Artificial Seeding of Pine in Central Oregon

by

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FOREST RESEARCH LABORATORY

The Forest Research Laboratory, Oregon State University, is part of the Forest Research Division of the Agricultural Experiment Station. The industry-supported program of the Laboratory is aimed at improving and expanding values from timberlands of the State.

A team of forest scientists is investigating problems of growing and protecting the timberland crop, while wood scientists endeavor to make the most of the material produced.

The current report stems from studies of forest management.

PURPOSE . . .

Develop the full potential of Oregon's timber resource by:

- increasing productiveness of forest lands with improved practices.
- improving timber quality through intensified management and selection of superior trees.
- reducing losses from fire, insects, and diseases--thus saving timber for products and jobs.

Keep development of the forest resource in harmony with development of other Oregon resources.

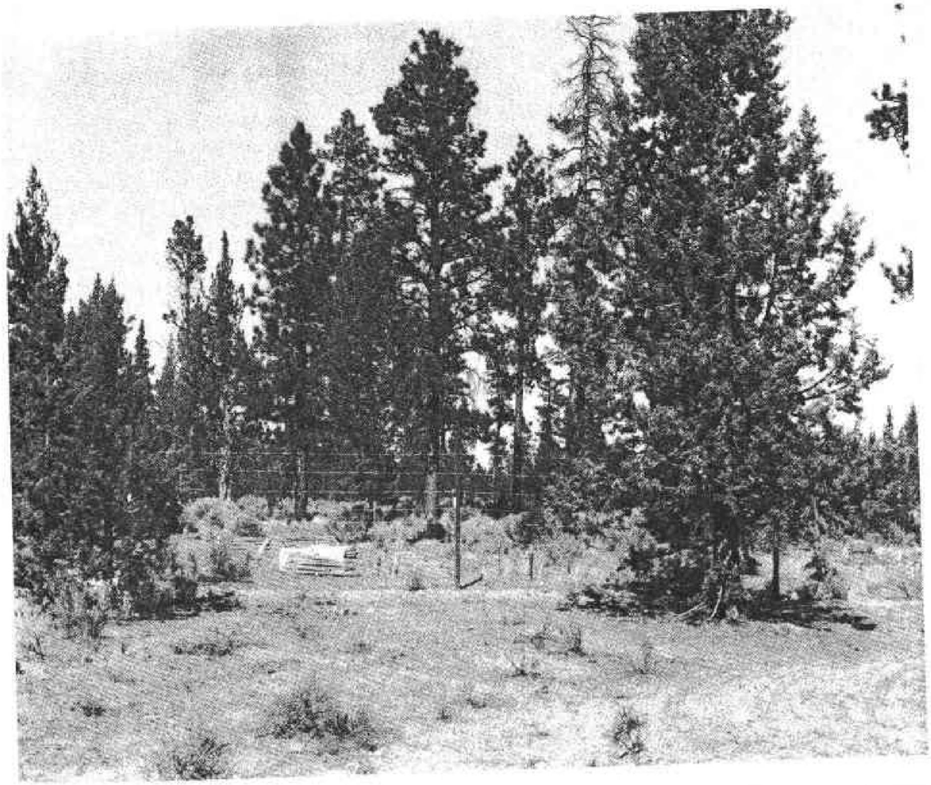
PROGRAM . . .

REGENERATION through studies of producing, collecting, extracting, cleaning, storing, and germinating seed, and growing, establishing, and protecting seedlings for new forests.

YOUNG-GROWTH MANAGEMENT through studies of growth and development of trees, quality of growth, relationship of soils to growth, methods of thinning, and ways of harvesting to grow improved trees.

FOREST PROTECTION through studies of weather and forest fire behavior to prevent fires, of diseases and insects to save trees, and of animals to control damage to regrowth.

TREE IMPROVEMENT through studies of variation, selection, inheritance, and breeding.



Part of the area at Tumalo Reservoir near Bend in central Oregon where artificial seeding of pine was studied.

ACKNOWLEDGMENTS

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SUMMARY

Past efforts to solve by artificial seeding the serious problem of regeneration in the eastern portion of the ponderosa pine region of central Oregon were largely unsuccessful. Continuing interest in artificial seeding and need for more information regarding environmental factors most critical for germination and initial development of pine in central Oregon prompted the present study.

Four areas, considered to be representative of common types of site, were chosen for the investigation. Plant and animal life, soils, and climatic features of these areas were studied and described.

Microclimatic conditions on different kinds of seedbed, mineral soil, pine needle litter, and brush litter, and their effect on germination and survival of seedlings were investigated in 1955. Mineral soil was found to be a more favorable seedbed than either kind of litter. Seedlings emerged earlier and temperatures remained lower on mineral soil than on litter, thereby reducing significantly losses of seedlings by heat on mineral soil.

Effect of shading on germination, survival, and development of seedlings in mineral soil was studied in 1956 and 1957. Shading had little effect on germination, but aided in survival of seedlings. Shaded seedlings showed increased growth in height, but poorer vertical and lateral development of roots than did seedlings in the open.

Drought was the most severe cause of mortality in the 1956-57 trial. Injuries caused directly and indirectly by frost contributed substantially to loss of seedlings. Fungi and insects did little damage.

Artificial seeding was judged unreliable for regenerating pine in the eastern portion of the ponderosa pine region of central Oregon. Too many environmental factors jeopardize emerging seedlings, and effective measures of protection are not economically feasible.

ARTIFICIAL SEEDING OF PINE IN CENTRAL OREGON

by

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INTRODUCTION

Chief objective of this investigation was to identify clearly those environmental factors that are most critical for establishing pine by direct seeding in the central Oregon counties of Wasco, Jefferson, Crook, Deschutes, Klamath, and Lake (Figure 1). Second aim was to determine variation of critical factors by locality within this region.

Some 150,000 acres of the six million acres of commercial forests of central Oregon are nonstocked. The problem of regenerating these forests is more serious than the nonstocked acres indicate, however, because little or no advance reproduction has become established under residual stands left from early logging.

Past trials with direct seeding in this region have produced discouraging results (9).* Continuing interest in seeding as a method for reforesting these areas was responsible for the present study.

Some two-thirds of the commercial forest of central Oregon is occupied by ponderosa pine.** The other third is stocked mainly with Douglas fir, lodgepole pine, and true firs. Since 1900, more than two million acres of ponderosa pine forests in the area have been logged. In early logging, ponderosa pine frequently was clear-cut, but cutting methods were followed later that removed only part of the stand.

The problem of regeneration is not equally serious throughout the region. In general, reproduction is satisfactory along the eastern slopes of the Cascade mountains. Difficulties in regeneration exist primarily in extensive plains to the east where annual precipitation is less than 20 inches.

While moisture is definitely a limiting factor in establishing seedlings in the eastern half of the pine belt, lack of natural reproduction may be caused by a combination of several factors. Every year, rodents and birds consume tremendous amounts of seed and drastically reduce

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*Numbers in parentheses refer to references cited.

**See Table 15, Appendix, for generic names of plants and animals discussed.

the number of seeds. Once a seedling has emerged, its survival is menaced by a harsh physical environment and depredation by animals. Years in which all conditions are favorable for germination and survival of natural reproduction are rare.

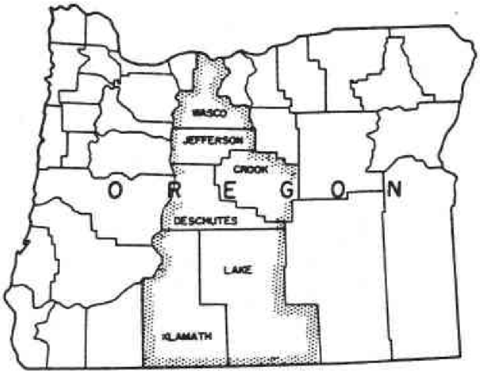


Figure 1. Counties in the pine region of central Oregon

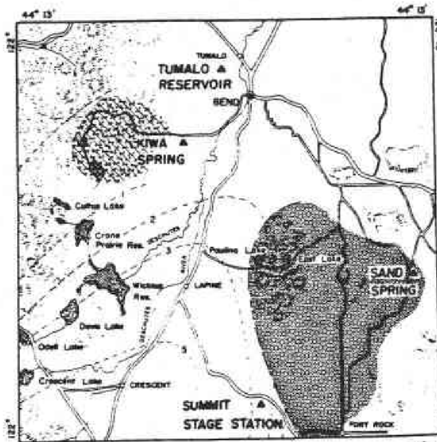


Figure 2. Locations of study areas, and origins of pumice deposits. Depth of Mazama pumice is indicated along broken lines. Devil's Hill is west of Kiwa Spring, and Newberry Crater is west of Sand Spring.

AREAS STUDIED

Soils and root structure, plant and animal life, temperatures of air and soil, precipitation, and soil moisture were examined at four diverse areas in selectively cut stands of ponderosa pine within 50 miles of the Newberry caldera at around 5000 feet elevation (Figure 2). General findings are described here; technical details are in the Appendix, Tables 11, 12, 13, and 14.

Soils and Root Structure

Soils at Summit Stage Station, Sand Spring, and Kiwa Spring were Regosols of the "Brown Forest Soils of the West."* A notable feature of soils at Summit Stage Station and Sand Spring was presence of difficultly penetrable, layered, gravelly pumice that caused storied formation of tree roots, as shown in Figures 3, 4, and 5. Pumice at Kiwa Spring was sandy.

Shallow soil at Tumalo Reservoir developed on alluvial sands mixed with pumice. This well-drained Brown Soil of the Deschutes series covers a rocky layer that has prevented roots of ponderosa pine from penetrating more than about 30 inches.

