Lodgepole pine regeneration in the West Yellowstone area as related to soil factors and moisture conservation practices
by James Edward Stermitz

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in SOILS
Montana State University
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Abstract:
Four methods of seedbed preparation were examined at 19 locations in the West Yellowstone, Montana area to determine the effect on germination and first year survival of lodgepole pine seedlings. Soil chemical and physical determinations were made to correlate the success of reseeding with soil properties.

The methods of seedbed preparation indicated a difference in seedling survival that varied with the soil and climatic factors. Treatments that were most successful were those that tended to conserve moisture more effectively.

Seedling survival was found to be correlated quite closely with soil properties. Soil silt content was found to be significantly correlated with seedling survival, and when considered with the clay content, provided an expression that predicts the success of a seeding program in a given area.

LODGEPOLE PINE REGENERATION IN THE WEST YELLOWSTONE AREA AS RELATED TO SOIL FACTORS AND MOISTURE CONSERVATION PRACTICES

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ABSTRACT

Four methods of seedbed preparation were examined at 19 locations in the West Yellowstone, Montana area to determine the effect on germination and first year survival of lodgepole pine seedlings. Soil chemical and physical determinations were made to correlate the success of reseeding with soil properties.

The methods of seedbed preparation indicated a difference in seedling survival that varied with the soil and climatic factors. Treatments that were most successful were those that tended to conserve moisture more effectively.

Seedling survival was found to be correlated quite closely with soil properties. Soil silt content was found to be significantly correlated with seedling survival, and when considered with the clay content, provided an expression that predicts the success of a seeding program in a given area.

INTRODUCTION

In many areas of Montana and Idaho, regeneration of lodgepole pine (Pinus contorta Doug.) has been inadequate after logging. Some of the areas are those in which the soil is high in relatively unweathered sands. A specific area where regeneration of lodgepole pine has been poor is that near West Yellowstone, Montana and Island Park, Idaho. Reseeding using normal procedures has failed to produce adequate stands in these areas. A more expensive method, that of planting nursery stock, has been required. Previous studies (12) indicate that the soils are high in obsidian and rhyolite sands and are subject to extreme drought conditions throughout the summer season. This results in high seedling mortality if the seedbeds are not prepared in some manner that helps to conserve moisture (16).

The success of a forest regeneration program will of course be highly dependent on the natural climatic and soil conditions. Practices resulting in successful forest establishment in one area may be entirely unsuccessful in another. There is a need to establish relationships between regeneration, success and measurable soil properties.

Ideally, one would like to base seeding rates on measurable factors that would allow a predicted stand density. In this manner, a forester could predict the cost involved in regenerating an area, perhaps even before the area was logged. He may also be able to choose a seedbed preparation that is most adapted to the soil and climatic factors of the area.

The purpose of this study was to determine the effectiveness of several moisture conserving seedbed treatments in promoting lodgepole

pine seedling survival in the West Yellowstone area. The experiment was also designed to study seedling survival as affected by soil physical and chemical properties.

LITERATURE REVIEW

Silvical considerations of lodgepole pine:

Lodgepole pine is a widely distributed tree of considerable economic importance, growing on widely varying soils. It has been found to grow over a wide climatic range, in areas of 160 inches of rainfall or 11 inches (24). In general, the species establishes best in full sunlight and disturbed soil free of vegetation. This is often at the expense of species such as Douglas-fir that are more shade tolerant and are less adapted to severe soil conditions (7, 23).

Lodgepole pine has a high germinative capacity, the seeds usually germinating in the spring following fall dissemination (24). Bates (1) found that most germination occurred at 70°F, but that a temperature fluctuation between 52 and 72°F caused a great deal of activity.

A short taproot is formed, its length apparently dependent on the moisture situation. Horton (10) found that the extent of the taproot was largely dependent on soil type and moisture conditions, with excessively fine or excessively coarse textures and extremely dry or wet conditions severely limiting taproot development. There was also large variability between trees on similar sites which may suggest genetic variation within the species. It appears that the taproot persists as the tree ages, but may be obscured by the lateral root system.

In areas where conditions for natural regeneration are optimum and large quantities of seed are stored in serotinous cones, lodgepole pine frequently overstocks, and thinning is desirable to obtain maximum growth. Dwarfmistletoe appears to become a problem when lodgepole pine is allowed

to perpetuate itself naturally, the spores disseminating from the old infested trees (27). As a management practice, lodgepole pine regeneration is better conducted under clear-cut logging conditions.

Information is lacking on the relationship between lodgepole pine regeneration and soil factors, but a great deal of work has been done with Douglas-fir. Hill, et al. (9) concluded that the ability to store water during the summer months was important in correlating soils with Douglas-fir site quality. Lowery and Youngberg (17) found that of the soil factors affecting Douglas-fir seedling survival, the number of days in which the soil water tension was greater than 15 atmospheres was most significant. When this approached 20 days, high mortality occurred. Youngberg (29) found that there was a rapid rate of seedling mortality after the moisture tension went above 1 atmosphere. He also found that by removing the vegetation from the plots, the soil moisture did not go below 15 atmospheres until August 28, while the vegetated plots reached 15 atmospheres in the first two weeks of June.

Previous lodgepole pine seeding studies by Lotan (16) in the West Yellowstone area have indicated that approximately 90% of the mortality was attributed to drought. Mortality occurred early in the season when precipitation ceased. Klages (13) found that the moisture content of the soils often fell below 15 atmospheres. This contributed greatly to mortality if the soils reached 15 atmospheres before the seedling roots extended below the first horizon, or five inches. This condition occurred early in the season and more often throughout the season on plots that

had a great deal of vegetation. The low moisture holding capacity was attributed to low silt and clay contents of the obsidian-derived soils. Lotan (16) found that mortality decreased considerably under seedbed treatments designed to conserve moisture. These treatments were disked, scalped, sprayed to kill grass, cultivated, V-shaped trenched, and furrowed. Of these, the most successful for seedling survival were cultivated and sprayed.

Bement and others (2) found that soil moisture was conserved for a longer period of time when the soil surface had been sprayed with liquid petroleum mulch. This accounted for a more rapid grass seedling establishment. Evidence of pre-emergence mulching of lodgepole pine appears to be lacking, but mulching has been successful on transplanted seedlings. Ursic (26) reported that straw mulch prevented soils from reaching 15 atmospheres tension for a longer period than unmulched. The effects on the survival of loblolly pine were slight, however. Stevens (23) concluded that the soil moisture and temperature interaction was highly significant in mulching studies. He concluded that in wet years, growth of spruce was greater on warmer soils. In dry years, soil temperature may be unimportant and moisture limiting so mulching may result in significant growth increases.

Soils of the area as related to geology:

The West Yellowstone area lies on the western edge of a Pliocene plateau that collapsed to form a caldera 30 miles in diameter (8). During late Quaternary, numerous flows of viscous rhyolite flowed into the

caldera. Rhyolite of the Pliocene are alkaline rocks which form a ring bounding the Quarternary flows. Flows from the Madison and Pitchstone Plateaus cover much of the ring and are composed of breccias of black obsidian and unconsolidated matrix of sandlike glass shards. Similarly, the Island Park Basin, 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 the soils of the area. Most of the soil is a loamy sand composed of slightly rounded, angular obsidian fragments and rhyolite, undoubtedly transported by water from the rim of the surrounding area. A unique feature of the area is the numerous ridges of very fine sand and silt which 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.

Soils of the West Yellowstone and Island Park areas are then composed largely of rather recent, relatively unweathered alluvium of obsidian and rhyolites. Soils of the Moose Creek Plateau area are largely the result of in-place weathering of the obsidian and rhyolite which compose the rim of the caldera. The soil has been classified as an andic cryopsamment (12).

MATERIALS AND METHODS

In August 1966, twenty sites [a] were selected in the West Yellowstone, Montana, Island Park and Moose Creek Plateau, Idaho, areas, in locations selected to represent the varying soil and climatic conditions. Locations with site numbers are given on the enclosed map (Figures 1 and 2). Area descriptions are given with the soil profile descriptions (Appendix).

Each experiment is a randomized complete-block consisting of 3 replications of 4 one-quarter milacre (3.3 x 3.3 feet) plots with one foot borders, the treatments being: (1) spaded, (2) spaded and liquid petroleum mulch applied, (3) sprayed with Dalapon to kill grass, and (4) check.

Designated plots were spaded and respective plots sprayed with Dalapon between August 22 and September 8, 1966. On October 12 and 13, lodgepole pine seed, treated with Endrin to repel rodents, was broadcast planted at the rate of 375 total seeds (approximately 206 viable seeds) per one-quarter milacre plot. Twenty-five seeds were also scattered in a small cultivated area, apart from the other experimental plots, and covered with a 1/4 inch mesh wire cone about eight inches in diameter. Twenty five seeds were also scattered in a small cultivated area near the cone.

