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USDA Forest Service
Research Paper INT-163, 1974

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Research conducted by Montana Agricultural Experiment Station and
funded by Intermountain Forest and Range Experiment Station
under Contract No. 12-11-204-12, Supplement No. 12

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CONTENTS

ABSTRACT

In direct seeding from soils of volcanic origin, seedbed preparation treatments affected germination and first-year survival insignificantly, compared to site differences. A strong positive relation between survival and the amount of silt plus clay in the soil was identified. Available potassium and total nitrogen had a negative influence, attributable to poor seed-soil contact and competition for moisture on the more fertile sites. The three soil properties explained 93 percent of the variance in seedling survival. A response surface for the three soil properties was developed, as an aid in predicting survival.

INTRODUCTION

In Montana, natural regeneration of lodgepole pine commonly results in overstocking. For reproduction of clearcut stands, forest managers generally can rely on seed stored in serotinous cones in the logging slash. On some cuttings near West Yellowstone, Montana, and Island Park, Idaho, however, stands of natural regeneration were inadequate, and studies were begun in 1961 to determine the causes of failure. Direct seeding trials varied in results (Lotan 1964). The more intensive seedbed treatments gave the highest germination and survival for the first year, but subsequent results varied with soils.[1] Both germination and survival after 5 years were higher on medium-textured soils in the Island Park area than on obsidian sands and gravels near West Yellowstone. The principal cause of first-year mortality was drought.

Success in forest regeneration is of course highly dependent on climate and soils. If the relation between seedling establishment and measurable soil properties could be defined, seeding rates could be based on reliable predictions of stand density. Then costs of regenerating an area might be predicted, even before timber is harvested. Also, the most suitable seedbed treatment could be more easily determined.

This study was designed to further explore the effect of physical and chemical properties of soils on seedling survival. Several moisture-conserving seedbed treatments were also tested. From the test results, correlations were sought that might serve as predictors of regeneration success in the study area.

STUDY AREA AND EXPERIMENTAL METHODS

The West Yellowstone area lies on the western edge of a Pliocene plateau that collapsed to form a caldera 30 miles in diameter (Hamilton 1960). During late Quaternary, viscous rhyolite flowed into the caldera. Pliocene rhyolites form a ring bounding the Quaternary flows. Much of the ring is covered by flows composed of brecias of black obsidian and unconsolidated matrix of sandlike glass shards. Similarly, the Island Park Basin in Idaho is a caldera 18 miles in diameter rimmed by rhyolite and filled with basalt.

Water has played an undetermined role in the formation of soils in the area. Most of the soil is a loamy sand composed of angular or slightly rounded obsidian fragments and rhyolite, undoubtedly transported by water from the rim of the area. A unique feature is the numerous ridges of fine sand and silt that extend into the basin from the edges. Two large streams, the South and Main Forks of the Madison River, cross the area, and large sections of stream-deposited sands and gravels are exposed along their banks.

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[1] Subsequent results are data on file, Forestry Sciences Laboratory, Bozeman, Montana.

Soil Characteristics

In 1964, a preliminary study was made of soils in this area to determine causes of poor germination and survival. Pits were dug and soils were examined in locations in the Hebgen Lake Basin (near West Yellowstone) numbered 1 to 8 in figure 1. Root concentration and structural development were greatest in the upper 13 cm. Soil material became noticeably more gravelly at about 50 cm.

Soil profile descriptions are given in Appendix I for site 1 (representing general soil conditions in the major part of the alluvial basin), site 6 (representing what may be somewhat less favorable soil conditions), and site 8 (representing favorable soil conditions for forest).