Storied roots on ponderosa pine were particularly evident at Sand Spring, where boundaries between layers of soil were distinct. Three zones of lateral roots developed in areas where Newberry pumice overlaid Mazama pumice, with layers of finer material between, above, and below (Figure 6).

Roots of rabbit-brush and sagebrush usually did not penetrate deeply in pumice layers, but spread horizontally at shallow depths (Figure 7). Bitter brush and squaw currant sent roots to depths of several feet.

Roots of ponderosa pine grew laterally at shallow depths in all areas. An extreme example of a large lateral root more than 100 feet long is shown in Figure 8.

Vegetation and Small Mammals

Most abundant rodent observed at Summit Stage Station, Sand Spring, and Kiwa Spring was the common western chipmunk. Others were the golden-mantled ground squirrel, Townsend's chipmunk, the

*The term, Brown Forest Soils of the West, is used to indicate that these soils do not fall in any of the officially recognized great soil groups.

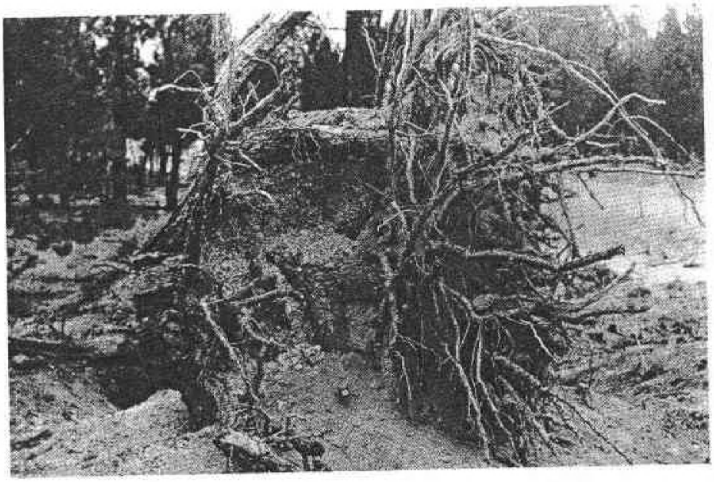


Figure 3. Two-storied root system of mature ponderosa pine at Sand Spring.

white-footed deer mouse, and occasionally Peale's meadow mouse and Great Basin pocket mouse (Appendix, Table 15). Signs of Deschutes pocket gophers were noted in these same three areas.

Summit Stage Station

Located in the north end of the Fremont National Forest, Summit Stage Station is characterized by mature stands of ponderosa pine in association with bitter brush, bottle-brush squirrel-tail and Elmer's stipa. The area had been logged selectively prior to 1948, leaving advance reproduction of ponderosa pine and lodgepole pine in sporadic groups.

Deer concentrate heavily here during fall and spring as they travel between forests and sagebrush desert in the east. A plantation of ponderosa pine established in 1948 nearly was destroyed by deer.

Although Summit Stage Station has served in some years as summer range for sheep, the area did not show signs of overgrazing.

Sand Spring

Sand Spring, easternmost of all areas studied, is near the eastern boundary of Deschutes National Forest, near the transition zone between pine forest and sagebrush desert.

The area had been logged in 1931. Cutting method followed was primarily economic selection.

Regeneration of both ponderosa pine and lodgepole pine has been poor since logging. Young trees that occur in small groups between mature trees were present at time of cutting.

Main vegetative cover at Sand Spring when studied was bitter brush, rabbit-brush, bottle-brush squirrel-tail, sagebrush, and squaw currant. General appearance of Sand Spring was that of an overgrazed area in which density of sagebrush and rabbit-brush had increased.

Kiwa Spring

Kiwa Spring is about 12 miles southwest of Bend in Deschutes National Forest. The virgin ponderosa pine was cut after 1920. The area since has become stocked with scattered groups of young-growth ponderosa pine. Numerous open spaces are occupied by Idaho bunchgrass and some manzanita and sticky laurel.

In addition to other rodents, snowshoe rabbits were present in brush fields adjoining the study area.

Tumalo Reservoir

Tumalo Reservoir is eight miles northwest of Bend. The original stand was largely ponderosa pine and scattered mature western juniper, with an understory of bitter brush and Idaho bunchgrass.

The area was logged by heavy selection cuts, leaving a scattered residual stand of ponderosa pine with groups of advanced reproduction. Following logging, the area was overgrazed and rabbit-brush became es-

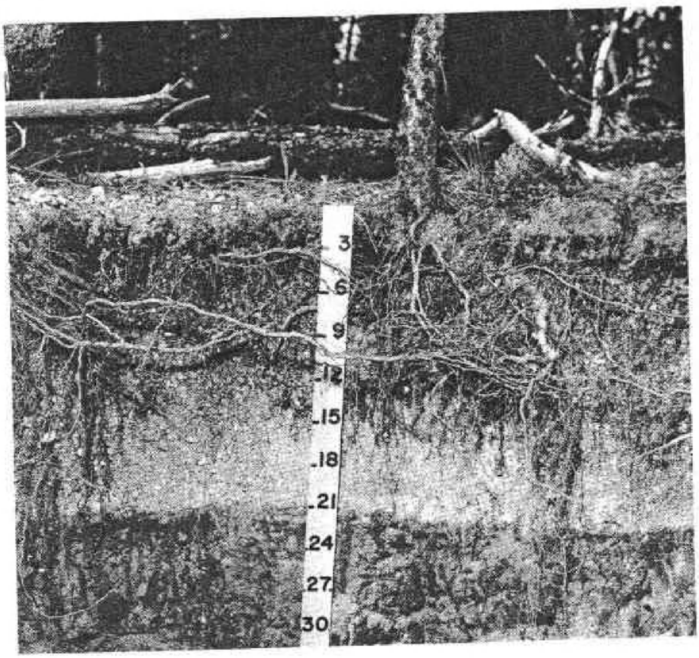


Figure 4. Roots of a 65-year-old ponderosa pine that had difficulty in penetrating a layer of pumice at Sand Spring.

tablished firmly. Western juniper has increased in the area since logging.

White-footed deer mouse was the predominant rodent found at Tumalo Reservoir. Other rodents present were common western chipmunk, golden-mantled ground squirrel, Great Basin pocket mouse, and Belding ground squirrel.

Climatic Conditions

Records of meteorological phenomena have been maintained at Bend for years. To compare these records with conditions at the four areas studied, temperatures, precipitation, and moisture in the soil were recorded at some or all of the four areas during parts of growing seasons from 1955 to 1958.

Temperature

The pine region of central Oregon has a distinctly continental climate, with hot summers and cold winters. Continental character of the

Figure 5. Root system of a 15-year-old lodgepole pine at Fremont siding. Horizons here are not separated so sharply as at Summit Stage Station, but even so, roots have penetrated deeply only through zones where fine material has been mixed with pumice gravel.

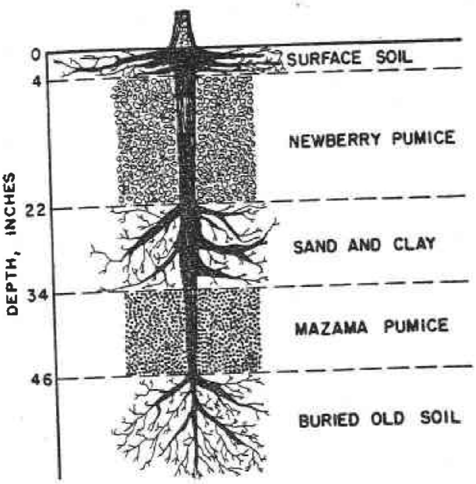


Figure 6. Schematic sketch of a 3-storied root system of mature ponderosa pine at Sand Spring. The buried old soil was fertile alluvial loamy sand.

climate also is indicated by large daily variations of temperature, especially during the growing season (Figures 9 and 10). Daytime temperatures in summer of 80 F and higher can fall to 32 F and below at night. Frosts occur any month (Table 11, Appendix). Limited data on temperature at the study areas indicated that frosts there were more frequent than at Bend.

Sand Spring usually reached the lowest daily minimum of the four study areas. Highest daytime temperatures, however, usually were attained at Tumalo Reservoir. However, the daily range in temperature at Kiwa Spring and Summit Stage Station often was nearly as great as at Tumalo Reservoir and Sand Spring.

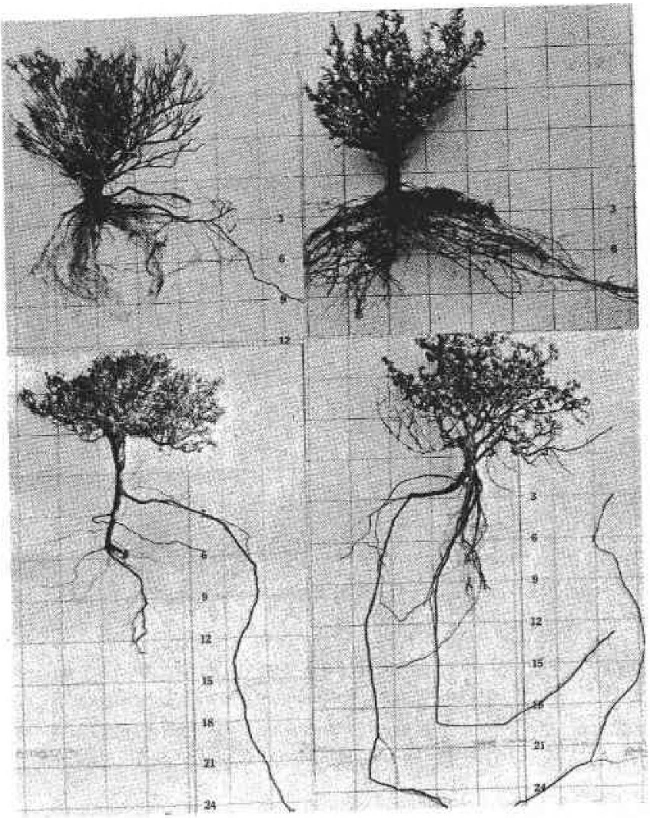
Precipitation

Annual precipitation in central Oregon ranges roughly from 10 to 20 inches. Extended periods of dry weather during summer months are common; in some years, as many as 12 consecutive weeks without rain have been recorded.