"Soil Gard"[b] liquid petroleum mulch was applied on designated plots of experiments near West Yellowstone, Montana and Island Park, Idaho on May 23 and 31, 1967, and in the Moose Creek Plateau area on June 19 and

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a/ Site No. 15 was later dropped, leaving 19 sites.
b/ Product of Alco Chemical Corporation.

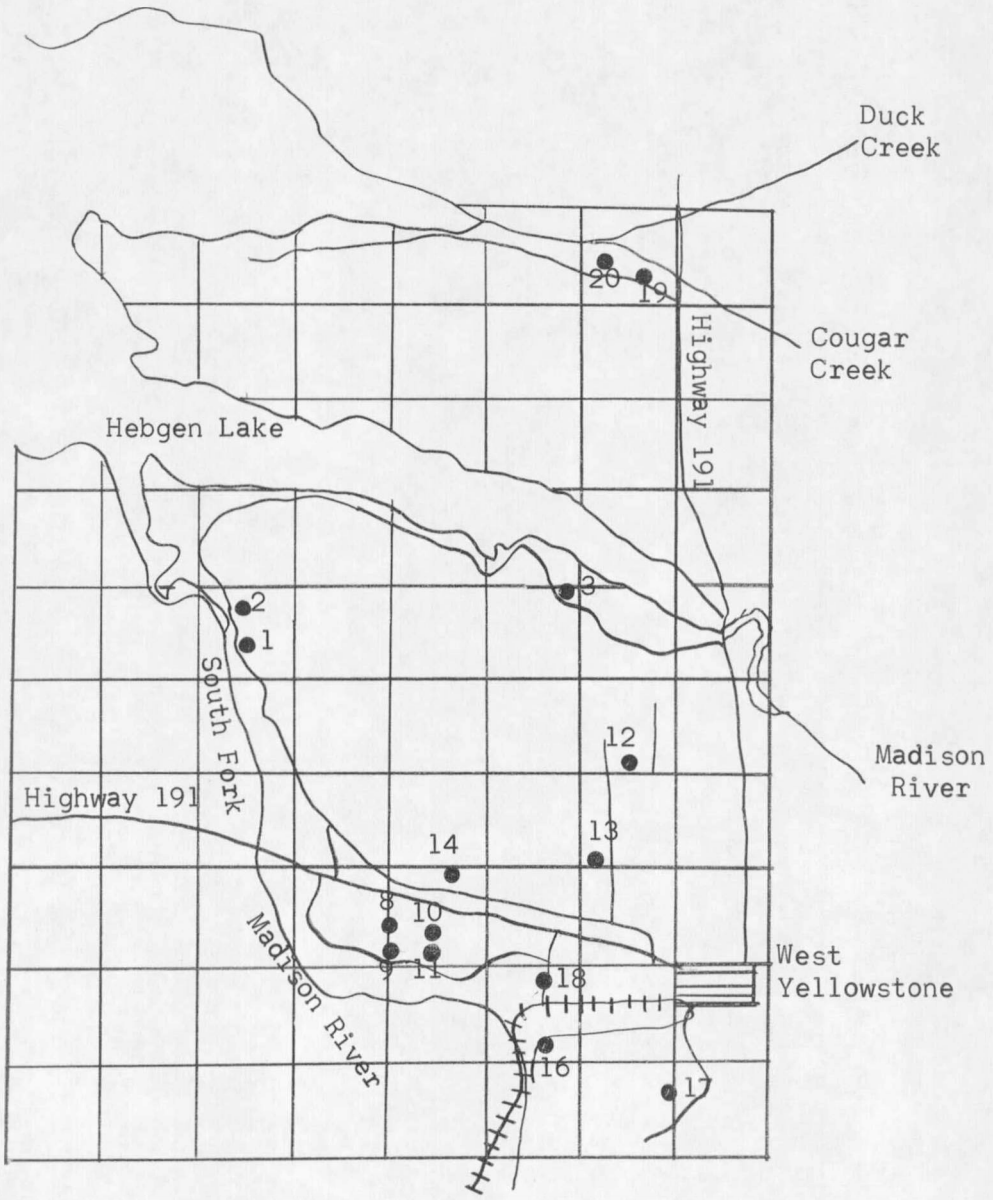


Figure 1. Map of experimental sites in the West Yellowstone area.

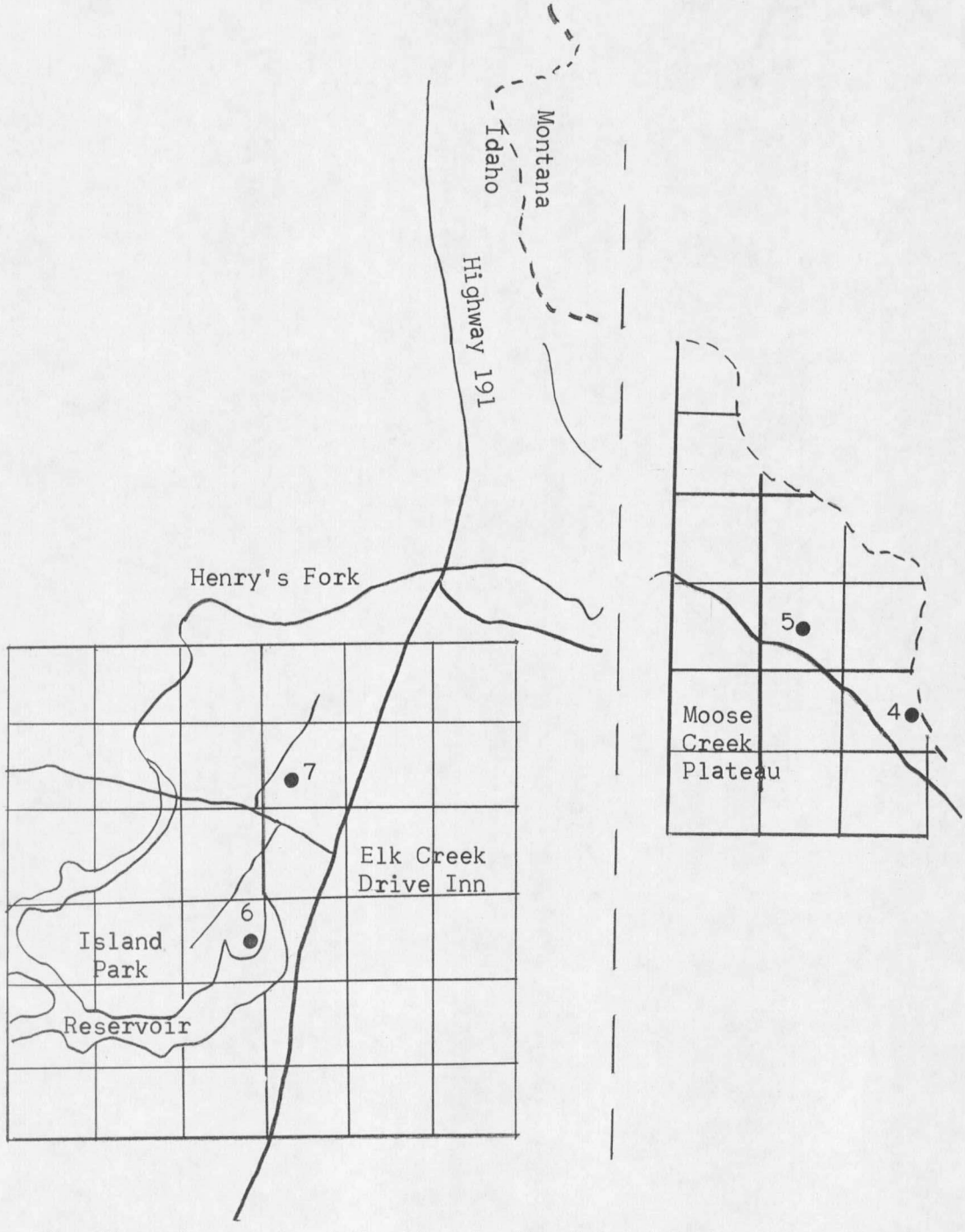


Figure 2. Map of experimental sites in the Island Park - Moose Creek Plateau, Idaho areas.

July 11. The mulch was diluted 1-5 with water and applied with a hand sprinkling can at a rate of approximately 1 gallon of concentrated mulch per 200 square feet. At the time mulch was applied, Tempils^{o} were applied on each of the plots for the specific temperatures of 125^{o}F and 150^{o}F. Those that had melted during the month were replaced at the time seedling counts were made, and the month that the specific melting temperature had been reached was noted. Seedling counts were made monthly by placing a colored toothpick by each seedling, a different color being used each month. Those seedlings dying during the previous month were then noted. The first seedling count was made on June 19 and 20, 1967. The last seedling count was made on September 19, 20, and 21, 1967.