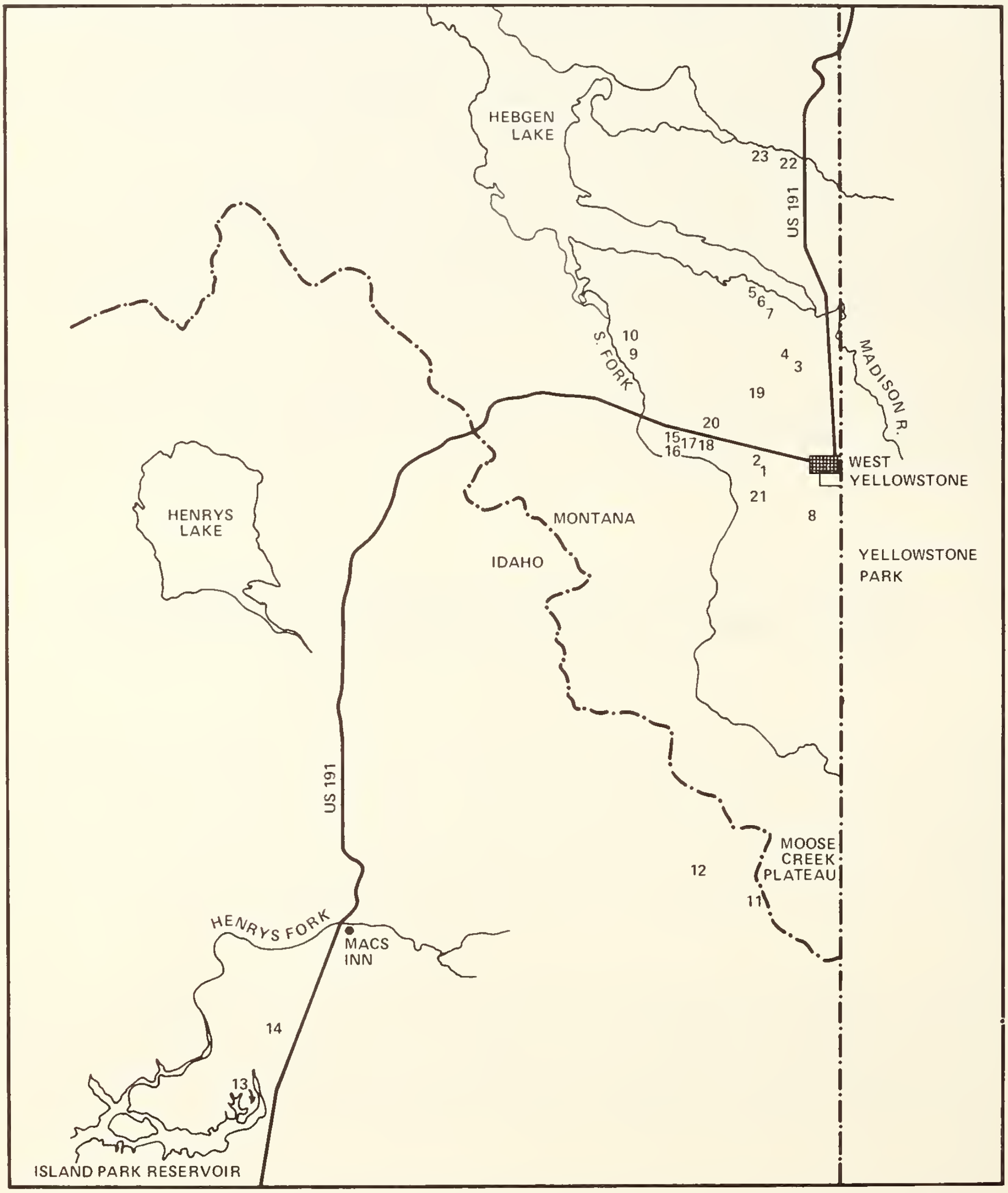

Figure 1.--Sites of soil profile pits and direct seeding trials.

Seeding Trials

Seeding trials were conducted at 19 locations, including four of the preliminary soil profile study sites. (No trials were conducted at profile sites 2, 3, 5, and 7. Fifteen of the sites were in the West Yellowstone area; two (13 and 14) at Island Park; and two (11 and 12) at Moose Creek Plateau (fig. 1). All sites were at elevations of about 2,000 m except sites 11 and 12, which were at 2,450 m.

Conditions varied on the test locations. The surface texture at eight sites were gravelly sandy loam over sand and gravel at 30 to 46 cm. At two other sites, texture was similar, but at one of these the loam was deeper over sand and gravel and at the other it was somewhat finer in the surface 35 cm. Five of the six remaining sites had deep loam, silt loam, and fine sandy loam textures, sometimes getting more clayey with depth. One site had surface horizons of sandy loam and fine sandy loam overlying sand and gravel at 23 cm. All but two sites were well drained. Site 8 was moderately well drained, and site 23 was poorly drained. Four sites were in natural openings in the forest; the others were in clearcut areas, several of which showed good regeneration in the vicinity of the test plots. The soil surface at site 13 had a dense sod mat of live and dead sedge roots.

Treatments

Each trial site was seeded in a randomized block design with three replications of four treatments: (1) spading, (2) spading plus application of a liquid petroleum mulch, (3) spraying with Dalapon, an herbicide, and (4) control. Plots were 1 m^2 and were surrounded by a buffer zone 30 cm wide. Spading and spraying with Dalapon were carried out between August 22 and September 8, 1966.

Lodgepole pine seed, treated with 17.5 percent anthraquinone and 2.5 percent Endrin (clean, untreated seed basis), was broadcast sown on October 12 and 13, 1966. Each plot received 375 total seeds with 55 percent viability. In addition, to check for rodent losses, 25 seeds covered with a 1/4-inch mesh wire cover and 25 seeds left uncovered were planted on a small cultivated area near the plots at each site.

The liquid petroleum (asphalt) mulch (Soil Gard, a product of Alco Chemical Corporation) was applied in May and June 1966. The mulch was diluted 1:5 with water and applied with a hand sprinkling can at a rate of about 4 liters (1 gal) of concentrated mulch per 20 m^2.

Seedling counts were made monthly; each seedling was marked with colored plastic toothpicks (a different color for each examination). The first count was made June 19-20, 1967, and final counts were made September 19-21, 1967. Mortality was noted at the monthly count.