Rainfall recorded in the four study areas was sparse after May in 1957, but fell in reasonable volume until July in 1958 (see Table 12, Appendix).

From data recorded in the study, Sand Spring may appear driest and Summit Stage Station wettest of the areas, but a record of precipitation for two growing seasons probably is insufficient to allow a valid comparison of rainfall among study areas. Data from measurements of soil moisture in the study areas provide a truer picture of the supply of water for seedlings than do the available records on rainfall.

Rabbit-brush Sagebrush



Bitter brush Squaw currant

Figure 7. Roots of brush species at Sand Spring.

Soil moisture

During 1956 and 1957, moisture in soil was measured in the four study areas from May to October. Colman fiberglas units were placed at depths of 2, 9, and 18 inches in the study areas, except at Sand Spring. There, fiberglas units were placed at depths of 2, 12, and 24 inches. Units were buried in open areas without brush or dense herbaceous vegetation. Readings were taken with a Berkeley soil-moisture meter at weekly intervals.

Depletion of water to the permanent wilting point in the surface two inches of soil was noted during both years. Because dry weather began early in 1957, the permanent wilting point was reached about one month sooner that year than in 1956. However, this difference did not affect the trend of moisture depletion typical of each area (Figure 11).

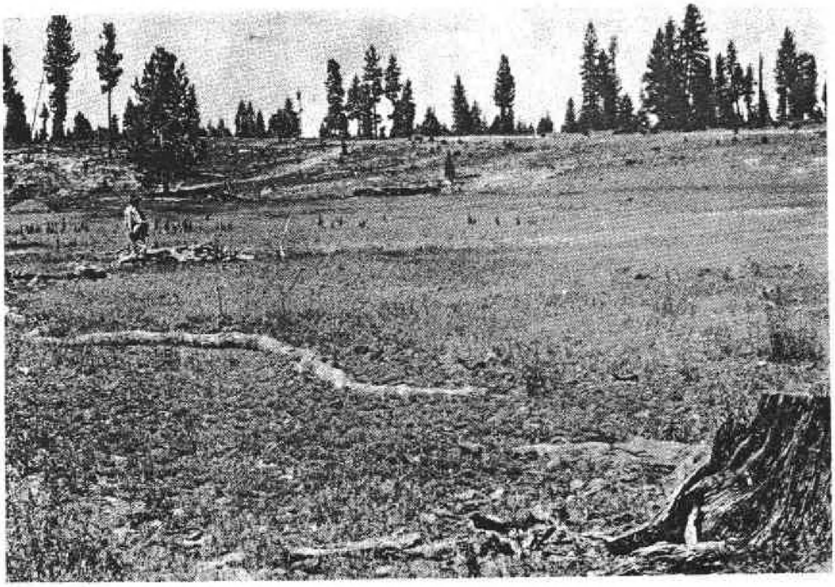


Figure 8. Lateral extension of roots in the area studied was exemplified by this mature ponderosa pine near Paulina Creek. The large root, bared by wind, was more than 100 feet long.

The uppermost two inches of soil at Tumalo Reservoir dried more rapidly than did soil near surfaces of the other areas. In 1956, the permanent wilting point was reached at Tumalo Reservoir by August first. Water remained in an unavailable state for the rest of the growing season. During the following year, moisture was depleted to the permanent wilting point by the first week of July and, except for a brief period in mid-July, was held at tensions above 15 atmospheres until the end of September.

Depletion of moisture to the permanent wilting point in the surface two inches did not occur until September in 1956 at Summit Stage Station, Sand Spring, and Kiwa Spring. Sand Spring was the first area and Kiwa Spring the last area to reach the permanent wilting point. The top two inches of soil in each area remained in this dry state only for a short time, as precipitation in early October quickly replenished the supply of moisture.

In 1957, a tension of 15 atmospheres was reached at Sand Spring by August 1, and at Summit Stage Station by August 20. Peak of moisture depletion occurred at Kiwa Spring late in September, but did not reach the permanent wilting point. As in the preceding year, rains in early October brought back favorable conditions of moisture.

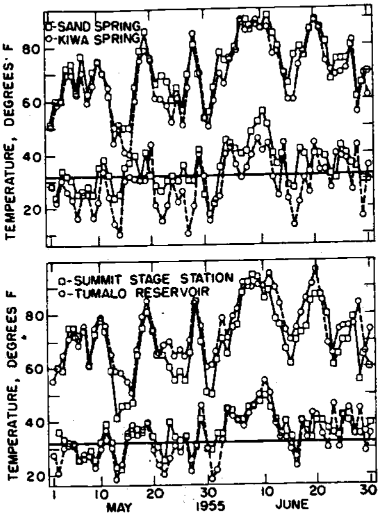


Figure 9. Maximal and minimal temperatures in the four areas during May and June of 1955.

Losses of water from the soil occurred in the surface soil earlier in 1957 than in 1956 (Figure 11). Nowhere did water in soil become depleted to the permanent wilting point at nine-inch depths, or below, but soil water was held early in the growing season at tensions above one atmosphere in some study areas. According to Richards and Wadleigh (10), a depression in vegetative growth is evident when moisture has reached a tension of one atmosphere. Water held at tensions greater than one atmosphere must be considered as difficultly available.

In 1956, a tension of one atmosphere was exceeded at depths of 9 and 18 inches early in July at Kiwa Spring and Tumalo Reservoir. The following year, the level of one atmosphere was reached at the 9-inch depth by mid-June, and at the 18-inch depth by early August. At Summit Stage Station, the tension of one atmosphere was not exceeded at the 18-inch depth until the end of the growing season in 1956 and 1957. Here, at the 9-inch depth, moisture became difficult to obtain in both years about one month later than it did at Kiwa Spring and Tumalo Reservoir. Water in soil at Sand Spring remained easily available at depths

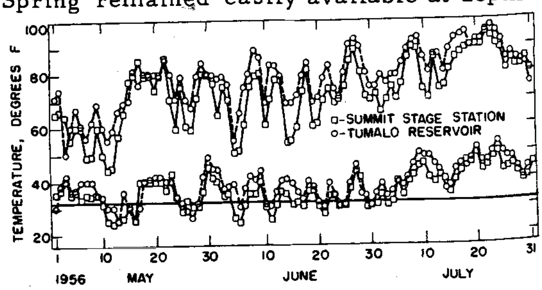


Figure 10. Maximal and minimal temperatures at Summit Stage Station and Tumalo Reservoir during the growing season of 1956.

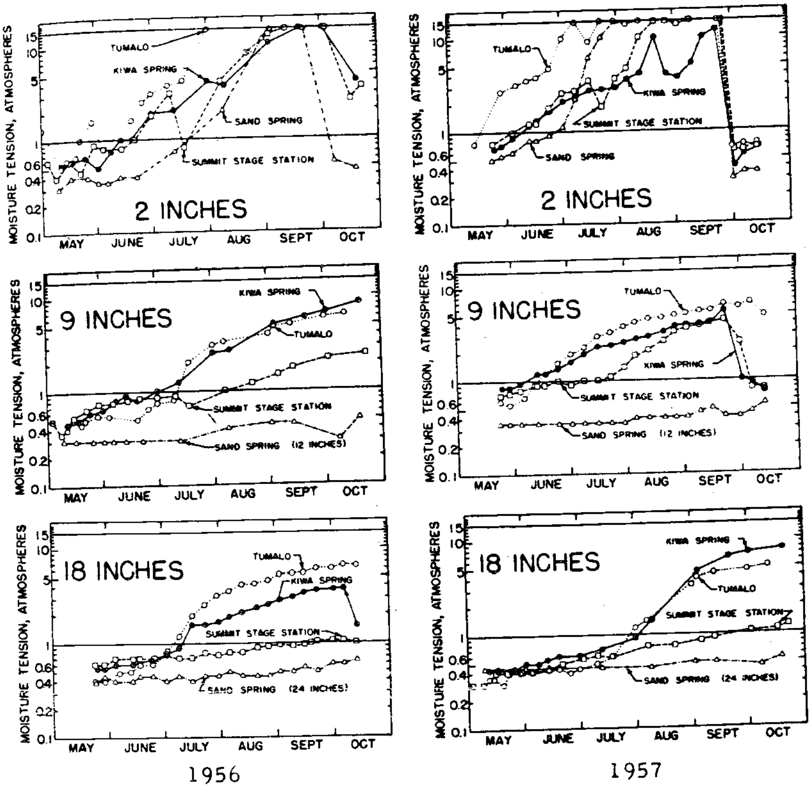


Figure 11. Trend of moisture depletion at three depths in the study areas during 1956 and 1957.

of 12 and 24 inches throughout the entire growing seasons of 1956 and 1957.

To summarize, Tumalo Reservoir had the most unfavorable moisture regime of the four areas studied. Both surface soil and subsoil dried rapidly after start of the rain-free season. At Kiwa Spring, moisture was retained considerably longer in the surface of the soil, but depletion of moisture in the deep layers of soil was almost as rapid as at Tumalo Reservoir. Pumice soils at Sand Spring and Summit Stage Station showed a remarkably high retention of moisture throughout the growing season, except for the surface layer of soil at Sand Spring. Gravel-sized pumice in the C horizon (4-24 inches) at Sand Spring was more effective in retaining moisture than was fine-textured pumice in the AC horizon (3-21 inches) at Summit Stage Station.