At the time of each monthly seedling count, moisture samples were taken and percentage moisture determined gravimetrically from check plots of each experiment at two depths, 0-6 and 6-12 inches. Eight experimental sites were chosen to represent the area and moisture samples were taken from all plots at 0-6 and 6-12 inch depths.

Soil samples were taken from each experiment at 0-3, 3-6, and 6-12 inch depths. The samples were air-dryed, weighed, and screened through a 2 mm screen, those fractions passing the screen considered as the fine earth percentage.

Analysis, 0-3, 3-6, and 6-12 inch depths:

Mechanical analyses were performed on all fine earth samples by the Bouyoucos method (4). The samples were placed in a milkshaker for 10 minutes to break the structure, and 5 ml. of 1N sodium hexametaphosphate

was used to disperse the soil. Specific surface was determined by the orthophenanthroline method as given by Lawrie (14). Extractable cations were extracted with neutral, normal ammonium acetate, as given by Bower (5). Extractable potassium and sodium were determined from the extract with the flame photometer. Calcium + magnesium was determined by the versenate titration method as suggested by Cheng and Bray (6). Extractable hydrogen was measured by replacement with sodium acetate at a pH of 8.2 and titrated to the phenophthalein end point with standard sodium hydroxide. Organic matter was determined by the Wakley-Black method as described by Jackson (11), using chromic acid and heat of dilution with sulfuric acid. Ferroin indicator was used and titrated to the red end point with 0.2 N ferrous ammonium sulfate.

Analysis, 0-6 inch depth:

The pH was determined with the glass electrode pH meter on a saturated paste. Nitrogen was determined by the micro Kjeldahl method. Sodium bicarbonate soluble phosphorus was extracted by the method as given by Olsen (20), the color being developed by chlorostannous reduced molybdophosphoric blue color method, in sulfuric acid (method 1, Jackson (11)). Available potassium was extracted with 1N ammonium acetate (Jackson, 11) and determined with the flame photometer.

Soil physical characteristics:

Bulk density was determined on undisturbed samples from selected experiments at 0-3, 3-6, and 6-12 inch depths, by the clod method (3).

Particle density was determined by measuring the displacement of water in a graduated cylinder after ample time had been given to expell air. Pore size distribution was determined by saturating an undisturbed core of soil with water, determining the amount of water by weight, subjecting the sample to 50 centimeters water tension, and again determining the amount of water. The total porosity is then approximated by the total amount of water present, by volume, at saturation; that being held above 50 centimeters tension being capillary, that below, non capillary. Percentage water at 15 atmospheres tension was determined on a pressure membrane as described by Richards (21).

Statistical procedure:

Data were analyzed by statistical methods described by Steele and Torrie (22). Computation work was processed by the IBM 1620 II computer at the Montana State University computing center.

RESULTS AND DISCUSSION

Seed losses:

Most lodgepole pine seeding operations are conducted in the fall, the seeds apparently having a higher germinative capacity if subjected to winter conditions. During winter, large amounts of seed are lost through natural processes such as wind, soil, and snow movement. Large losses are often experienced due to birds and rodents.

The seed used in this experiment was treated with Endrin to repel rodents, but large losses occurred in the natural forest clearings of the experimental area, especially on sites 1, 2, and 3. On these sites, small holes were bitten into the seed coat and the inner seed removed, the empty seed coats remaining on the plots. It was suspected that mice could have caused the damage, so several White-Footed Deer Mice were live-trapped and fed lodgepole pine seed treated with Endrin. It was observed that the mice ate the seeds in much the same manner as was observed in the field. However, they would not eat the seeds until the seed coat had been rinsed with water, apparently removing sufficient amounts of repellent.

The study suggests that Endrin is not entirely effective in repelling rodents if the project is to be conducted over winter. This was anticipated at the onset of the experiment and it was felt that plots should be covered with screen. Several screened frames were placed over plots in the early fall. After observing the plots after the first snowfall, it was decided that the frames imposed unnatural canopy effects, and the plots were there-after left exposed, with the exception of the

screened rodent study at each site.

Germination:

Percentage germination in the rodent study along with the average germination on experimental plots is given in Table I. In general, germination was greater on the small exposed areas of the rodent study than on the experimental plots at the same site. Much greater germination occurred under the wire cones of the rodent study, in all cases.

Plots were observed in the West Yellowstone area on May 23, and in the Island Park area on May 31, when mulch was applied. Deep snow banks surrounded the area, but all experimental sites were free of snow, with the exception of the Moose Creek Plateau area. Some germination was observed on all experiments. Bates (1), found that most germination of lodgepole pine seeds occurred at 70°F, but a temperature fluctuation from 52 to 72°F was conducive to germination. Climatological data from the West Yellowstone weather bureau station indicates that a maximum air temperature of 78°F was reached on May 22. This, coupled with the night lows, probably represents a condition favorable for germination. This condition is probably attained as soon as the snow leaves the ground.

Germination occurred throughout the season to a greater degree than previous experiments have indicated (12, 16). At West Yellowstone, 61.7% of the germination occurred in June, 34.2% in July, 3.9% in August, and 0.2% in September. At Island Park, 45.3% of the germination occurred in June, 46.3% in July, and 8.4% in August. On Moose Creek Plateau, 33.7% of the germination occurred in July, 56.5% in August, and 9.8% in September.

Table I. Average germination percentage by plot and on rodent study.

Site	Average	Rodent Study	
		Under cone	Outside cone
		%	
1	1.2	48.0	0
2	0.6	24.0	4.0
3	0.3	76.0	0
4	5.1	48.0	16.0
5	5.8	64.0	28.0
6	1.6	76.0	12.0
7	4.9	48.0	8.0
8	1.2	28.0	0
9	2.6	48.0	20.0
10	1.0	--	--
11	1.6	32.0	4.0
12	3.2	4.0	0
13	0.6	32.0	0
14	2.7	--	--
16	10.0	64.0	12.0
17	11.6	92.0	24.0
18	4.9	92.0	12.0
19	1.2	8.0	4.0
20	12.5	--	--

Mortality:

In general, mortality was fairly well distributed over the summer, with a slightly higher mortality rate beginning in late July and increasing as the season progressed. Mortality occurred later in the season than other studies in the area have indicated (12, 16), and is probably the result of the extremely wet spring followed by a dryer than normal July and August. No statistical analysis was made on the information concerning the month in which mortality occurred as related to the month in which seedlings germinated, but the information was examined in data form. No general conclusions should be drawn from this, but it appears that the soils with large amounts of gravel on the surface and those with a very fine textured soil on the surface represent harsh seedbeds late in the season. Seedlings germinating late in the season on these sites are subject to higher mortalities.

Statistical analysis of germination and survival:

Total numbers of lodgepole pine seedlings germinating and surviving at the end of the season, per plot, is given in Tables II and III. A statistical analysis considering the replications, sites, treatments, and site x treatment interaction is also given. In all of the statistical analyses performed, survival was considered in terms of the total numbers of seedlings surviving at the end of the season, on the particular plot in question. This may be complicated by the fact that the two comparisons, germination and survival overlap, but this approach tends to make the final results more meaningful when interpreted in a practical sense.

Table II. Number of seeds germinating per plot, averaged across reps.

Site	Treatment: Spade	Spade + mulch	Spray	Check	Mean
1	3.66	1.66	5.33	6.67	4.33 g
2	3.33	1.33	2.00	2.67	2.33 g
3	1.00	0.67	1.67	1.33	1.17 g
4	29.00	16.00	16.67	14.67	19.08 b
5	33.0	21.00	15.00	18.00	21.75 b
6	6.34	10.33	2.67	4.00	5.84 g
7	33.67	15.67	9.33	15.00	18.42 bcd
8	7.33	2.67	5.33	2.34	4.42 g
9	11.00	6.00	14.43	7.67	9.78 cdefg
10	7.00	4.00	1.67	2.67	3.84 g
11	4.33	13.00	5.67	1.00	6.00 g
12	10.00	7.00	15.00	15.33	11.83 bcdef
13	5.33	1.33	2.00	1.33	2.50 g
14	13.33	8.67	9.00	13.00	11.00 bcdefg
16	36.33	40.33	48.33	25.00	37.49a
17	67.33	61.67	29.34	15.33	43.42a
18	21.00	13.00	28.67	11.00	18.42 bcde
19	5.00	7.33	5.67	0.33	4.58 g
20	36.34	20.33	75.32	56.33	47.08a
Mean	17.60a	13.26ab	15.42ab	11.24 b	

All means followed by the same letter are not significantly different at the 5% level.

Analysis of Variance, Germination

Variation due to	DF	Sum of Squares	Mean Squares	F
Reps	2	546.38	273.19	1.89
Sites	18	33932.04	1885.11	13.10**
Treatments	3	1950.68	650.23	4.51**
Sites X Treatments	54	8810.90	163.16	1.13
Error	150	21581.62	143.88	
Total	227	66821.63		

** Significant at the 1% level

Table III. Number of seedlings per plot surviving at end of season, averaged across reps.