Soil Analysis

The soil variables measured included a wide range of characteristics related to fertility and water-holding capacity. Available water-holding capacity was thought to be a major influence on tree growth on these soils. Earlier measurements on the eight sites for which soil profiles had been described in 1964 indicated that two sites had a high available water content. At that time, tree growth in the vicinity of the three sites suggested that they were more favorable than the other locations studied.

Soil samples for fertility measurements were taken from each trial site at depths of 0 to 15 cm and analyzed for pH of a saturated paste, for total nitrogen by the micro-Kjeldahl technique, for available phosphorus by the sodium bicarbonate method (Olsen and others 1954), and for available potassium by extraction with ammonium acetate (Jackson 1958). Soil samples for physical and chemical characterization were taken from each trial site at depths of 0 to 7.5, 7.5 to 15, and 15 to 30 cm. They were air-dried, weighed, and screened through a 2-mm sieve (the fine earth fraction passed through the sieve). The fine earth fractions were analyzed for sand, silt, and clay by hydrometer (Bouyoucos 1936), using sodium hexametaphosphate to disperse the soil. Specific surface was determined with orthophenanthroline (Lawrie 1961). Percent water at 15 atmospheres tension was determined on a pressure membrane (Richards 1965). Organic matter was determined by the Walkley-Black method as described by Jackson (1958), using chromic acid and heat of dilution of sulfuric acid. Exchangeable cations were extracted with neutral normal ammonium acetate (Bower and others 1952). Exchangeable potassium was determined with a flame photometer and calcium plus magnesium by versenate titration (Cheng and Bray 1951). Exchangeable hydrogen was replaced by sodium acetate at pH 8.2 and measured by titration to the phenolphthalein end point. Undisturbed soil cores were taken at the same three depths from eight trial sites considered to be representative. Capillary and noncapillary porosity were measured by means of a Leamer and Shaw (1941) tension table, at 50-cm tension. Bulk density was calculated from the ovendry weight of the cores, and particle density from the volume of water displaced in a graduated cylinder by the soil in the cores.

RESULTS

Seedbed Treatments

Lodgepole pine is frequently seeded in the fall because it is difficult to get to sites in the spring. During winter, seeds are lost to birds and rodents, and are removed from the planting site by wind and by soil and snow movement. Although seed used in test plots was treated to repel birds and rodents, much was lost, especially on sites in natural forest openings (such as sites 6, 9, and 10). Animals, presumably mice, bit small holes in the seedcoat and removed seed contents. Several white-footed deer mice were live-trapped and later fed lodgepole pine seed treated with the repellent. They would not eat freshly treated seed, but if seeds were rinsed with water, the mice readily ate them. Apparently the anthraquinone-Endrin repellents are not entirely effective in repelling rodents if seed remains on site over winter. On the sites affected, where seeds were protected by wire screens, average emergence was 51 percent, whereas it was only 9 percent for those exposed to rodents.

Germination extended over a period of four months (table 1). Some germination was observed near the end of May when, except for those on the Moose Creek Plateau, test sites were free of snow (even though deep snowbanks surrounded the openings). Conditions are usually favorable for germination upon snowmelt in the area. Climatological data from the West Yellowstone Weather Station indicate a maximum temperature of 78°F on May 22. This agrees with previously published statements that temperature fluctuation from 52° to 72°F is conducive to germination (Bates 1930). In these tests, more germination occurred in July than in earlier experiments reported by Lotan (1964).

Table 1.--*Periodicity of germination of lodgepole pine seeds, June to September 1967, near West Yellowstone, Montana*

Sites	Germination			
	June	July	August	September
	Percent			
West Yellowstone No. 1, 4, 6, 8-10, 15-23	62	34	4	0.2
Moose Creek Plateau No. 11, 12	--	34	56	10.0
Island Park No. 13, 14	45	46	8	--

As might be expected, total number of seeds germination was slightly higher on spaded plots than on control plots (table 2). Results of spade-plus-mulch, and spray treatments, were intermediate. Analysis of variance indicated that seedbed treatments were not significantly effective in increasing survival at the end of the first season. Spading, which removed all competing vegetation, resulted in the highest survival (table 2). The spade-plus-mulch treatment was expected to be more effective. The mulch was applied in late May; its application a month later, after the rainy season and before dry weather caused moisture losses, might have been more successful.

Spraying also failed to increase survival noticeably. Field observations indicated that spray applied the fall before seeding was effective in retarding growth of grasses and sedges in the following season. Spraying probably had a retarding effect on germination when the grass or sedge was particularly thick, however; the dead grass formed a mat that appeared to prevent seed from reaching the soil surface.

Site Influences

Germination and survival were both significantly better on five sites (8, 11, 12, 21, and 23--see table 2). All but one of these sites had medium-textured soils. Site 23, the exception, was poorly drained. The only medium-textured soil with poor germination and survival was 13. It had a dense sod mat and, apparently, a high rodent population; germination was good when seeds were protected from rodents. Survival data showed an overall statistically significant interaction between site and treatment effects; that is, treatments were not equally effective at all sites. Spading was apparently more effective on medium-textured soils.