EFFECT OF SEEDBED

Studies of regeneration in many types of forests and climates have made foresters aware that nature of the seedbed may have a decisive influence upon germination and first-year survival of seedlings. Differences in physical characteristics of seedbeds can be expected to create widely differing microclimates in regions with a distinctly continental climate such as central Oregon. For this reason, present study began with an investigation of how seedbeds that are common to selectively cut stands of ponderosa pine affect initial establishment of pine seedlings.

Experimental Methods

Bare soil, pine needle litter, and bitter brush litter were selected as seedbeds at Sand Spring, Summit Stage Station, and Tumalo Reservoir. The same seedbeds were chosen at Kiwa Spring, except that manzanita litter was selected rather than bitter brush litter. Three plots, 18 inches square, were established on each type of seedbed, for a total of nine plots in each study area. Vegetation on and near the plots was removed to eliminate effect of competition by other plants and to expose the plots to full sunlight.

One-half of each plot was planted with 200 seeds of local ponderosa pine in October 1954; the other half of each plot was planted similarly to lodgepole pine. Seeds were placed at a depth of about three-quarters of an inch.

The seedbeds were screened with 5/16-inch-mesh hardware cloth to protect seeds from animals. The cages were placed over the seedbeds and left in place for duration of the study. Each study area was fenced with barbed wire to keep out livestock.

Information on microclimatic conditions on bare seedbeds and seedbeds covered with pine needle litter was obtained at Sand Spring and Tumalo Reservoir. During May and June 1955, surface temperatures were recorded continuously with Foxboro thermographs, whose sensitive elements were pressed horizontally halfway into surfaces of the seedbeds.

Results

Establishment of ponderosa pine seedlings was almost a complete failure. Since mortality of lodgepole was even greater and followed similar trends, remarks are restricted to ponderosa pine.

Table 1. Influence of Seedbed on Germination among 600 Ponderosa Pine Seeds in 1955 in Each of Four Areas.

Area	Mineral soil		Pine needle litter		Litter of brush species	
	No.	%	No.	%	No.	%
Summit Stage Station	499	83	405	68	478	80
Sand Spring	145	24	96	16	87	15
Kiwa Spring	392	65	484	81	399	67
Tumalo Reservoir	38	6	235	39	226	38

Germination

Proportion of seeds that germinated varied considerably among study areas. Germination was high at Summit Stage Station and Kiwa Spring, but was low at Tumalo Reservoir and Sand Spring (Table 1).

Relationship between type of seedbed and number of germinated seeds was not the same for each study area (Table 1). At Summit Stage Station and at Sand Spring, germination was higher on mineral soil than on litter-covered seedbeds, while the reverse was true at Tumalo Reservoir and Kiwa Spring.

Ordinarily, the surface of litter dries out more rapidly than does the surface of mineral soil. However, at Tumalo Reservoir the opposite was found.

Germination began on the mineral seedbeds during the second week of May and nearly was completed by the end of the month (Figure 12). On the litter-covered seedbeds, germination started a week later and extended into the second week of June.

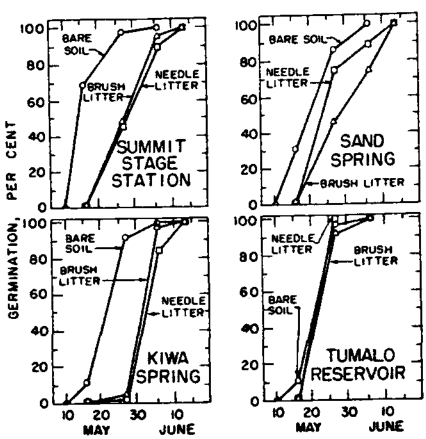


Figure 12. Time of germination on three different surfaces at the four study areas. Percentages are based on total seeds that germinated.

Table 2. Mortality of Ponderosa Pine Seedlings at End of First Growing Season, Per Cent, Based on Number Emerged from Each Type of Seedbed.

Seedbed	Cause of mortality					
	Heat	Disease	Insects	Rodents	Frost	Total
	%	%	%	%	%	%
Summit Stage Station						
Mineral soil	47	0	2	36	0	85
Needle litter	96	0	0	0	0	96
Bitter brush litter	100	0	0	0	0	100
Sand Spring						
Mineral soil	18	0	0	82	0	100
Needle litter	97	0	0	3	0	100
Bitter brush litter	97	0	1	0	2	100
Tumalo Reservoir						
Mineral soil	98	2	0	0	0	100
Needle litter	100	0	0	0	0	100
Bitter brush litter	100	0	0	0	0	100
Kiwa Spring						
Mineral soil	48	0	0	0	0	48
Needle litter	86	0	0	0	0	86
Manzanita litter	99	1	0	0	0	100

Mortality

Excessively high temperatures were reached on the seedbeds during warm weather of the last week of May. Under these circumstances, delay of germination on the litter-covered seedbeds proved fatal to seedlings. Most seedlings were killed by injuries from heat as soon as they emerged. Mortality from heat was significantly lower on mineral soil than on litter (Table 2), with exception of Tumalo Reservoir. Temperatures on the surface of the soil rose so high at this location that even seedlings several weeks old and on mineral soil succumbed to heat.

High temperatures were recorded on litter in each study area (Figure 13). However, litter-covered seedbeds at Sand Spring reached temperatures lethal to seedlings more frequently and for a longer period of time than did those at Tumalo Reservoir (Table 3). Furthermore, the difference in temperature between litter and mineral soil was considerably greater at Sand Spring than at Tumalo Reservoir. Higher

Table 3. Frequency and Duration of Temperatures above 140 F on Mineral Soil and Litter in Seedbeds in 1955.

Month	Mineral soil			Needle litter		
	Fre-quency	Duration		Fre-quency	Duration	
		Avg	Range		Avg	Range
	Days	Hours	Hours	Days	Hours	Hours
Sand Spring						
May	0	0	0	12	2.5	0.5-5
June	12	2.8	1-4	22	4.4	0.5-7
Tumalo Reservoir						
May	0	0	0	4	1.5	1-3
June	14	2.7	0.5-4	19	2.7	0.5-4.5

temperatures attained on litter-covered seedbeds at Sand Spring suggested that solar radiation was stronger in this location than at Tumalo Reservoir. Absence of a proportionate increase of temperature on mineral seedbeds at Sand Spring resulted in a wide gap in temperature between litter and mineral soil that probably was caused by nature of mineral soil. The surface layer of mineral soil at Sand Spring consisted of

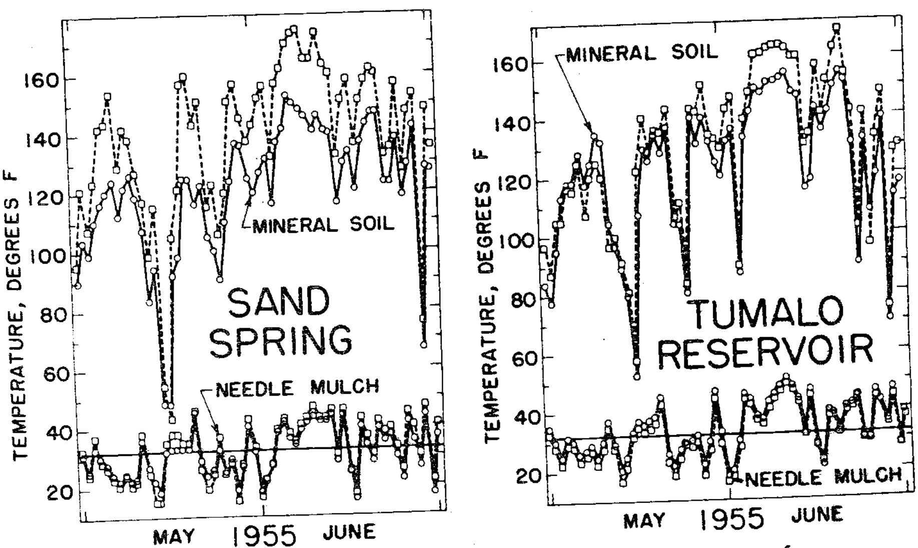


Figure 13. Maximal and minimal temperatures at the surface on mineral soil and needle mulch at Sand Spring and Tumalo Reservoir in early growing season of 1955.

whitish-gray pumice that was heated much less efficiently by insolation than was the surface layer of dark-brown loam at Tumalo Reservoir.

Mortality caused by heat did not occur after June 15. However, rodents destroyed most remaining seedlings at Summit Stage Station and Sand Spring (Table 4). Only on mineral seedbeds at Kiwa Spring did seedlings survive the first growing season.

Minimal temperatures on surfaces of seedbed frequently went below 32 F in both study areas (Figure 13). Here, again, was an interesting difference between temperatures on seedbeds at Tumalo Reservoir and Sand Spring. Litter reached lower temperatures than did mineral soil at Tumalo Reservoir, while the opposite, with few exceptions, was true for Sand Spring.

Ordinarily, materials that absorb heat readily during the day also reradiate heat strongly during the night, and become cooler than do other materials. Why this was not true at Sand Spring can not be explained satisfactorily. This phenomenon probably was caused in some way by physical properties of the pumice gravel at Sand Spring.

EFFECT OF SHADE

The first trial demonstrated that heat was instrumental in causing mortality of seedlings, especially on litter-covered seedbeds. Consequently, the effect of shade was studied in 1956.

Experimental Methods

Only bare soil was used as seedbeds at the four areas in 1956. Fully shaded, partially shaded, and unshaded plots, 18 inches square, were replicated three times at each study area, except at Kiwa Spring. There, eleven plots were established. Plots at Kiwa Spring were left unshaded because the tests in 1955 had shown that here, high temperature of the surface soil was not so important a factor in limiting survival of seedlings as it was in the other study areas.