Site	Treatment: Spade	Spade + mulch	Spray	Check	Mean	
1	1.33	0	0	0	0.33	d
2	0.67	0	0.33	0.33	0.33	d
3	0	0.33	0.67	0	0.25	d
4	26.67	14.00	16.00	13.33	17.50	c
5	28.67	18.67	13.00	14.00	18.58	c
6	3.67	5.34	1.33	2.00	3.08	d
7	9.33	4.33	3.67	2.67	5.00	d
8	0.67	0	1.67	0.33	0.67	d
9	0.67	1.33	0	0	0.50	d
10	3.33	2.00	0.67	2.00	2.00	d
11	0	0.33	0	0	0.08	d
12	6.33	6.33	9.33	12.67	8.67	d
13	0.67	0.33	0.33	0	0.33	d
14	1.67	2.33	2.33	1.67	2.00	d
16	35.67	34.33	43.33	22.00	33.83	b
17	43.00	41.67	23.67	11.33	29.92	b
18	1.33	2.00	0.33	0	0.92	d
19	0.67	4.67	0.33	0	1.42	d
20	27.00	12.67	65.33	53.67	39.67	a
Mean	10.07a	7.93a	9.60a	7.16a		

All means followed by the same letter are not significantly different at the 5% level.

Analysis of Variance, Survival

Variation due to	DF	Sum of Squares	Mean Squares	F
Reps	2	224.52	112.26	1.31
Sites	18	30193.26	1677.40	19.61**
Treatments	3	792.52	264.18	3.08*
Sites X Treatments	54	8021.47	148.54	1.73**
Error	150	12829.47	85.53	
Total	227	52061.26		

* Significant at the 5% level
** Significant at the 1% level

From the statistical analysis, it appears that the effect of sites and treatments are significant, but in terms of survival, the interaction of treatments with sites is highly significant. Subsequent analysis by the Duncan's multiple range test indicates that the only differences in germination between treatments, at the 5% level, is between the spaded and check treatments. No significant differences in survival between treatments were found at the 5% level. This would indicate that in terms of survival on the overall experiment, differences due to treatments did exist, but were inconsistant and were masked by the differences due to sites.

Seedling survival as related to seedbed treatments:

In terms of overall treatment means, spading appears to be slightly better than the other treatments, although not significantly so at the 5% level. This corresponds to the cultivated treatment that Lotan (10) found to be best. Spraying to kill grass also increased survival to a slight degree. This treatment, which was applied in the fall previous to planting, appeared to be quite effective in preventing the growth of grasses and sedges throughout the following season. It did have an apparent retarding effect on germination of lodgepole pine seeds where the grass or sedge was particularly thick. In these cases, the dead grass formed a mat that was too thick to allow the lodgepole pine seeds to reach the soil surface. This was particularly noticeable at site 6.

An examination of the experimental area a week after mulch was applied indicated that mulched plots tended to shed water and appeared

dryer than the unmulched plots, after a heavy rain. The extent to which this situation persisted is not known, but it was observed that the film had broken sufficiently to allow rain penetration by late June.

There is some indication that petroleum mulches may impose a moisture stress on sands of low moisture holding capacity. Mulch will tend to conserve moisture present in the soil, but in soils of low water holding capacity, the small amount of water conserved may be used quite rapidly by growing plants. If the film of mulch impedes regeneration of the soil moisture, then it is quite likely that a depressing effect on seedling survival will result. The lodgepole pine seedlings apparently were able to penetrate the film with no difficulty.

As the season progressed, more weeds grew on the mulched plots than the others. This effect was also noted by Lippert (15). The degree of moisture depletion on these plots and the subsequent depression of lodgepole pine seedling survival is not known.

Soil moisture:

Moisture samples were taken on all plots of selected sites, but a statistical analysis indicated that no significant differences in soil moisture existed between treatments. It is quite likely that sampling was inadequate and reflects the moisture depletion by plants near the area sampled. There was a significant difference in soil moisture on check plots between sites.

A comparison of soil moisture content and 15 atmosphere percentages indicates that none of the sites had reached 15 atmospheres tension until

the August measurement and most of the sites had a higher moisture content than the 15 atmosphere percentage by September 20. This is highly misleading, however. It is quite probable that daily moisture determinations would indicate that the sandy soils reach 15 atmospheres tension quite frequently. The frequent rain showers may also periodically increase the soil moisture to a tension less than 15 atmospheres. Therefore, the daily or weekly regime may be more important than the monthly moisture status or the 15 atmosphere percentage.

Seedlings taken from the moist and dry plots showed considerable differences in root growth. The inability of roots to penetrate to greater depths in the dry soils is probably in part due to the very firm layer that forms at approximately 4 inches (see profile descriptions, Appendix), when the soil becomes dry.

Soil temperature:

The highest value of Tempils^{o} selected, 150^{o}F (65^{o}C) is approximately that suggested by Meyer and Anderson (19) as the temperature at which plant cells break down. Soil surface temperatures are very difficult to measure, as the temperature is dependent on the placement and construction of the device measuring the temperature. In the case of Tempils^{o}, the temperature at which they melt may not be representative of the soil temperature due to direct solar radiation on the pills, and the position of the pills on the plot. For instance, if the pill is so situated that it receives shade from a plant during the hottest part of the day, the plot will be represented as being much cooler.

In analyzing the temperature data, it was felt that a more representative presentation could be given by averaging all replications and sites, by treatment (Figure 3). It appears that a greater percentage of spaded plots reached a higher temperature early in the season, followed by mulched, spray, and check. Whether this is significant is not known, as the experiment does not constitute a sample that is suitable for statistical analysis.

It was thought that the mulched treatment may result in higher soil temperatures, as suggested by Takatori, et al (25). However, data from the West Yellowstone area does not confirm this. Perhaps a degree of shading was present, due to weed cover. It is also quite possible that the albedo of the surface was increased by the light colored mulch. This would tend to reflect more solar radiation, lowering the surface temperature, but raising the temperature at a distance above the soil surface. This could cause greater damage to the trees, as Ursic (26) suggests.

Seedling survival as related to soil characteristics:

A general fertility analysis of the 0-6 inch soil layer at all sites is given in Table IV. These values constitute a fertility level that would be considered low for most agricultural crops, but would probably be within the minimum requirements for lodgepole pine establishment, based on the limits set by Wilde (28) for conifer establishment.

Soil characteristics, on a fine earth basis, are given in Table V. Soil physical characteristics (porosity, bulk density, and particle density) were performed on eight of the sites that were chosen to represent the