In specific soil characteristics, the sites varied widely. Values for all characteristics measured are given in Appendix II. The study sites would be considered low in available nitrogen and potassium, and medium to high in available phosphorus for most agricultural crops, but were within limits set by Wilde (1964) for conifer establishment. Specific requirements of lodgepole pine seedlings have not been established. The pH of all sites was close to 6.0, which is also within the recommended range. An analysis of variance indicated that physical and chemical soil properties varied significantly between sites and depths sampled.

Table 2.--*Emergence and survival of lodgepole pine seedlings, by seedbed treatment*

	Treatment				
Site	Control	Spade	Spade + Mulch	Spray	Mean
		SEEDLINGS EMERGING (AV./M^2)			
West Yellowstone					
1	11.0	21.0	13.0	28.7	18.4
4	15.3	10.0	7.0	15.0	11.8
6	1.0	1.0	.7	1.7	1.1
8	15.3	67.3	61.7	29.3	43.4
9	6.7	3.7	1.7	5.3	4.3
10	1.7	3.3	1.3	2.0	2.1
15	2.3	7.3	2.7	5.3	4.4
16	7.7	11.0	6.0	14.3	9.8
17	2.7	7.0	4.0	2.7	3.8
18	1.0	4.3	3.0	5.7	3.5
19	2.0	5.3	1.3	2.0	2.7
20	11.0	13.3	8.7	9.0	10.5
21	25.0	36.3	40.3	48.3	37.5
22	.3	5.0	7.3	5.7	4.6
23	56.3	36.3	20.3	75.3	47.1
Moose Creek Plateau					
11	14.7	29.0	16.0	16.7	19.1
12	18.0	33.0	21.0	15.0	21.8
Island Park					
13	4.0	6.3	10.3	2.7	5.8
14	15.0	33.7	15.7	9.3	18.4
Mean	11.1	17.6	12.7	15.4	
		SEEDLINGS SURVIVING (AV./M^2)			
West Yellowstone					
1	.0	1.3	2.0	.3	.9
4	12.7	6.3	6.3	9.3	8.7
6	.0	.0	.3	.7	.2
8	11.3	43.0	41.7	23.7	29.9
9	.0	1.3	.0	.0	.3
10	.0	.7	.0	.3	.2
15	.3	.7	.0	1.7	.7
16	.0	.7	1.3	.0	.5
17	2.0	3.3	2.0	.7	2.0
18	.0	.0	.3	.0	.1
19	.0	.7	.3	.3	.3
20	1.7	1.7	2.3	2.3	2.0
21	22.0	35.7	34.3	43.3	33.8
22	.0	.7	4.7	.3	1.4
23	53.7	27.0	12.7	65.3	39.7
Moose Creek Plateau					
11	13.3	26.7	14.0	16.0	17.5
12	14.0	28.7	18.7	13.0	18.6
Island Park					
13	2.0	3.7	6.3	1.3	3.3
14	2.7	9.7	4.3	3.7	5.1
Mean	7.1	10.1	8.0	9.6	

The large variation among sites made a screening process of simple and multiple linear regressions necessary to identify soil variables that most effectively predicted seedling survival. Those finally chosen as relatively simple variables that consistently gave high correlations were levels of total nitrogen (percent), available potassium (p/m), and silt plus clay (percent), all measured to a depth of 15 cm. The linear regression equations for mean survival (S) in seedlings per square meter were as follows:

$$S = 0.60 \times \text{percent silt plus clay} - 11.4 \qquad (r^2 = 0.414)$$

$$0.88 \times \text{percent silt plus clay} - 230 \times \text{percent nitrogen} - 2.2 \; (R^2 = 0.668)$$

$$0.63 \times \text{percent silt plus clay} - 318 \times \text{percent nitrogen} + 0.11 \times \text{p/m potassium} - 5.7 \; (R^2 = 0.732)$$

In this calculation, mean survival data for all treatments were used to achieve the greater confidence possible when survival is measured over a larger number of plots.

To further define the relationships of the three variables, a response surface (fig. 2) was developed using techniques described by Jensen (Jensen and Homeyer 1970, 1971; Jensen 1973). The mathematical functions used in fitting this surface are given in Appendix III. These models are of particular benefit for use in the larger information systems. The same relationships are shown in table 3 for use where adequate data-processing capabilities are not available. The data may be interpolated in linear fashion for small differences in table 3.