Partial shade was created by a section of snow fence bent in a half-circle and placed over the seedbed (Figure 14). Full shade was provided by covering a section of snow fence with burlap (Figure 15). At any given time, about half of the area on the partially shaded seedbeds was shaded by slats of the snow fence. Intensity of light on fully shaded seedbeds was slightly less than five per cent of that of full sunlight.

Protection against rodents was improved by a simple device. A sheet-metal frame, 23 inches square and 7 inches deep, was dug into the ground. A cage of hardware cloth was fitted tightly inside the buried frame of sheet metal (Figure 16). The sheet-metal frame was intended to prevent large rodents, particularly the golden-mantled ground squirrel, from digging under the screen into the seedbed, or from moving the screen from the seedbed.

Plots were sown in October 1955, with seeds obtained from a nearby source. At Summit Stage Station, Sand Spring, and Kiwa Spring, nine plots were sown to ponderosa pine and lodgepole pine. At Kiwa

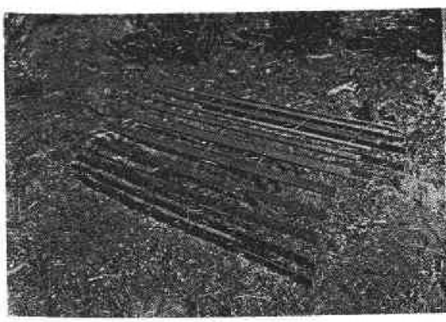


Figure 14. Partially shaded plot.

Figure 15. Fully shaded plot.

Table 4. Germination of Pine Seed in 1956 Under Various Conditions of Shade.

Shade	Ponderosa			Lodgepole			Jeffrey		
	Sown	Germinated		Sown	Germinated		Sown	Germinated	
			Per cent			Per cent			Per cent
Summit Stage Station									
None	600	539	90	600	349	58	--	--	--
Partial	600	518	86	600	404	67	--	--	--
Full	600	519	86	600	453	76	--	--	--
All plots	1,800	1,576	87	1,800	1,206	67	--	--	--
Sand Spring									
None	600	437	73	600	433	72	--	--	--
Partial	600	497	83	600	482	80	--	--	--
Full	600	477	79	600	392	65	--	--	--
All plots	1,800	1,411	78	1,800	1,307	73	--	--	--
Tumalo Reservoir									
None	600	334	56	600	324	54	--	--	--
Partial	600	388	65	600	322	54	--	--	--
Full	600	404	67	600	191	32	--	--	--
All plots	1,800	1,126	63	1,800	837	46	--	--	--
Kiwa Spring									
None	1,000	858	86	800	674	84	400	272	68

Spring, four plots were sown to ponderosa pine and lodgepole pine, one to ponderosa pine only, and two to Jeffrey pine. Each plot received 200 seeds of each species in that plot. Seeds were planted at a depth of three-quarters of an inch in all study areas. Germination of seed and development of seedlings were measured weekly during spring and early summer, and at monthly intervals for the remainder of the year.

Results

Shading the seedbeds had little effect on germination, but did aid survival of seedlings and modified their growth.

Germination

Germination began in all study areas about May 1, about two weeks sooner than it had in the preceding year, and was almost completed by the third week of May. Seeds of the three species of pine started to germinate at about the same time. Few differences were noted between the start of germination on unshaded, or partially shaded plots, but germination was delayed on fully shaded plots.

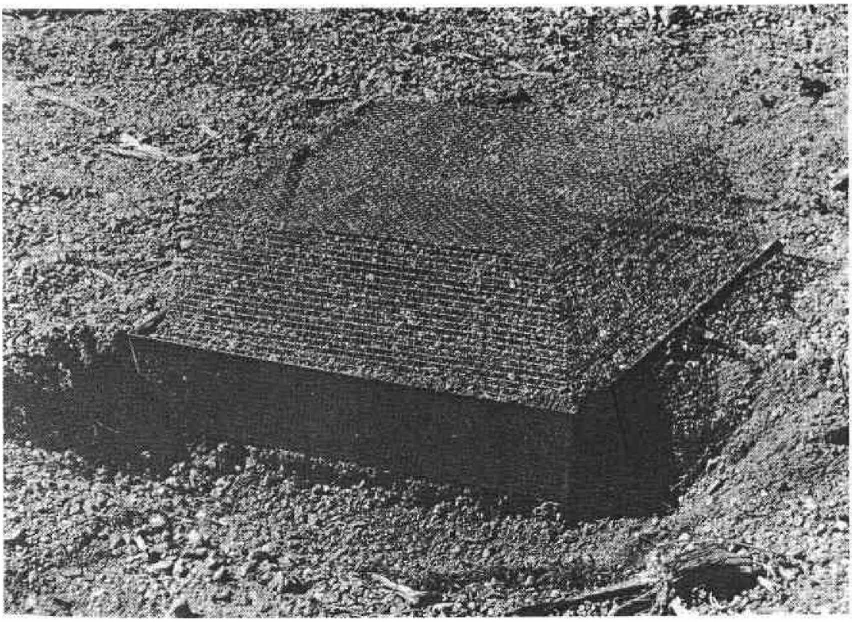


Figure 16. Exclosure for rodents, consisting of a cage of hardware cloth and a base of sheet metal.

Table 5. Percentages of Seedlings That Died between May 1956 and October 1957, Based on Number Emerged in Spring 1956.

Shade	Cause of mortality								
	Drought	Heat	Frost heave	Dis-ease	In-sects	Ro-dents	Win-ter*	Un-known	All
				PONDEROSA PINE					
Summit Stage Station									
None	21	0	3	3	3	0	0	0	30
Partial	14	0	1	5	2	0	0	2	24
Full	9	0	3	1	4	0	0	1	18
Sand Spring									
None	35	1	0	16	9	0	16	3	80
Partial	19	3	0	12	5	0	5	3	47
Full	25	0	0	11	2	0	5	1	44
Tumalo Reservoir									
None	.72	0	0	9	17	0	0	2	100
Partial	72	0	0	4	2	0	0	2	80
Full	41	0	0	8	9	0	0	4	62
Kiwa Spring									
None	44	0	35	3	5	2	0	0	89
				LODGEPOLE PINE					
Summit Stage Station									
None	53	0	17	8	12	0	0	0	90
Partial	42	0	12	1	8	0	0	0	63
Full	51	0	12	0	2	0	0	2	67
Sand Spring									
None	59	4	0	6	5	0	3	1	78
Partial	30	4	0	6	7	0	5	0	52
Full	28	0	0	9	2	0	4	1	44
Tumalo Reservoir									
None	74	0	0	5	6	0	0	13	98
Partial	86	0	0	2	3	0	2	2	95
Full	57	0	0	9	15	0	0	13	94
Kiwa Spring									
None	53	0	20	4	22	1	0	0	100
				JEFFREY PINE					
Kiwa Spring									
None	36	0	27	2	10	0	2	0	77

*Physiological drought in winter.

Differences among study areas in numbers of germinated seeds (Table 4) were small compared to the preceding year. Again, Tumalo Reservoir had the lowest germination of all study areas.

In all areas, ponderosa pine had a higher percentage of germinating seeds than had lodgepole pine. However, relationship between shade and germination was not discernible. Germination under any of the three conditions of light was not consistently either high or low in each area for either species (Table 4). At Summit Stage Station, for instance, germination of ponderosa pine was best on open, and poorest on fully shaded plots, but germination of lodgepole pine was poorest on open, and best on fully shaded plots. By contrast, this situation was reversed at Tumalo Reservoir.

At Summit Stage Station, many seeds were worked to the surface by frost without adversely affecting germination. Indications of frost heaving of seeds were not noted in the other study areas.

Mortality

Hot weather did not prevail in 1956 during the main period of germination, so there was no recurrence of an immediate mass killing of seedlings by heat as in 1955. However, various biotic and physical agencies, especially drought, did take a heavy toll of seedlings in the first 18 months after germination (Table 5). Causes of mortality will be discussed further.

Percentages of surviving seedlings in the four study areas (see Table 6) indicated the following:

- Tumalo Reservoir had the lowest survival of seedlings of all study areas.
- More seedlings survived of ponderosa pine than of lodgepole pine.
- Shading seedbeds increased survival of seedlings.

Survival of ponderosa pine was superior to that of lodgepole pine in only three areas. In the fourth area, at Sand Spring, there was little difference in survival between ponderosa pine and lodgepole pine. Shading seedbeds was apparently of little consequence to survival of ponderosa pine during the first year at Summit Stage Station, and to survival of lodgepole pine during the second year at Tumalo Reservoir.

Microclimate

Information was obtained about temperature on open and partially shaded plots at Tumalo Reservoir and Summit Stage Station. From May 1 to July 31, 1956, surface temperatures were recorded continuously by Foxboro thermographs, with temperature-sensitive elements buried halfway into the surface of the seedbed.

Comparison of daily maximal and minimal temperatures on unshaded and partially shaded seedbeds in the two areas (Figure 17) emphasized one fact immediately. The difference in temperature between unshaded and shaded seedbeds was much larger at Tumalo Reservoir than at Summit Stage Station. The obvious conclusion is that shading was more effective at Tumalo Reservoir than at Summit Stage Station. However, to appreciate the significance of this circumstance for development of seedlings, further consideration has to be given to the conditions of temperature on seedbeds in the two areas.

Maximal temperatures on partially shaded seedbeds were nearly the same in both areas (Figure 17). However, maximal temperatures on unshaded seedbeds were generally from 10 to 20 degrees higher at Tumalo Reservoir than at Summit Stage Station. Unshaded surfaces at Tumalo Reservoir not only reached higher temperatures, but these high temperatures occurred more frequently and lasted longer than at Summit Stage Station (Table 7). In July 1956, for instance, temperatures exceeding 140 F were reached every day of the month on unshaded seedbeds at Tumalo Reservoir. Temperatures on unshaded seedbeds at Summit Stage Station exceeded 140 F during the same month only on 15 days, and average duration of temperatures above 140 F was about one-fourth shorter than at Tumalo Reservoir.