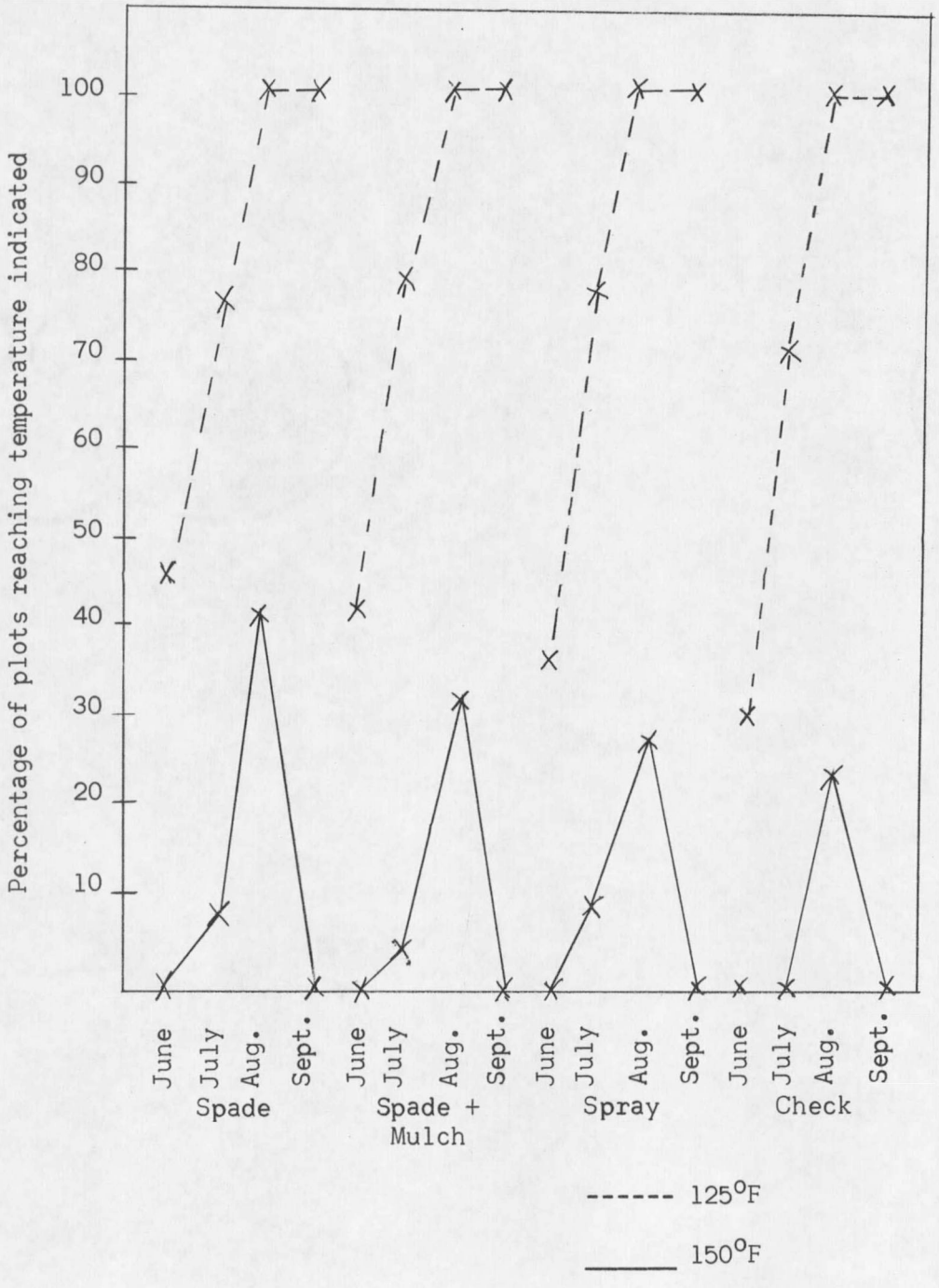


Figure 3. Tempil° study showing distribution of soil surface temperatures by treatment and month.

Table IV. Soil analysis, 0-6" depths.

Site	pH	Total N	Available P	Available K
		%	ppm	ppm
1	5.9	0.0836	11.7	153
2	5.9	0.1009	9.0	208
3	6.3	0.1413	8.5	243
4	5.5	0.1312	41.0	205
5	5.6	0.0981	24.8	188
6	5.6	0.1528	20.1	245
7	5.5	0.1023	10.5	218
8	6.0	0.0706	5.9	108
9	6.0	0.0764	9.2	130
10	5.9	0.0584	11.2	150
11	5.7	0.0505	8.7	115
12	5.7	0.0591	7.2	108
13	6.1	0.0633	5.8	98
14	5.8	0.0534	7.6	118
16	5.7	0.0678	16.8	223
17	5.7	0.0894	19.6	278
18	5.7	0.0620	13.0	145
19	6.1	0.0433	6.0	95
20	5.7	0.0389	8.5	163

Table V. Soil physical and chemical properties of experimental area.

Site	Depth	Fine Earth	Mech. Analysis			Specific Surface	Water, 15 Atm.	O.M.	Extr. Cations			
			Sand	Silt	Clay				K	Na	Ca+Mg	H
	inches		%			m^2/g	%		meq/100g			
1	0-3	75	79.6	15.0	5.4	20.9	5.9	2.7	0.46	0	4.97	1.59
	3-6	74	80.6	14.0	5.4	26.2	5.3	1.7	0.32	0	4.22	1.67
	6-12	80	84.4	9.8	5.8	16.1	3.8	0.65	0.31	0.19	3.57	1.64
2	0-3	79	74.0	18.4	7.6	34.0	8.6	3.3	0.55	0	5.72	2.42
	3-6	78	76.1	16.4	7.5	29.6	4.3	1.2	0.32	0.02	3.58	1.39
	6-12	81	81.2	11.0	7.8	19.7	3.8	0.45	0.28	0.21	3.46	1.09
3	0-3	60	67.8	25.3	6.9	41.7	10.8	4.8	0.74	0.06	8.68	2.37
	3-6	51	68.9	23.2	7.9	29.2	7.9	2.4	0.52	0.02	5.99	1.46
	6-12	49	75.4	16.8	7.8	22.5	5.1	0.71	0.41	0.10	5.57	1.09
4	0-3	87	44.0	41.0	15.0	74.7	11.6	6.6	0.81	0.02	4.04	8.72
	3-6	100	41.5	43.4	15.1	67.8	9.0	4.0	0.39	0.02	3.74	7.45
	6-12	93	43.4	40.8	15.8	48.0	8.9	2.0	0.37	0.19	2.01	7.11
5	0-3	82	52.6	39.8	7.7	40.5	8.4	3.9	0.52	0.04	3.74	6.63
	3-6	79	59.3	28.0	12.7	50.3	8.2	2.3	0.44	0.02	2.41	6.15
	6-12	84	51.4	36.8	11.8	40.6	7.5	1.5	0.42	0.12	1.86	6.13
6	0-3	93	48.0	38.6	13.4	56.4	19.7	8.0	1.05	0	11.55	6.45
	3-6	87	44.1	41.3	14.6	43.5	6.5	1.7	0.52	0	5.15	2.44
	6-12	86	45.2	40.0	14.8	42.0	5.7	0.95	0.42	0.14	4.73	2.28
7	0-3	74	66.1	25.7	8.2	48.0	12.7	6.4	0.71	0.02	6.09	6.04
	3-6	75	68.8	23.0	8.2	33.0	6.2	1.8	0.46	0.02	3.73	2.66
	6-12	70	66.2	25.0	8.8	26.8	5.1	0.95	0.46	0.24	3.22	2.37

Table V. Cont'd.

Site	Depth	Fine Earth	Mech. Analysis Sand	Silt	Clay	Specific Surface	Water, 15 Atm.	O.M.	Extr. Cations K	Na	Ca+Mg	H
	inches		%			m^2/g	%		meq/100g			
8	0-3	78	78.4	15.9	5.7	24.1	5.6	2.9	0.31	0.02	4.80	1.84
	3-6	6	81.3	12.9	5.8	21.4	5.1	1.3	0.24	0.02	3.55	1.39
	6-12	63	78.2	13.6	8.2	18.6	4.3	0.43	0.27	0.12	3.18	1.09
9	0-3	70	76.8	18.2	5.0	25.0	6.7	2.9	0.40	0.08	4.72	2.28
	3-6	73	77.8	16.2	6.0	26.8	4.3	1.0	0.30	0	3.11	1.00
	6-12	70	79.8	13.0	7.2	25.7	4.1	0.44	0.34	0.14	4.14	1.00
10	0-3	98	74.8	20.4	4.8	24.0	7.1	2.5	0.56	0	8.36	2.22
	3-6	97	70.3	24.8	4.9	18.1	4.4	1.5	0.37	0.06	3.04	1.48
	6-12	98	71.8	23.0	5.2	11.8	3.6	0.64	0.39	0.16	2.42	1.28
11	0-3	83	80.3	13.3	6.4	23.1	5.6	2.6	0.32	0	3.96	2.49
	3-6	85	80.2	13.4	6.4	19.8	5.2	1.4	0.24	0.02	2.88	2.18
	6-12	93	81.8	12.0	6.2	17.3	4.5	0.43	0.27	0.12	3.27	1.55
12	0-3	67	75.7	16.9	7.4	29.3	7.7	3.1	0.44	0	4.51	3.08
	3-6	69	76.2	16.4	7.9	27.2	3.6	0.54	0.24	0.06	2.94	1.14
	6-12	71	70.0	20.0	10.0	22.6	3.8	0.31	0.23	0.08	3.52	1.09
13	0-3	64	75.4	17.9	6.7	30.0	5.9	2.7	0.27	0	3.89	1.99
	3-6	69	74.4	15.4	9.2	34.0	4.5	0.66	0.31	0	3.52	1.12
	6-12	69	79.8	12.0	8.2	22.9	3.8	0.33	0.34	0.16	3.88	1.09
14	0-3	57	68.9	23.0	8.1	36.3	6.9	3.6	0.42	0	6.13	3.33
	3-6	67	71.9	19.5	8.6	31.8	4.4	0.9	0.26	0	3.34	2.17
	6-12	63	80.8	12.0	7.2	21.9	3.7	0.31	0.23	0.10	3.62	1.00

Table V. Cont'd.