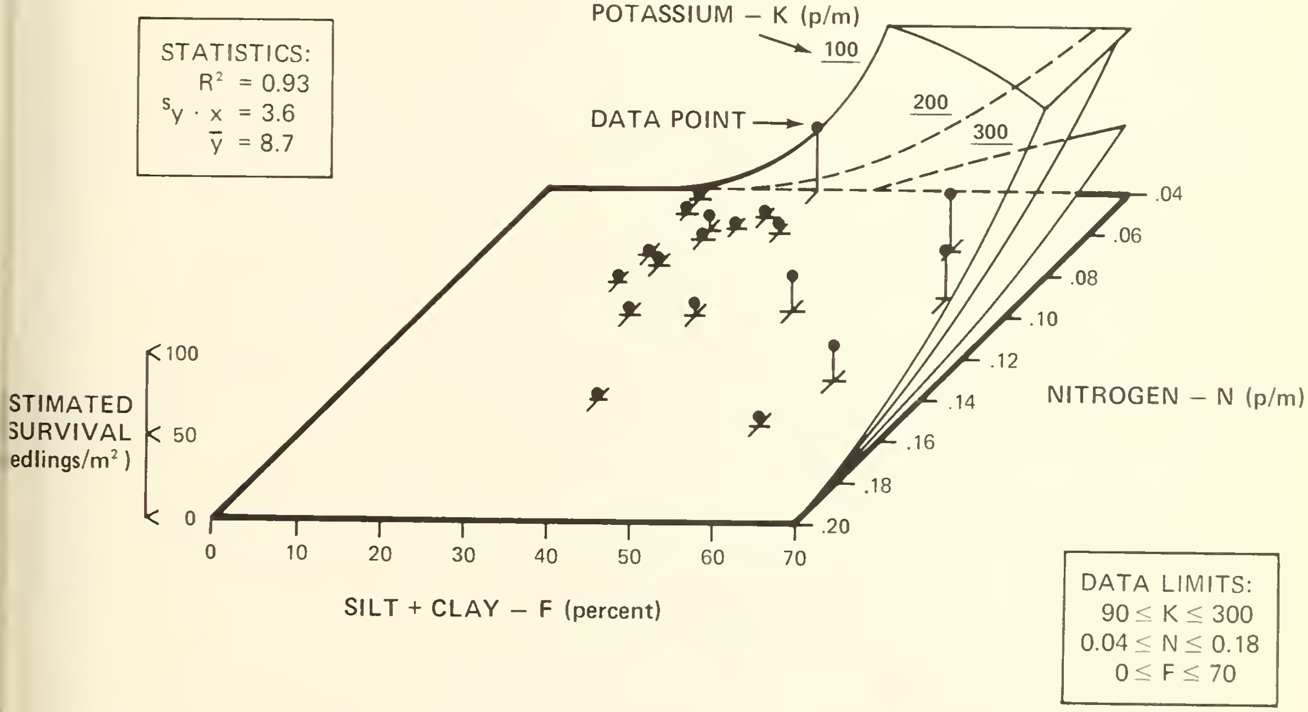

Figure 2.--Relation of lodgepole pine seedling survival at end of first summer to silt plus clay fraction, total nitrogen, and available potassium in the surface soil (to 15 cm deep). Based on tests near West Yellowstone, Montana. Although it is not included as a constraint in the mathematical model, a practical survival maximum of 100 exists here and should be included in the computer model.

Table 3.--*Estimated survival of lodgepole pine, in seedlings per square meter, at end of summer, according to silt plus clay fraction, total nitrogen, and available potassium, based on data from tests near West Yellowstone, Montana*

Potassium (p/m)	Nitrogen (p/m)	Seedlings surviving when percent silt + clay is ...						
		10	20	30	40	50	60	70
100	0.04	0	4	25	94	200	200	[1]200
	.06	0	1	6	23	59	110	160
	.08	0	1	4	14	36	68	100
	.10	0	0	3	11	27	50	74
	.12	0	0	2	7	19	35	52
	.14	0	0	1	5	12	22	32
	.16	0	0	1	2	6	12	17
	.18	0	0	0	1	2	4	6
	.20	0	0	0	0	0	0	0
200	.04	0	1	6	19	45	79	112
	.06	0	1	4	14	32	56	80
	.08	0	1	3	11	25	44	62
	.10	0	0	2	8	18	33	46
	.12	0	0	2	6	13	23	32
	.14	0	0	1	4	8	14	20
	.16	0	0	1	2	4	8	11
	.18	0	0	0	1	1	2	4
	.20	0	0	0	0	0	0	0
300	.04			0	4	17	34	42
	.06			0	3	14	27	34
	.08			0	2	11	21	27
	.10			0	2	8	16	20
	.12			0	1	6	11	14
	.14			0	1	4	7	9
	.16			0	0	2	4	5
	.18			0	0	1	1	2
	.20			0	0	0	0	0

[1] Computer truncation of the relation at a maximum of 200 is shown. A practical maximum is probably near 100.

DISCUSSION

Total nitrogen is a measure of organic matter in the soil. It reflects the amount of vegetation present in the past and indicates the probable growth of grass and weeds that might compete with the seedlings. Probably, the negative relation of nitrogen to survival is due partly to poor seed-to-soil contact on sites with high organic accumulation and partly to greater competition for moisture on the more fertile sites. The negative effect of available potassium is more difficult to explain than that of nitrogen but may have a similar basis.

Significant differences among treatments were not evident, but differences among the nonreplicated sites were significant. If soil variables are accounted for, however, comparison of least squares coefficients (see Appendix III) shows that results of spraying and spading treatments were more affected by soil variables than were the control and mulched plots. The spading and spraying treatments removed vegetation that caused seed and seedling losses in the control plots. Mulching was apparently less successful, but the effects of mulch are unclear in field studies such as this. The results of these tests suggest the relative effectiveness of the three treatments for natural regeneration or direct seeding when climate and vegetation are similar to those in the study area. The effectiveness of seedbed treatment would probably be more pronounced, however, in seasons with less precipitation than was encountered here. In addition, rodent populations have a great influence on results, particularly when seed supply is marginal.