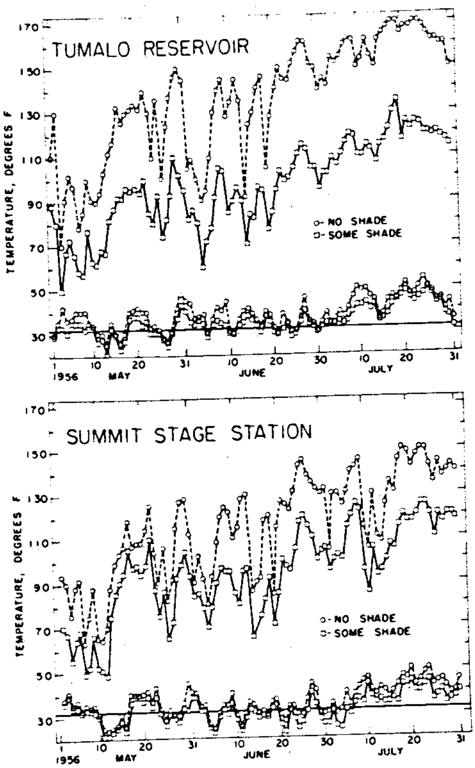
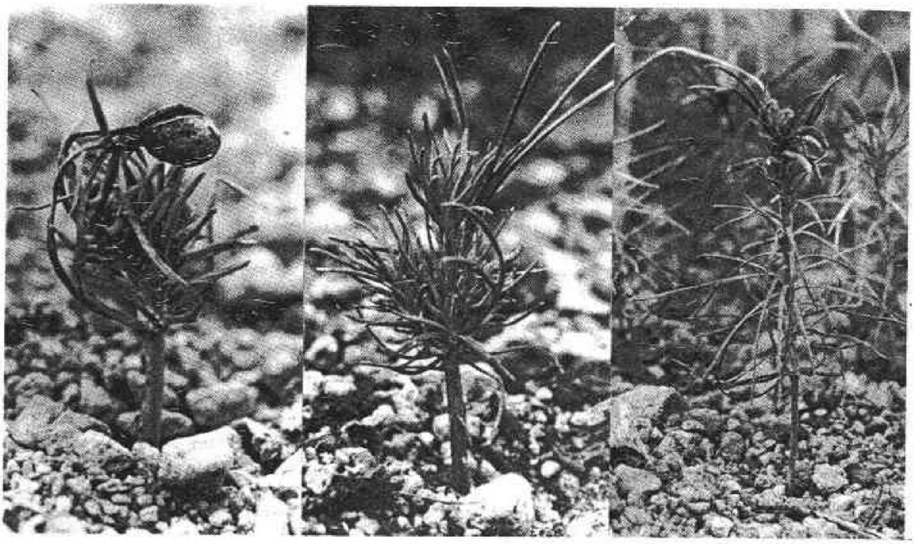


Figure 17. Maximal and minimal temperatures on partially shaded and unshaded seedbeds at Tumalo Reservoir and Summit Stage Station in the growing season of 1956.



A B C

Figure 18. Two-year-old seedlings of ponderosa pine at Sand Spring; A, unshaded; B, partially shaded; C, fully shaded.

Growth

At end of the first and second growing seasons, seedlings from each study area were selected at random and removed from plots for measurements of growth. Ten of the seedlings from each study area were obtained from unshaded plots, and ten from fully shaded plots. At Tumalo Reservoir, seedlings had to be selected from partially shaded plots, because few seedlings survived on the unshaded plots.

Differences in height were observed among species and seedlings that grew under different exposures to light (Figure 18). Height of Jeffrey pine and ponderosa pine consistently was greater than that of lodgepole pine. Shaded seedlings grew taller than did unshaded seedlings, regardless of species. Unshaded seedlings appeared stunted and had short needles that frequently were greenish-brown. At Sand Spring, seedlings on unshaded seedbeds still retained their seed coats by the end of the second growing season (Figure 18 A). Partially shaded seedlings looked healthy and vigorous, being in size between seedlings grown in the open and in full shade (Figure 18B). Although seedlings in full shade were tallest of all seedlings, they were slender (Figure 18C) and had long, yellowish-green needles.

Rapid development of roots of seedlings during the first and second year is likely to have greater significance for survival than will fast

Table 8. Length of Roots and Tops (in Inches) of Seedlings at the End of First (1956) and Second (1957) Growing Seasons.

Description of seedlings	Summit Stage Station		Sand Spring		Tumalo Reservoir		Kiwa Spring	
	Root	Top	Root	Top	Root	Top	Root	Top
End of first growing season								
Ponderosa pine								
No shade	9.47*	2.02	6.90	1.60	8.95**	1.75**	7.54	2.00
Shade	7.32	2.50	5.45	2.65	8.24	1.83	--	--
Lodgepole pine								
No shade	4.26	1.45	6.52	1.25	7.50**	1.34**	6.25	1.38
Shade	3.33	2.00	4.80	1.65	6.48	1.68	--	--
Jeffrey pine								
No shade	--	--	--	--	--	--	9.41	2.25
End of second growing season								
Ponderosa pine								
No shade	11.89	2.16	7.68	1.81	11.20**	2.28**	8.24	2.01
Shade	7.68	2.87	6.10	2.68	10.07	2.36	--	--
Lodgepole pine								
No shade	4.84	1.77	6.53	1.46	9.12**	1.50**	6.43	1.62
Shade	3.74	2.48	5.00	1.81	8.55	1.57	--	--
Jeffrey pine								
No shade	--	--	--	--	--	--	12.15	2.83

*Each value represents an average from 5 seedlings.

**Partial shade.

growth in height. Seedlings with deep roots are less likely to be affected by drought and by frost heaving.

Pattern of growth was similar in roots and stems, so far as differences in species were concerned. Elongation of roots of Jeffrey pine and ponderosa pine was greater than was that of lodgepole pine (Table 8). However, effect of shading on growth of roots was the reverse of the effect on increase in height. Roots of unshaded seedlings were longer than were those of shaded seedlings. Rapid drying of the surface soil was most likely the major reason for this difference in development of roots. At end of the first growing season, seedlings in the open and in shade showed little difference in development of lateral roots. This difference had changed by the end of the second growing season. Unshaded seedlings had more profuse lateral root systems than did shaded seedlings (Figure 19). Mycorrhizae formed on both exposed and shaded seedlings, but the proportion of black and white mycorrhizae differed distinctly on open and shaded plots.*

DIRECT SEEDING

In 1957, a small area at Kiwa Spring was seeded under conditions not strictly comparable to those of previous trials. However, the results were considered pertinent to the problem of establishing pine by seeding.

The study area at Kiwa Spring was joined at its western border by the old Big Spring Burn. This burn had failed to restock, and a solid cover of manzanita and sticky laurel had developed. Efforts to convert the brush fields into productive forest land provided an opportunity to test artificial seeding.

Brush on part of the burn was killed in 1954 with a 2, 4-D spray. Beneath the dead brush, 50 plots were seeded with tetramine-treated seeds of ponderosa pine and Jeffrey pine in the fall of 1956.

Some 293 seedlings of ponderosa pine and 288 seedlings of Jeffrey pine emerged during the spring of 1957. By end of the growing season, more than half of the Jeffrey pine seedlings and about one-third of the ponderosa pine seedlings remained alive. Mortality of seedlings was caused by a variety of factors, chiefly frost, drought, and insects, as can be noted in Table 9. Because the area was cleared the following year for planting, development of seedlings could not be followed further.

Table 9. Loss of Seedlings at Kiwa Spring at End of the First Growing Season; Percentages Based on Number of Seedlings Emerging.

	Cause of mortality						
Species	Drought	Heat	Frost	Insects	Rodents	Other	Total
Ponderosa pine	19	9	32	5	3	0	68
Jeffrey pine	6	3	10	20	0	2	41

*An investigation of mycorrhizal development on shaded and unshaded plots was made by Dr. E. Wright concurrently with the present study.

Some indication that texture of the soil may have influenced growth of roots was given at Sand Spring. Roots penetrated barely into the C_1 horizon, although moisture conditions there were highly favorable. Pumice gravel in the C horizon apparently presented a physical barrier that hindered elongation of roots.

Causes of Mortality

Physical and biotic agents causing mortality of seedlings varied in their effectiveness from year to year, and from one area to another (Tables 2, 5, 9). Despite this variation, an idea was obtained of the relative importance of various factors responsible for losses of seedlings.

Drought

The trial of shading in 1956 demonstrated that drought should be regarded as a major threat to establishment of seedlings by direct seeding in the eastern half of the pine region of central Oregon. At the same time, this study provided evidence that severity of the drought problem may vary considerably among different localities within this region.

Study areas were of two distinct groups in regard to mortality caused by drought. Tumalo Reservoir and Kiwa Spring suffered heavy losses of first- and second-year seedlings through drought, but such losses were comparatively small at Summit Stage Station and Sand Spring (see Table 10). The high mortality by drought at Tumalo Reservoir and Kiwa Spring was a consequence of rapid and severe depletion of soil moisture at these two areas (Figure 11). At Tumalo Reservoir, the situation probably was aggravated further by excessively high temperatures in seedbeds that must have caused abnormally high transpiration.

These extremely unfavorable conditions of soil moisture and temperature also explain why shading was most effective at Tumalo Reservoir (Table 10). Whatever amount of moisture was preserved under shade must have been of vital importance to seedlings in this area. At Summit Stage Station, on the other hand, shading did not appear to change the amount of moisture enough to be important for survival of seedlings.