Site	Depth	Fine Earth	Mech. Analysis			Specific Surface	Water, 15 Atm.	O.M.	Extr. Cations			
			Sand	Silt	Clay				K	Na	Ca+Mg	H
	inches		%			m^2/g	%		meq/100g			
16	0-3	100	46.3	45.2	8.5	42.4	9.7	4.2	0.90	0.02	6.19	3.03
	3-6	100	42.8	48.7	8.5	35.8	6.6	2.0	0.42	0	5.37	2.28
	6-12	100	45.8	46.0	8.2	22.9	4.8	0.99	0.38	0.18	4.11	1.73
17	0-3	100	41.4	50.6	8.0	33.7	11.3	4.8	1.10	0	7.22	3.84
	3-6	100	36.9	53.4	9.7	33.3	4.9	1.3	0.36	0	4.11	2.29
	6-12	100	39.8	50.0	10.2	28.4	4.4	0.82	0.32	0.16	3.73	2.19
18	0-3	78	67.3	24.5	8.2	39.0	7.1	4.0	0.52	0.02	5.58	3.12
	3-6	79	66.8	23.5	9.7	38.4	5.3	1.2	0.34	0	4.01	2.28
	6-12	75	75.8	16.0	8.2	27.1	4.3	0.29	0.27	0.16	3.69	1.69
19	0-3	82	80.9	13.7	5.4	21.4	5.9	2.5	0.34	0	3.84	1.67
	3-6	82	80.4	13.2	6.4	20.3	4.7	0.78	0.22	0	3.17	0.79
	6-12	85	81.8	11.0	7.2	18.2	4.2	0.31	0.18	0.06	3.07	0.72
20	0-3	87	71.9	18.7	9.4	29.8	6.2	2.1	0.24	0	3.70	1.57
	3-6	74	62.9	23.7	13.4	34.3	5.9	1.3	0.15	0	3.49	1.43
	6-12	83	72.8	18.0	9.2	23.2	4.8	1.1	0.16	0.06	2.71	1.19

experimental area. This was found to be necessary due to the difficulty in obtaining undisturbed samples, and the necessity of replicating the measurements numerous times. The material is present in Table VI.

An analysis of variance of the soil characteristics is given in Table VII. It can be seen that most of the soil characteristics vary significantly between sites and with depth.

A fairly good relationship appears to exist between seedling survival at the end of the first season and the mean silt percentage of the soil. It appears from the data that most of the sites that had 2 or more trees surviving per plot also had a silt content greater than 20% (Table VIII).

The linear equations describing the relationships between percentage seedling survival and soil characteristics on a whole soil basis, along with correlation coefficients, are given in Table IX. It appears from this that the silt content is the most highly correlated soil factor associated with seedling survival. Other factors contributing significantly are fine earth percentage, percentage sand, clay, water at 15 atmospheres, and organic matter. Apparently factors at lower depths are significant in contributing to survival even though the seedling roots may not penatrate this depth. It also appears that those factors significant in promoting seedling survival are also those factors related to the moisture holding capacity of the soil.

Multiple regressions of soil factors and seedling survival indicate that a larger amount of variation can be explained when more soil factors are examined together. It also appears that there is a higher correlation

Table VI. Soil physical properties on eight selected sites of the experimental area.

Site	Depth	Total pore space by volume	Capillary pore space by volume	Non-capillary pore space by volume	Bulk density	Particle density
	Inches	%			g/cc	g/cc
1	0-3	48.8	22.3	26.4	1.43	2.50
	3-6	45.4	18.6	26.8	1.42	2.18
	6-12	37.9	16.9	21.0	1.34	2.17
5	0-3	53.4	38.5	14.9	1.10	2.76
	3-6	61.2	42.8	18.4	1.29	2.40
	6-12	44.0	34.9	9.1	1.23	2.17
6	0-3	68.4	55.5	12.9	1.17	2.43
	3-6	67.1	50.1	17.0	1.38	2.20
	6-12	52.8	37.7	15.1	1.57	2.36
9	0-3	38.5	15.7	22.8	1.38	2.55
	3-6	40.6	19.4	21.2	1.50	2.30
	6-12	41.7	12.9	28.8	1.59	2.31
12	0-3	42.9	26.9	16.0	1.44	2.34
	3-6	33.3	7.8	25.5	1.57	2.28
	6-12	33.1	17.5	15.6	1.47	2.25
17	0-3	58.8	49.9	8.9	1.19	2.54
	3-6	53.4	46.5	6.9	1.22	2.17
	6-12	47.5	41.8	5.7	1.25	2.30
18	0-3	41.4	22.3	19.1	1.14	2.28
	3-6	53.2	29.7	23.5	1.58	2.28
	6-12	45.2	21.1	24.1	1.65	2.13
20	0-3	23.6	21.5	2.1	1.26	1.91
	3-6	38.1	26.1	12.0	1.85	2.28
	6-12	32.5	26.2	6.3	1.36	2.35

Table VII. Analysis of variance of soil chemical and physical characteristics.

Soil characteristic	Fine Earth	Sand	Silt	Clay	Sp. Sur.	15 Atm.	O.M.	Extr. K	Extr. Na	Extr. Ca+Mg	Extr. H
Mean Square, Depths	0.0	28.7	44.7	7.0	552.1	77.8	51.1	0.3	0.1	27.3	11.0
D.F., Depths	3	3	3	3	3	3	3	3	3	3	3
Mean Square, Sites	490.0	608.4	457.1	22.0	367.1	9.6	2.1	0.04	0.0	1.0	0.4
D.F., Sites	18	18	18	18	18	18	18	18	18	18	18
Mean Square, Error	16.8	9.3	7.7	0.9	20.2	3.3	0.6	0.01	0.1	1.0	0.4
D.F., Error	36	36	36	36	36	36	36	36	36	36	36
F, Depths	0.00	3.05	5.76**	7.41**	27.2**	23.6**	77.2**	24.3**	9.55**	26.7**	30.0**
F, Sites	29.0**	64.7**	58.9**	23.2**	18.1**	2.92**	3.18**	3.91**	0.77	3.76	25.2**

* Significant at 5% level
** Significant at 1% level

Table VIII. Mean seedling survival by plot as compared to soil silt percentage.

Site	Mean survival, trees per plot	Silt percentage
20[a]	39.67	20.1
16	33.83	46.6
17	29.92	51.3
5	18.50	34.9
4	17.50	41.7
12[b]	8.67	18.2
7	5.00	24.6
6	3.08	40.0
10	2.00	22.7
14	2.00	18.2
19	1.42	12.6
18	0.92	21.3
8	0.67	14.1
9	0.50	15.8
2	0.33	15.3
1	0.33	12.9
13	0.33	15.1
3[c]	0.25	21.8
11	0.08	12.9

a/ High water table

b/ Apparent water table lense

c/ Rodent damage to seeds

Table IX. Linear regression equations and regression coefficients of lodgepole pine seedling survival as related to soil factors.

Soil measurement	Soil depth	Equation	r	r^2	F Reg.
% Fine earth	0-3"	Y = -9.18 + .14 X	.540	.296	7.55*
	3-6"	Y = -6.48 + .11 X	.412	.176	3.85
	6-12"	Y = -7.06 + .12 X	.486	.236	5.57*
% Sand	0-3"	Y = 6.59 - .08 X	.249	.062	1.18
	3-6"	Y = 11.36 - .17 X	.529	.280	6.99*
	6-12"	Y = 7.51 - .09 X	.339	.115	2.33
% Silt	0-3"	Y = -1.37 + .18 X	.655	.429	13.52**
	3-6"	Y = - .94 + .15 X	.652	.425	13.32**
	6-12"	Y = - .78 + .16 X	.677	.458	15.22*
% Clay	0-3"	Y = -1.57 + .62 X	.498	.248	5.94*
	3-6"	Y = -2.10 + .62 X	.566	.321	8.50**
	6-12"	Y = -1.72 + .57 X	.489	.239	5.65*
Sp. Surface	0-3"	Y = - .64 + .10 X	.405	.164	3.52
	3-6"	Y = - .90 + .12 X	.457	.209	4.76
	6-12"	Y = - .87 + .15 X	.436	.190	4.22
15 Atm. %	0-3"	Y = .47 + .27 X	.283	.080	1.57
	3-6"	Y = -2.52 + 1.09 X	.497	.247	5.91*
	6-12"	Y = -1.89 + 1.11 X	.484	.234	5.52*
Org. Matter %	0-3"	Y = .70 + .53 X	.242	.059	1.13
	3-6"	Y = .43 + 1.54 X	.359	.129	2.68
	6-12"	Y = - .45 + 4.68 X	.615	.378	10.96**
Extr. K	0-3"	Y = - .13 + 5.37 X	.431	.186	4.12
	3-6"	Y = .38 + 7.31 X	.210	.044	.84
	6-12"	Y = .14 + 8.76 X	.219	.048	.91
Extr. Ca + Mg	0-3"	Y = 1.32 + .23 X	.122	.015	.28
	3-6"	Y = -2.40 + 1.59 X	.130	.170	3.70
	6-12"	Y = .38 + .73 X	.141	.020	.39
Extr. H	0-3"	Y = .91 + .52 X	.283	.080	1.58
	3-6"	Y = 1.04 + .70 X	.342	.117	2.38
	6-12"	Y = 1.09 + .76 X	.358	.128	2.65

* Significant at 5% level
** Significant at 1% level
Y = % survival
X = Soil characteristics

between survival and soil factors at the 6-12 inch depth. Multiple regression coefficients are given in Table X. Multiple regression equations are given in Table XI.