SUMMARY

Preliminary studies in the West Yellowstone area found soils to be formed primarily from obsidian and rhyolite sandy and gravelly materials. These studies suggested that the low water-holding capacity associated with coarse volcanic soils is a strong influence on seedling establishment.

Direct seeding trials were conducted on soils with a wide range of physical and chemical properties. Three seedbed treatments wre incorporated into the trials: spading, spading plus mulch, and spraying with herbicide.

Large numbers of seed were lost through rodent damage. Seed treatment as used here evidently becomes ineffective in repelling rodents after it has been washed with rain or snow.

Weather stations located in the experimental area indicated an unusually wet spring the year this experiment was conducted. Seedbed treatments did not exhibit the pronounced effect on seedling survival that might be experienced in a drier year. Spading proved most effective in increasing the number of seedlings surviving the first summer. Asphalt mulch was not successful.

Seedling survival varied markedly with soil characteristics. Screening by means of simple and multiple regressions indicated that soil suitability for direct seeding could be evaluated in that area by analysis for silt plus clay content, total nitrogen, and available potassium. Survival after the first season was positively correlated with silt plus clay and negatively correlated with nitrogen potassium. Together, these three factors accounted for 93 percent of the variance in survival after the first summer. A mathematical function for the relationship was used to develop a response surface for computer prediction.

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APPENDIX I

Soil Profiles

Site 1

Location: 75 m northwest of the weather station near Lotan's plot in cutover area. NE 1/4, sec. 32, T. 13 S., R. 5 E.

0-5 cm A_1	10 YR 3/2 gravelly sandy loam; weak fine granular; friable; many medium and fine roots; porous; loam material coating the sand and gravel; pH 6.0; clear wavy boundary.
5-13 cm B_{21}	10 YR 3/3 sandy loam; weak fine granular; friable; many medium and fine roots; porous; pH 5.7; clear boundary.
13-25 cm B_{22}	10 YR 4/3 gravelly sandy loam; single grain; loam material coating sand and gravels; porous; abundant obsidian; pH 5.6; clear wavy boundary.
25-35 cm C_1	Variegated gravel and sand (obsidian and rhyolite); few roots; pH 5.9.
35-55 cm C_2	Same as above except increase in obsidian gravels; pH 6.0.
55-81 cm C_3	Gravels are larger than in above horizons; pH 6.0.

Site 6

Location: In sagebrush. NE 1/4, sec. 8, T. 13 S., R. 5 E.

0-5 cm A_1	Very dark grayish brown 10 YR 3/2 gravelly sandy loam; weak fine granular; friable; numerous medium and fine roots; many gravels at surface; pH 6.2.
5-20 cm B_{ir2}	Dark brown 10 YR 3/3 gravelly loam; weak fine granular; friable; many medium and fine roots; pH 6.2; clear wavy boundary.
20-38 cm B_{ir3}	Dark grayish brown 10 YR 4/2 - 3/3 gravelly loamy sand; single grain; firm; common medium roots; pH 6.3; gradual boundary.
38-76 cm IIC	Variegated gravel and sand; single grain common and medium roots; obsidian gravel increase below 65 cm; pH 6.6.

Site 8

Location: In lodgepole pine strip north of area reseeded by helicopter just south of pulpwood camp. NW 1/4, sec. 3, T. 14 S., R. 5 E.

0-15 cm A_1	10 YR 3/2 silt loam; moderate medium granular; friable; many medium and fine roots; pH 5.7; clear wavy boundary.
15-35 cm B_{21}	10 YR 4/2 silt loam; moderate medium platy; friable; few medium roots; pH 6.1; abrupt boundary.
35-48 cm B_{22}	10 YR 5/2 with 5/4 common distinct mottles; silt loam; firm; coarse prisms breaking to moderate to medium blocky; pH 6.1; abrupt smooth boundary.
48-66 cm IIC_1	10 YR 4/2 and 5/2 clay loam; weak fine blocky; firm, sticky and plastic; pH 5.8; abrupt boundary.
66-100 cm IIC_2	10 YR 5/4 sticky clay--auger sample; pH 6.4.
100+ cm $IIIC_3$	7.5 YR 4/4 clay; pH 6.7.