The three species of pine were not affected equally by severe moisture stress. A much higher percentage of lodgepole pine than of ponderosa pine succumbed to drought in each study area on unshaded seedbeds as well as on shaded seedbeds. Jeffrey pine, in turn, proved to be more drought resistant than was ponderosa pine. The greater drought tolerance of Jeffrey and ponderosa pine probably was related to rapid development of their root systems. This view is supported by reports in the literature (4, 2, 6, 7) that rapid elongation of roots to escape drying of soil is an important factor in survival of tree seedlings.

Table 10. Effect of Shading on Mortality Caused by Drought in 1956 and 1957.*

Area	Ponderosa pine						Lodgepole pine						Jeffrey pine	
	No shade		Partial shade		Full shade		No shade		Partial shade		Full shade		No shade	
	1956	1957	1956	1957	1956	1957	1956	1957	1956	1957	1956	1957	1956	1957
Summit Stage Station	8	15	9	5	5	4	51	49	16	42	19	49	--	--
Sand Spring	21	33	17	5	14	19	48	51	18	23	16	18	--	--
Tumalo Reservoir	95	100	49	49	14	35	94	50	78	63	75	39	--	--
Kiwa Spring	36	48	--	--	--	--	66	100	--	--	--	--	26	23

*Percentages for 1956 are based on the numbers of seedlings emerged in spring 1956; percentages for 1957 are based on the numbers of seedlings alive on May 15, 1957.

Most of the mortality caused by drought occurred late in the growing season, when soil-moisture stress became most severe, but soil did not have to reach the permanent wilting point before seedlings were killed by drought. This reaction was particularly noticeable in 1957. Permanent wilting point was reached only in the uppermost two inches of soil. Seedlings were in their second year of growth, and their roots had penetrated into deep layers of soil. Mortality caused by drought was considerable toward the end of the second growing season. High temperatures and strong winds probably had caused excessive transpiration. In consequence, the water balance of many seedlings became so unfavorable that they were killed, although available moisture in the soil was not exhausted completely.

Heat

Injury by heat long has been recognized as a frequent cause of mortality of seedlings. Numerous investigations have established that excessively high temperatures of surface soil are mainly responsible for this kind of mortality (13).

Mortality caused by heat accounted largely for failures in the trial of various seedbeds (Table 2). The main period of germination in 1955 coincided with a period of high temperatures. Most emerging seedlings were killed even before they had shed their seed coats.

The part of the seedling that was injured by heat was dependent on the type of seedbed. Heat constrictions were found around the bases of stems on seedlings that grew in mineral soil. Seedlings growing through litter composed chiefly of needles displayed constrictions on the upper portion of the stem, because the lower part of the stem had been protected by litter. When cotyledons were at, or near, the surface of the layer of litter, they, rather than the stem, were injured.

In the trial of shading, heat caused losses of seedlings only at Sand Spring, and there these losses were negligible (Table 5). Similarly, mortality of seedlings caused by heat was modest in the trial of direct seeding in the old Big Spring Burn adjacent to Kiwa Spring. Injury by heat occurred only in first-year seedlings early in the growing season in both trials.

Lack of mortality by heat in 1956, particularly at Tumalo Reservoir, was surprising because of temperatures measured on surfaces of seedbeds. Temperatures of seedbeds in excess of 140 F prevailed at Tumalo Reservoir for a daily average of nearly four and three-quarter hours in July 1956. Temperatures of such magnitude and duration were lethal for two-month-old seedlings of ponderosa pine in the laboratory experiments of Baker (1), Roeser (11), and Paelinek (8).

Frost

Frosts may occur in the pine region of central Oregon throughout the entire year (Table 11, Appendix). They may lead to mortality of seedlings in different ways; by actual freezing of seedlings, by frost heaving, or by physiological drought in winter.

Internal formation of ice, causing rupture of tissues and dehydration of the protoplasm, has been considered responsible for killing by frost (5). A few seedlings killed directly by frost were found in spring of 1956 at Tumalo Reservoir and at Kiwa Spring. Considerable mortality caused by frost occurred in spring of the following year at the old Big Spring Burn (Table 9). Injury to seedlings by frost became noticeable when needles reddened, or when needles and upper parts of stems showed amber discoloration.

Alternate freezing and thawing of the soil tends to lift seedlings out of the ground. This process was discussed in detail by Schramm(12). Frost heaving results frequently in death of seedlings because roots are broken or the roots become exposed and dry out.

Frost heaving was observed in late fall 1956 at Kiwa Spring and in spring 1957 at Summit Stage Station and Kiwa Spring. Losses of seedlings were highest at Kiwa Spring (Table 5), probably because of severity of frost heaving in this area. Lodgepole pine was lifted more rapidly than were ponderosa pine and Jeffrey pine, resulting in higher mortality of lodgepole pine seedlings. Because the percentages were based on numbers of seedlings emerged in spring 1956, Table 5 gives the erroneous impression that at Kiwa Spring, lodgepole pine suffered less from frost heaving than did ponderosa pine or Jeffrey pine. If based on numbers of seedlings alive on October 20, 1956, percentages of seedlings killed by frost heaving are 97 for lodgepole, 59 for ponderosa, and 33 for Jeffrey pine.

Physiological drought in winter occurs on warm days while the ground is still frozen. Roots of seedlings in frozen ground cannot replenish rapidly enough water lost by increased transpiration, so tops of seedlings dry out. This type of mortality was encountered at Sand Spring in early spring of 1957, but losses of seedlings were few (Table 5).

Fungi

Damping-off fungi caused mortality of newly germinated seedlings in spring of 1956 (Table 5). Isolations showed that the fungi belonged to *Fusarium* and *Pythium* spp. Severity of infection could not be related to degree of shade on seedbeds.

Insects

Most losses of seedlings caused by insects were attributed to leaf-cutting ants (Table 5), that fed on and shredded needles and stems of first-year seedlings. Activity of these insects extended throughout the entire growing season, but was most pronounced in late May and June.

These ants nest in underground chambers that open to the surface with a small hole surrounded by a crater. Losses of seedlings were most severe on those parts of the plots that were adjacent to nests.

A different type of damage by insects was observed on Jeffrey pine seedlings in late fall of 1957 at the Big Spring Burn. Needles were clipped off either partially or completely. The insect that caused this damage could not be determined, but the injury suggested that grasshoppers were responsible.

Rodents and birds

Rodents and birds probably constitute two of the most serious menaces to regeneration in the ponderosa pine region of central Oregon. Considerable efforts were made during study to exclude rodents and birds from plots. Despite these efforts, heavy losses of seeds and seedlings occurred in 1955 at Sand Spring and to a lesser degree at Summit Stage Station (Table 2).

At Sand Spring, large tunnels were dug under cages into the plots, and both seeds and seedlings were eaten. Soil on the plots was disturbed thoroughly. In some instances, cages were moved completely off seedbeds. Damage probably was done by the golden-mantled ground squirrel, most abundant seed-eating rodent in this area. Later observations on behavior of this animal when enclosed inside cages demonstrated its ability to move such cages.

At Summit Stage Station, cages also were undermined and seeds and seedlings destroyed. Damage indicated the activity of an animal other than the golden-mantled ground squirrel, however. There was little disturbance of the soil, except for small pits where seeds had been. Seedlings were cut at the ground line, or their cotelydons were partly clipped. Conclusive evidence was not obtained as to the animal that caused losses, but indications were that the Great Basin pocket mouse may have been responsible.

Sheet-metal frames that were inserted underneath cages in 1956 prevented damage by rodents, except at Kiwa Spring. There, Deschutes pocket gophers tunneled under the sheet-metal frames and killed some seedlings (Table 5).

Birds feed on ponderosa pine seeds (3) and seedlings, but determination of the extent of damage by birds met with extraordinary difficulties. Cages used in the present study protected seeds and seedlings from depredations by birds, but extensive damage by birds to natural regeneration was observed at Summit Stage Station, Kiwa Spring, and Tumalo Reservoir. Seed coats were plucked from the tips of the cotyledons, or the entire top of the seedling was clipped.

CONCLUSIONS

Artificial seeding cannot be regarded as a reliable method of establishing new forests in the eastern half of the pine region of central Oregon. Too many environmental factors jeopardize regeneration by direct seeding, and effective measures of protection are not economically feasible.

Of all climatic factors that limit regeneration by direct seeding, drought occurs most regularly. Almost every summer has from 8 to 14 consecutive weeks without precipitation.

Conditions of drought are not equally severe on all sites. Soils that consist largely of unweathered pumice have high capacity for holding water and lose moisture more slowly than do mature soils.

Shade retards desiccation of the soil and aids in regeneration by direct seeding.

Drying of soil usually is accompanied by high temperature of the surface layer. However, mortality caused by heat has to be feared mainly when hot spells occur early in the growing season. High temperatures in seedbeds have disastrous effects during or immediately after germination of seeds.

Shortly after emergence, seedlings were killed quickly by heat in all types of seedbeds. Seedbeds of litter were heated rapidly even in mild weather and reached lethal temperatures, while temperature in seedbeds of mineral soil remained well below the critical level.

Frost is the third climatic factor that poses a serious threat to survival of seedlings. Because frosts occur throughout the year, danger of damage by frost is always present. Physiological drought and frost heaving are menaces during the cold months of the year.

The harsh climatic conditions of central Oregon were endured better in the seedling stage by Jeffrey pine and ponderosa pine than by lodgepole pine.

Aside from a severe climate, certain biotic agents constitute other obstacles to regeneration by direct seeding. Depredation of seeds and seedlings by rodents and birds is a potential threat to any seeding project. Insects and damping-off fungi, however, are unlikely to be limiting factors to regeneration of pine by direct seeding.

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APPENDIX

Tables of data on frosty days, precipitation during growing seasons, profiles for soil of the four areas studied, a table of chemical characteristics of the four sites, and a list of common and generic names for plants and animals that were significant in the study are included here.

