of snow mold on pines. Little damage was found in pine plantings, however, except during the 1961-62 winter when snow mold was especially bad. During that winter, 21 percent of the 1,362 surviving pine seedlings suffered damage, which was equally divided between open-grown and shaded seedlings.

11. Survival of planted spruces was increased by shading, but pine survival was as good in the open as under shade

It has been demonstrated that spruce seedling mortality was heaviest during the first winter after planting, and that it could be reduced significantly by shading during the growing season.[7] Pine mortality, which averaged considerably less than spruce, was not reduced by summer shading.

[7] *Ronco, Frank. Planting in beetle-killed spruce stands. U. S. Forest Serv. Rocky Mountain Forest and Range Exp. Sta. Res. Note 60, 6 pp. 1961.*

Table 6.--Percentage[1] of live seedlings injured by snow mold in all Engelmann spruce planting trials (injury was recorded when a seedling had one or more branches killed)

Winter	Open-grown seedlings	Shade-grown seedlings
	- - - - Percent - - - -	
1957-58	32	19
1958-59	0	0
1959-60	24	0
1960-61	0	0
1961-62	30	19
1962-63	5	1
1963-64	0	0
1964-65	10	13

[1] The percent value in any given year includes the surviving seedlings from all trials planted up to 5 years previously.