APPENDIX II

Soil Characteristics

Table 4.--*Soil fertility measurements, 0 to 15 cm deep, on test sites near West Yellowstone, Montana*

Site	pH	Total nitrogen	Available phosphorus	Available potassium
		Percent	*(p/m)*	*(p/m)*
1	5.7	0.062	13.0	145
4	5.7	.059	7.2	108
6	6.3	.141	8.5	243
8	5.7	.089	19.6	278
9	5.9	.084	11.7	153
10	5.9	.101	9.0	208
11	5.5	.131	41.0	205
12	5.6	.098	24.8	188
13	5.6	.153	20.1	245
14	5.5	.102	10.5	218
15	6.0	.071	5.9	108
16	6.0	.076	9.2	130
17	5.9	.058	11.2	150
18	5.7	.050	8.7	115
19	6.1	.063	5.8	98
20	5.8	.053	7.6	118
21	5.7	.068	16.8	223
22	6.1	.043	6.0	95
23	5.7	.039	8.5	163

Table 5.--*Physical and chemical properties of the soil on test sites near West Yellowstone, Montana*

Site	Depth	Fine earth	Mechanical analysis			Specific surface	Water at 15 atm	Organic matter	Exchangeable cations		
			Sand	Silt	Clay				K	Ca+Mg	H
	cm	- - - - - *Percent* - - - - -				*m²/g*	- - - *Percent* - - -		- - - *meq/100g* - - -		
1	0-7.5	78	67.3	24.5	8.2	39.0	7.1	4.0	0.52	5.58	3.12
	7.5-15	79	66.8	23.5	9.7	38.4	5.3	1.2	.34	4.01	2.28
	15-30	75	75.8	16.0	8.2	27.1	4.3	.29	.27	3.16	1.69
4	0-7.5	67	75.7	16.9	7.4	29.3	7.7	3.1	.44	4.51	3.08
	7.5-15	69	76.2	16.4	7.9	27.2	3.6	.54	.24	2.94	1.14
	15-30	71	70.0	20.0	10.0	22.6	3.8	.31	.23	3.52	1.09
6	0-7.5	60	67.8	25.3	6.9	41.7	10.8	4.8	.74	8.68	2.37
	7.5-15	51	68.9	23.2	7.9	29.2	7.9	2.4	.52	5.99	1.46
	15-30	49	75.4	16.8	7.8	22.5	5.1	.71	.41	5.57	1.09
8	0-7.5	100	41.4	50.6	8.0	33.7	11.3	4.8	1.10	7.22	3.84
	7.5-15	100	36.9	53.4	9.7	33.3	4.9	1.3	.36	4.11	2.29
	15-30	100	39.8	50.0	10.2	28.4	4.4	.82	.32	3.73	2.19
9	0-7.5	75	79.6	15.0	5.4	20.9	5.9	2.7	.46	4.97	1.59
	7.5-15	74	80.6	14.0	5.4	26.2	5.3	1.7	.32	4.22	1.67
	15-30	80	84.4	9.8	5.8	16.1	3.8	.65	.31	3.57	1.64
10	0-7.5	79	74.0	18.4	7.6	34.0	8.6	3.3	.55	5.72	2.42
	7.5-15	78	76.1	16.4	7.5	29.6	4.3	1.2	.32	3.58	1.39
	15-30	81	81.2	11.0	7.8	19.7	3.8	.45	.28	3.46	1.09
11	0-7.5	87	44.0	41.0	15.0	74.7	11.6	6.6	.81	4.04	8.72
	7.5-15	100	41.5	43.4	15.1	67.8	9.0	4.0	.39	3.74	7.45
	15-30	93	43.4	40.8	15.8	48.0	8.9	2.0	.37	2.01	7.11
12	0-7.5	82	52.6	39.8	7.7	40.5	8.4	3.9	.52	3.74	6.63
	7.5-15	79	59.3	28.0	12.7	50.3	8.2	2.3	.44	2.41	6.15
	15-30	84	51.4	36.8	11.8	40.6	7.5	1.5	.42	1.86	6.13
13	0-7.5	93	48.0	38.6	13.4	56.4	19.7	8.0	1.05	11.55	6.45
	7.5-15	87	44.1	41.3	14.6	43.5	6.5	1.7	.52	5.15	2.44
	15-30	86	45.2	40.0	14.8	42.0	5.7	.95	.42	4.73	2.28
14	0-7.5	74	66.1	25.7	8.2	48.0	12.7	6.4	.71	6.09	6.04
	7.5-15	75	68.8	23.0	8.2	33.0	6.2	1.8	.46	3.73	2.66
	15-30	70	66.2	25.0	8.8	26.8	5.1	.95	.46	3.22	2.37
15	0-7.5	78	78.4	15.9	5.7	24.1	5.6	2.9	.31	4.80	1.84
	7.5-15	6	81.3	12.9	5.8	21.4	5.1	1.3	.24	3.55	1.39
	15-30	63	78.2	13.6	8.2	18.6	4.3	.43	.27	3.18	1.09
16	0-7.5	70	76.8	18.2	5.0	25.0	6.7	2.9	.40	4.72	2.28
	7.5-15	73	77.8	16.2	6.0	26.8	4.3	1.0	.30	3.11	1.00
	15-30	70	79.8	13.0	7.2	25.7	4.1	.44	.34	4.14	1.00
17	0-7.5	98	74.8	20.4	4.8	24.0	7.1	2.5	.56	8.36	2.22
	7.5-15	97	70.3	24.8	4.9	18.1	4.4	1.5	.37	3.04	1.48
	15-30	98	71.8	23.0	5.2	11.8	3.6	.64	.39	2.42	1.28
18	0-7.5	83	80.3	13.3	6.4	23.1	5.6	2.6	.32	3.96	2.49
	7.5-15	85	80.2	13.4	6.4	19.8	5.2	1.4	.24	2.88	2.18
	15-30	93	81.8	12.0	6.2	17.3	4.5	.43	.27	3.27	1.55
19	0-7.5	64	75.4	17.9	6.7	30.0	5.9	2.7	.27	3.89	1.99
	7.5-15	69	74.4	15.4	9.2	34.0	4.5	.66	.31	3.52	1.12
	15-30	69	79.8	12.0	8.2	22.9	3.8	.33	.34	3.88	1.09
20	0-7.5	57	68.9	23.0	8.1	36.3	6.9	3.6	.42	6.13	3.33
	7.5-15	67	71.9	19.5	8.6	31.8	4.4	.9	.26	3.34	2.17
	15-30	63	80.8	12.0	7.2	21.9	3.7	.31	.23	3.62	1.00
21	0-7.5	100	46.3	45.2	8.5	42.4	9.7	4.2	.90	6.19	3.03
	7.5-15	100	42.8	48.7	8.5	35.8	6.6	2.0	.42	5.37	2.28
	15-30	100	45.8	46.0	8.2	22.9	4.8	.99	.38	4.11	1.73
22	0-7.5	82	80.9	13.7	5.4	21.4	5.9	2.5	.34	3.84	1.67
	7.5-15	82	80.4	13.2	6.4	20.3	4.7	.78	.22	3.17	.79
	15-30	85	81.8	11.0	7.2	18.2	4.2	.31	.18	3.07	.72
23	0.7-5	87	71.9	18.7	9.4	29.8	6.2	2.1	.24	3.70	1.57
	7.5-15	74	62.9	23.7	13.4	34.3	5.9	1.3	.15	3.49	1.43
	15-30	83	72.8	18.0	9.2	23.2	4.8	1.1	.16	2.71	1.19