Practical considerations:

By considering the silt + clay content of the soil on a whole soil basis (silt + clay percentages taken times the fine earth percentage), the relationships with seedling survival may be expressed by several linear equations. The first equation expresses the relationships on the check plots and is given as $Y = -0.254 + 0.08X$, where Y = percentage of total seeds planted which survived the first season, and X = silt + clay content in the first foot of soil. The equation given has a correlation coefficient of .35. The second equation explains the relationships between seedling survival and silt + clay content on the spaded plots and is given as $Y = 2.718 + .20X$ which has a correlation coefficient of .82. If 1000 lodgepole pine trees per acre is considered a desirable stocking rate (16), solving the equations yields the information that 57,273 seeds would be needed on the natural sites and 35,460 on the cultivated sites to achieve the desired stand density on soils having a 25% silt + clay content. At a silt + clay content of 50%, 26,695 seeds per acre would be required on the natural sites and 13,734 seeds on the cultivated sites. Different values would be obtained if the seed viability was significantly different than that used in the experiment.

Several factors should be considered before these results are to be used in a practical sense. First, more or less than 1000 first-year

Table X. Multiple regression coefficients and "F" values of lodgepole pine seedling survival as related to soil factors in the 6-12 inch depth.

Regression	Soil factor	F regression	r	r^2
1	% Fine earth	6.61*	.68	.46
	% Sand	5.85*		
	% Clay	.52		
2	% Fine earth	10.20**	.82	.68
	% Sand	9.03**		
	% Clay	.80		
	Extr. K.	9.15**		
3	% Fine earth	9.66**	.82	.62
	% Sand	8.55**		
	% Clay	.76		
	Extr. K	.54		
	Sp. surface	8.39*		
4	% Fine earth	18.64**	.92	.85
	% Sand	16.51**		
	% Clay	1.47		
	Extr. K	1.04		
	Sp. surface	8.11*		
	Org. matter %	21.15**		
5	% Fine earth	26.08**	.96	.92
	% Sand	19.76**		
	% Silt	.99		
	% Clay	6.65*		
	Sp. surface	1.58		
	15 Atm. %	2.48		
	Org. matter %	6.00*		
	Extr. K	28.87**		
	Extr. Ca + Mg	.16		
	Extr. H	2.39		

* Significant at 5% level

** Significant at 1% level

Table XI. Multiple regression equations of lodgepole pine seedling survival as related to soil properties in the 6-12 inch depth.

Regression	Equation
1	Y = .43 + .17 fine earth - .18 sand - .30 clay
2	Y = 10.42 + .19 fine earth - .22 sand - .54 clay - 28.51 K
3	Y = 5.55 + .50 fine earth - .61 sand - .69 clay + .12 K - 30.70 sp. surface
4	Y = -2.66 - .33 fine earth - .70 sand + 1.17 clay - .46 K + 6.25 sp. surface - 35.66 org. matter
5	Y = 5733.4 - 161.67 fine earth + 110.18 sand + 65.16 silt + 13.23 clay - 5.98 sp. surface + 13.86 15 atm. % - 15.68 org. matter - 32.86 K - .93 Ca + Mg - 1.73 H

Y = % survival

seedlings may be required to assure an adequate stand at maturity. Then too, the data presented may reflect the success attained in a fairly moist year. Dryer years probably would require a much larger seedling rate. The equation for natural sites contains a large amount of unexplained variation, as might be expected. Such things as vegetation and topography undoubtedly contribute a great deal to the regression, but are difficult to measure. By cultivating, or in some way preparing the seedbed, much of the extraneous variation can be reduced.

SUMMARY AND CONCLUSIONS

Direct reseeding trials were conducted on soils of low moisture holding capacity to determine the success of several seedbed treatments on lodgepole pine seedling survival. Sites were chosen to represent a range of varying soil physical and chemical properties in an attempt to correlate reseeding success with natural factors.

Large numbers of seed were lost through rodent damage on many of the sites situated in natural forest clearings. The seed treatment evidently becomes ineffective in repelling rodents after it has been washed with rain or snow.

Weather stations located in the experimental area indicated a very wet spring which resulted in good germination. Seedbed treatments did not exhibit the pronounced effect on seedling survival that may be experienced in a dry year. Cultivated treatments did prove to be slightly better in establishing seedlings that would survive the first season. Mulching was not as successful in seedling establishment, perhaps due to weed growth and to lack of early moisture penetration through the petroleum mulch.

There was some indication that seedling survival may be related to root penetration. The small amount of clay is apparently quite effective in cementing the sand particles to form a dense layer at about 4-6 inches, when the soil becomes dry. Plots that remained moist throughout the season had adequate root penetration, and survival was greater than plots that dried and prevented adequate root development.

Seedling survival was found to vary markedly with the type of soil. Examination of the data and subsequent linear regressions indicated that

survival was positively correlated with soil silt content. The silt + clay fraction, when correlated with survival, may then demonstrate an important relationship which helps to explain reseeding success. Other significant soil properties were fine earth percentage, sand, organic matter, and 15 atmosphere percentages. It appears that those factors contributing significantly to survival are factors which are also responsible for the moisture holding capacity of the soil.

APPENDIX

Experimental Site Descriptions and Soil Profile Descriptions

Site 1

Location: NE. 1/4 Sec. 14, T13S, R4E. Natural clearing in lodgepole pine forest, West Yellowstone, Montana.

Elevation: 6580 ft.

Vegetation: Sparsely vegetated with needle-and-thread (Stipa comata), moss, and numerous pusseytoes (Antennaria rosea).

Description by Stermitz

0-4"	Dark brown (10YR 3/3, moist) loamy sand; loose gravel at surface, little mulch; structureless; boundary clear, wavy; numerous roots.
4-13"	Yellowish-brown to brown (10YR 5/4, dry; 10YR 4/3, moist) loamy sand; very weak subangular blocky, breaking to single grain; firm in place, friable; boundary diffuse; abundant roots.
13-16"	Brown to dark brown (10YR 5/3, dry; 10YR 4/3, moist) loamy sand; very weak subangular blocky; not quite as firm in place as above, friable; boundary clear, wavy; fewer roots than above.
16-48"	Stratified sands and gravels.

Site 2

Location: NE. 1/4 Sec. 14, T13S, R4E. Natural clearing in lodgepole pine forest, West Yellowstone, Montana.

Elevation: 6580 ft.

Vegetation: Quite heavily covered with sagebrush (Artemisis tridentata), sparsely vegetated with needle-and-thread (Stipa comata), moss, and pusseytoes (Antennaria rosea).

Description by Stermitz

0-4"	Very dark grayish-brown (10YR 3/2, moist) sandy loam; loose litter mulch and gravel arrangement on surface; no structure; numerous roots.
4-10"	Brown to dark brown (10YR 5/3, dry; 10YR 4/3, moist) loamy sand; weak subangular blocky breaking to single grain; firm, friable; boundary diffuse; abundant roots, charcoal.
10-18"	Brown to dark brown (10YR 5/3, dry; 10YR 4/3, moist) same as above but lacking firmness in place; fewer roots.
18-45"	Stratified sands and gravels; few roots.

Site 3

Location: NE. 1/4 Sec. 8, T2S, R5E. Natural clearing in lodgepole pine forest, West Yellowstone, Montana.

Elevation: 6580 ft.

Vegetation: Sparsely vegetated with Idaho fescue (Festuca idahoensis), moss, pusseytoes (Antennaria rosea), and some sagebrush (Artemisia tridentata).

Description by Southard and Klages

0-2"	A_{11}	Very dark grayish-brown (10YR 3/2) gravelly sandy loam; weak fine granular, friable; numerous medium and fine roots; many gravels at surface.
2-8"	$B_{ir}2$	Dark brown (10YR 2/2) gravelly sandy loam; weak fine granular; friable; many medium and fine roots; clear wavy boundary.
8-15"	$B_{ir}3$	Dark grayish-brown (10YR 4/2 - 3/3) gravelly loamy sand; single grain; common medium roots; gradual boundary.
15-30"	IIC	Variegated gravels and sand, single grain; common and medium roots; obsidian gravel increases below 26 inches.

Site 4

Location: E. 1/2 Sec. 28, T15S, R5E. Clear cut area in lodgepole pine forest, 200 ft. E, 100 ft. W of timber, Moose Creek Plateau, Idaho.

Elevation: 8150 ft.

Vegetation: Sparsely vegetated with sedge (Carex rossii), low huckleberry (Vaccinium scoparium).

Description by Stermitz

0-9"	Dark brown (10YR 3/3, moist) loam; moderate-medium plates; firm, friable, nonsticky, nonplastic; gradual boundary; abundant roots.
9-19"	Dark yellowish-brown (10YR 4/4, moist) dark brown (10YR 3/4) mottles along roots; loam - fine sandy loam; weak fine platy; slightly firm and friable, nonsticky, nonplastic; clear, wavy boundary; few roots.
19-32"	Yellowish-brown (10YR 5/4) silt loam, weak fine platy; moderately firm in place, friable; nonsticky, nonplastic; clear, wavy boundary; few roots.
32-70"	Dark brown (10YR 4/3) silty clay loam; weak, thick plates; firm in place; slightly sticky, plastic; grades into a mixture of fragmental obsidian stones at lower portions.