Frost and Precipitation

Table 11. Number of Days with Frost Recorded at Bend and at the Study Areas.

Month	1955					1956			1957
	Bend	Summit Stage Station	Tumalo Reservoir	Sand Spring	Kiwa Spring	Bend	Sand Spring	Tumalo Reservoir	Bend
Jan.	27	--*	--	--	--	26	--	--	31
Feb.	27	--	--	--	--	28	--	--	25
Mar.	31	--	--	--	--	27	--	--	22
April	25	--	--	--	--	22	--	--	23
May	21	15	22	28	22	8	10	10	7
June	6	1	6	10	6	8	15	8	4
July	7	--	4	12	4	0	3	1	2
Aug.	2	--	--	13	--	1	2	3	5
Sept.	12	--	--	--	--	10	7	--	6
Oct.	19	--	--	--	--	21	--	--	17
Nov.	22	--	--	--	--	26	--	--	27
Dec.	26	--	--	--	--	25	--	--	26

*No data.

Table 12. Precipitation in Inches at the Four Study Areas During Two Growing Seasons.

Month	Tumalo Reservoir		Kiwa Spring		Summit Stage Station		Sand Spring	
	1957	1958	1957	1958	1957	1958	1957	1958
May	1.08	1.34	1.08	1.19	1.06	1.02	1.01	1.79
June	0.10	3.43	0.20	2.85	1.01	4.22	0.17	2.24
July	0.22	1.09	2.90	0.66	0.43	1.57	0.09	0.90
Aug.	0.15	0.0	0.40	0.0	0.09	0.0	0.0	0.0
Sept.	0.75	0.37	0.34	0.45	2.46	0.29	1.42	0.0
Oct.*	0.45	0.0	1.19	0.02	1.30	0.0	0.76	0.20
Total	2.75	6.23	6.11	5.17	6.35	7.10	3.45	5.13

*First half of the month only.

Soil Profiles

Three of the areas, Kiwa Spring, Sand Spring, and Summit Stage Station, had soil classified as Regosols of the "Brown Forest Soils of the West." These contained difficultly penetrable layers of pumice from the early explosion of Mt. Mazama, or from later eruption of the Newberry caldera and Devil's Hill.

Soil at Tumalo Reservoir was a Brown Soil of the Deschutes series.

Profiles that follow exemplify characteristics of the four areas.

Table 13. Soil Profiles for the Four Study Areas.

Kiwa Spring

Horizon	Depth Inches	Color	pH	Texture
A_1	0-3	Dark reddish-brown, 5 YR 2/2 moist*	5.2	Loamy sand, single-grain, dry loose, moist loose, nonsticky, nonplastic
AC	3-8	Reddish-brown, 5 YR 3/4 moist	5.2	Loamy sand, single-grain, dry loose, moist loose, nonsticky, nonplastic
C	8-18	Reddish-brown, 5 YR 3.5/4 moist	5.5	Loamy sand, single-grain, dry loose, moist loose, nonsticky, nonplastic
D_1	18-32	Reddish-brown, 5 Yr 3/4 moist	5.5	Sandy clay, massive, moist friable, slightly sticky, slightly plastic
D_2	32+	Yellowish-red, 5 YR 4/7 moist	5.8	Clay, weak-fine, medium subangular blocky, moist firm, sticky, plastic

*Munsell color notations as described in Soil Manual, Handbook 18, U. S. Dept. of Agriculture.

Table 13. (Continued).

Sand Spring

Horizon	Depth Inches	Color	pH	Texture
A_1*	0-2	Very dark brown, 10 YR 2/2 moist**	6.3	Loamy coarse sand, single-grain, dry loose, moist loose, nonsticky, nonplastic
AC	2-4	Dark brown, 10 YR 6/3 moist	6.0	Gravelly loamy coarse sand, single-grain, dry loose, moist loose, nonsticky, nonplastic.
C_1	4-18	Pale brown, 10 YR 6/3	6.0	Coarse pumice gravel, single-grain, dry loose, moist loose, nonsticky, nonplastic
C_2	18-24	Pale brown, 10 YR 6/2 moist	6.0	Pumice gravel, single-grain, dry loose, moist loose, nonsticky, nonplastic
D_1	24-48	Brown, 10 YR 4/3 moist	6.0	Loamy sand, single-grain, dry loose, moist loose, nonsticky, nonplastic
D_2	48+	Brown, 10 YR 4/3 moist		Sandy clay loam, massive to weak, fine subangular blocky, moist firm, slightly sticky, slightly plastic

*Covered by a thin layer of light-grey pumice gravel.

**Munsell color notations.

Table 13. (Continued).

Summit Stage Station

Horizon	Depth Inches	Color	pH	Texture
A_{00}	0-1			Sporadic cover of litter.
A_1	1-3	Very dark brown, 10 YR 2/2 moist*	5.8	Loamy coarse sand, weak medium crumb to single grain, dry loose, moist very friable, nonsticky, nonplastic.
AC	3-21	Dark grayish-brown, 10 YR 4/2 moist	6.2	Loamy coarse sand, single-grain, dry loose, moist very friable, non-sticky, nonplastic
C_1	21-36	Yellowish-brown, 10 YR 5/6 moist	6.2	Fine and medium pumice gravel
C_2	36-54	Pale brown 10 YR 6/3 moist	6.3	Coarse sand, single-grain, dry loose, moist loose, nonsticky, nonplastic
D	54+	Dark brown, 7.5 YR 3/2 moist	6.5	Sandy clay loam, massive to very weak, fine sub-angular blocky, dry soft, moist friable, slightly sticky, slightly plastic

*Munsell color notations.

Table 13. (Continued).

Tumalo Reservoir

Horizon	Depth Inches	Color	Texture
A_1	0-3	Dark brown, 10 YR 3/3 dry*	Coarse sandy loam, weak fine granular, dry loose, moist loose, nonsticky, nonplastic.
A_3	3-5	Dark brown, 10 YR 3.5/3 dry	Sandy loam, single grain to very weak medium granular, dry loose, moist loose, nonsticky, nonplastic
B_1	15-20	Dark yellowish-brown, 10 YR 3/4 dry	Loam, weak fine sub-angular blocky, dry moist, moist very friable, slightly sticky, slightly plastic.
B_2	20-28	Dark yellowish-brown 10 YR 3.5/4 dry	Sandy clay loam, dry hard, moist firm, sticky, plastic
B_2Dr	28+		Stony, sandy clay loam; mixture of B_2 material and rock

*Munsell color notations.

Chemical Characteristics of Soil

Table 14. Chemical Analyses of Soils in Study Areas.

Horizon	Cation exchange capacity	Calcium	Potassium	Magnesium	Phosphorus	Nitrogen	Organic matter	pH
	Milliequivalents to 100 g soil				Lb to acre	Per cent	Per cent	
Summit Stage Station								
A_1	14.62	4.80	0.46	0.75	40	0.14	6.74	5.8
AC	10.84	1.80	0.53	0.75	28	0.03	1.08	6.0
Sand Spring								
A_1	15.25	7.00	0.46	1.00	43	0.10	6.30	5.9
AC	25.45	7.70	0.33	4.20	21	0.15	7.06	5.5
C_1	10.08	3.00	0.13	1.75	8	0.02	0.82	6.2
Tumalo Reservoir								
A_1	12.60	5.25	0.92	2.40	31	0.05	1.41	6.3
A_3	13.39	4.60	1.00	3.75	12	0.03	1.70	6.5
Kiwa Spring								
A_1	15.87	2.70	0.61	0.65	16	0.09	4.15	5.6
AC	12.20	2.60	0.70	0.70	14	0.04	1.28	6.1
C	13.64	3.20	1.15	1.20	13	0.03	0.74	6.2

Table 15. Plants and Animals in the Vicinity of the Four Study Areas.

Trees	
Jeffrey pine	Pinus Jeffreyi Grev. & Balf.
Lodgepole pine	Pinus contorta Dougl.
Ponderosa pine	Pinus ponderosa Laws.
Western juniper	Juniperus occidentalis Hook.
Western larch	Larix occidentalis Nutt.
True firs	Abies sp.
Small vegetation*	
Bitter brush	Purshia tridentata (Pursh.) D. C.
Elmer's stipa	Stipa elmeri Piper and Brodie
Idaho bunchgrass	Festuca idahoensis Elm.
Manzanita	Arctostaphylos spp.
Rabbit-brush	Chrysothamnus nauseosus (Pall.) Britt.
Sagebrush	Artemisia tridentata Nutt.
Sticky laurel	Ceanothus velutinus Dougl.
Squaw currant	Ribes cereum Dougl.
Bottle-brush squirrel-tail	Sitanion hystrix (Nutt.) J. G. Sm.
Animals	
Belding ground squirrel	Citellus beldingi oregonus Merriam
Common western chipmunk	Eutamias amoenus amoenus J. A. Allen
Deschutes pocket gopher	Thomomys monticola nasicus Merriam
Golden-mantled ground squirrel	Citellus lateralis chrysodeirus Merriam
Great Basin pocket mouse	Perognathus parvus parvus Peale
Mule deer	Odocoileus hemionus hemionus Rafinesque
Oregon cottontail	Sylvilagus nuttallii nuttallii Bachman
Peale's meadow mouse	Microtus montanus montanus Peale
Snowshoe rabbit	Lepus americanus klamathensis Merriam
Townsend's chipmunk	Eutamias townsendii senex J. A. Allen
White-footed deer mouse	Peromyscus maniculatus gambelii Baird
Insects	
Leaf-cutting ant	Atta sp.
Pine grasshopper	Melanoplus punctulatus Scudder

*From A Manual of the Higher Plants of Oregon, by M. E. Peck. Binfords & Mort, Portland, Oregon. 1941.

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