Table 6.--*Physical properties of soil on eight selected test sites near West Yellowstone, Montana*

Site	Depth	Total pore space by volume	Capillary pore space by volume	Noncapillary pore space by volume	Bulk density	Particle density
	cm	*Percent*			*g/cc*	
1	0-7.5	41.4	22.3	19.1	1.34	2.28
	7.5-15	53.2	29.7	23.5	1.07	2.28
	15-30	45.2	21.1	24.1	1.17	2.13
4	0-7.5	42.9	26.9	16.0	1.34	2.34
	7.5-15	33.3	7.8	25.5	1.52	2.28
	15-30	33.1	17.5	15.6	1.50	2.25
8	0-7.5	58.8	49.9	8.9	1.05	2.54
	7.5-15	53.4	46.5	6.9	1.01	2.17
	15-30	47.5	41.8	5.7	1.21	2.30
9	0-7.5	48.8	22.3	26.4	1.28	2.50
	7.5-15	45.4	18.6	26.8	1.19	2.18
	15-30	37.9	16.9	21.0	1.35	2.17
12	0-7.5	53.4	38.5	14.9	1.29	2.76
	7.5-15	61.2	42.8	18.4	.93	2.40
	15-30	44.0	34.9	9.1	1.22	2.17
13	0-7.5	68.4	55.5	12.9	.77	2.43
	7.5-15	67.1	50.1	17.0	.72	2.20
	15-30	52.8	37.7	15.1	1.11	2.36
16	0-7.5	38.5	15.7	22.8	1.31	2.55
	7.5-15	40.6	19.4	21.2	1.37	2.30
	15-30	41.7	12.9	28.8	1.35	2.31
23	0-7.5	23.6	21.5	2.1	1.46	1.91
	7.5-15	38.1	26.1	12.0	1.41	2.28
	15-30	32.5	26.2	6.3	1.59	2.35

APPENDIX III

Survival Function

$$S = .90106\ YP \left\{ \frac{e^{-\left|\frac{\frac{F}{100} - 1}{1 - I}\right|^{n}} - e^{-\left(\frac{1}{1 - I}\right)^{n}}}{1 - e^{-\left(\frac{1}{1 - I}\right)^{n}}} \right\}$$

Where:

$$YP = A + B$$

$$A = (5959.3 - 16.711\ K)(0.2 - N)^{1.6}$$

$$B = \left\{ (6.0053 \times 10^{18})\ e^{-\left|\frac{\frac{(300 - K)}{220} - 1}{0.48}\right|^{10}} \right\} (0.2 - N)^{20}$$

$$n = 3 + 2.2\ e^{-\left|\frac{\frac{(K - 90)}{210} - 1}{0.325}\right|^{6}}$$

$$I = 0.4975 + 0.0425\ e^{-\left|\frac{\frac{(300 - K)}{210} - 1}{0.62}\right|^{4.7}}$$

Limits:

$90 \leq K \leq 300$

$0.04 \leq N \leq 0.18$

$0 \leq F \leq 70$

$R^2 = 0.93$

$s_{y \cdot x} = 3.6$

$\bar{y} = 8.7$

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