Site 5

Location: Sec. 20, T15S, R5E. Center of clear cut area in lodgepole pine forest, Moose Creek Plateau, Idaho.

Elevation: 8000 ft.

Vegetation: Same as site 4.

Description by Stermitz

0-8"	Dark brown (10YR 3/3, moist) sandy loam; moderate-medium plates; soft, friable; nonsticky, nonplastic; numerous roots; boundary clear, wavy.
8-19"	Dark brown (10YR 4/3) loam; fine plates, gradual boundary; numerous roots.
19-45"	Brown (10YR 5/3) sandy loam; coarse prisms; firm in place, also firm, friable out of place; nonsticky, nonplastic; abrupt boundary; has appearance of pan; few roots.
45-60"	Brown (10YR 5/3) sandy loam mixed with coarse fragments of obsidian.

Site 6

Location: NE. 1/4 Sec. 21, T13N, R3E. Clear cut area in lodgepole pine forest, Island Park, Idaho. Slash piled and burned.

Elevation: 6500 ft.

Vegetation: Densely vegetated with sedge (Carex rossii) plains reedgrass (Calamagrostis montanensis) and smooth brome (Bromus inermis)

Description by Stermitz

1/2-0"	Dense mat of dead, decaying sedge.
0-1"	Very dark grayish-brown (10YR 3/2, moist) sandy loam; loose mulch arrangement; abundant roots; boundary clear, wavy.
1-7"	Brown (10YR 5/3, dry; 10YR 4/2 moist) loam; some mottles; very weak fine platy structure; firm, friable; boundary diffuse; abundant roots.
7-30"	Pale brown to brown (10YR 6/3, dry; 10YR 5/3, moist) dark brown (10YR 4/3) mottles along roots; sandy loam; coarse prisms; firm in place, moderately firm out of place; slightly sticky, plastic; boundary clear, wavy; abundant roots.
30-45"	Dark grayish-brown (10YR 4/2, moist) sandy loam mixed with obsidian gravels; few roots.

Site 7

Location: SW. 1/4 Sec. 10, T13N, R3E. Clear cut area in lodgepole pine forest, Island Park, Idaho. Slash piled and burned. Plot located on a ridge.

Elevation: 6500 ft.

Vegetation: Sparsely vegetated with sedge (Carex rossii), smooth brome (Bromus inermis).

Description by Stermitz

0-1"	Very dark grayish-brown (10YR 3/2) loam; loose mulch arrangement; boundary clear, wavy; abundant roots.
1-7"	Brown to dark brown (10YR 5/3, dry; 10YR 4/2, moist) sandy loam; some mottles; very weak fine platy structure; firm, friable; boundary diffuse; abundant roots.
7-30"	Pale brown to brown (10YR 6/3, dry; 10YR 5/3, moist; dark brown (10YR 4/3) mottles along roots; sandy loam; firm in place, moderately firm out of place; nonsticky, non-plastic; boundary clear, wavy; numerous roots.
30-45"	Dark grayish-brown (10YR 4/2, moist) sandy loam mixed with obsidian gravels; very few roots.
45-60"	Large, undifferentiated gravels and stones.

Site 8

Location: SW. 1/4 Sec. 30, T13S, R5E. Clear cut area in lodgepole pine forest, West Yellowstone, Montana.

Elevation: 6620 ft.

Vegetation: Lupine (Lupinus sp.) sedge (Carex rossii) green needlegrass (Stipa viridula) foxtail barley (Hordeum jubatum) western wheatgrass (Agropyron smithii).

Description by Stermitz

0-3" Grayish-brown to very dark grayish-brown (10YR 5/2, dry; 10YR 3/2, moist) very loose loamy sand; no structure; litter mulch on surface mixed with gravel; boundary clear, wavy; abundant roots.

3-8" Grayish-brown to dark grayish-brown (10YR 5/2, dry; 10YR 4/2, moist) loamy sand; weak subangular blocky, breaking to single grain structure; firm, friable; boundary diffuse; abundant roots.

8-16" Brown to dark brown (10YR 5/3, dry; 10YR 4/3, moist) loamy sand; very weak subangular blocky; lacks firmness in place when moist, becomes firm when dry; friable; boundary diffuse; few roots.

16-48" Variegated sands and gravels.

Site 9

Location: SW. 1/4 Sec. 30, T13S, R5E. Clear cut area in lodgepole pine forest, West Yellowstone, Montana. May have been a small natural clearing in forest, slight west slope, 50 ft. east of timber.

Elevation: 6620 ft.

Vegetation: Green needlegrass (Stipa viridula), Idaho fescue (Festuca idahoensis), yellow eriogonum (Eriogonum flavum), lupine (Lupinus sp.) some sage (Artemisia tridenta) and small quaking aspen (Populus tremuloides).

Description by Stermitz

0-3" Very dark grayish-brown (10YR 3/2, moist) loamy sand; loose gravelly arrangement with little or no litter mulch; no structure; boundary abrupt, wavy; numerous roots.

3-12" Pale brown to dark grayish-brown (10YR 6/3, dry; 10YR 4/2, moist) loamy sand; very weak subangular blocky, breaking to single grain structure; firm, friable; boundary diffuse; numerous roots.

12-18" Brown to dark brown (10YR 5/3, dry; 10YR 4/3, moist); same as above except lacks firmness in place, especially when wet; boundary diffuse; abundant roots.

Site 9 (Cont'd)

18-22" Dark brown to very dark grayish-brown (10YR 4/3, dry; 10YR 3/2, moist) coarse loamy sand; single grain structure; abrupt boundary; few roots.

22-48" Variegated sands and gravels of obsidian and rhyolite; few roots.

Site 10

Location: SW. 1/4 Sec. 30, T13S, R5E. Clear cut area in lodgepole pine forest, West Yellowstone, Montana. Slight west slope, 100 ft. west of timber.

Elevation: 6620 ft.

Vegetation: Good natural regrowth of lodgepole pine, Idaho fescue (festuca idahoensis), green needlegrass (Stipa viridula), sedge (Carex rossii), strawberry (Fragaria virginiana), lupine (Lupinus sp.), slender wheatgrass (Agropyron trachycaulum), yarrow (Achillea lanulosa).

Description by Southard and Stermitz

0-4"	Light brownish-gray to dark grayish-brown (10YR 6/2, dry; 10YR 4/2, moist) fine sandy loam; moderate fine granular, soft and friable; nonsticky, nonplastic; abundant roots; abrupt boundary.
4-9"	Dark brown (10YR 3/3) fine sandy loam; moderate medium blocky, friable; nonsticky; breaks into moderate-medium granules; clear boundary; abundant roots.
9-14"	Grayish-brown (10YR 5/2) sandy loam, some mottling along root channels; moderate-medium blocky, friable; nonsticky; gradual boundary; few roots below 14 inches.

Site 11

Location: SW. 1/4 Sec. 30, T13S, R5E. Clear cut area in lodgepole pine forest, 200 ft. north of timber, 200 ft. east, West Yellowstone, Montana.

Elevation: 6620 ft.

Vegetation: Sparse vegetation consisting of Idaho fescue (Festuca idahoensis), green needlegrass (Stipa virdula), and foxtail (Hordeum jubatum).

Description by Southard and Stermitz

1-0"	Litter, loose mulch arrangement.
0-2"	Very dark grayish-brown (10YR 3/2) loamy sand; loose mulch arrangement; no structure; abrupt boundary; numerous roots.
2-9"	Very dark grayish-brown (10YR 3/2) loamy sand; very weak subangular blocky, breaking to single grain structure; firm, friable; boundary diffuse; abundant roots.
9-16"	Dark grayish-brown (10YR 4/2) coarse sandy loam; same as above except lacks firmness in place; boundary clear, wavy, fewer roots than above.

Site 11 (Cont'd)

16-22" Very dark grayish-brown (10YR 3/2) loamy sand; single grain structure; abrupt wavy boundary; few roots.

22-48" Variegated sands and gravels of obsidian.

Site 12

Location: SE. 1/4 Sec. 16, T13S, R5E. Originally 50 ft. south of timber in clear cut area. Timber north of plot was logged in July, 1967. Slash piled, not burned. West Yellowstone, Montana.

Elevation: 6630 ft.

Vegetation: Very sparsely vegetated with water leaf (Phacellia capitatum), foxtail (Hordeum jubatum), sedge (Carex rossii), bitterbrush (Purshia tridentata). Plot area appears more moist than immediate surrounding area.

Description by Stermitz

0-3" Dark brown to very dark grayish-brown (10YR 4/3, dry; 10YR 3/2, moist) very loose gravelly loamy sand; no structure; little mulch on surface; boundary abrupt; abundant roots.

3-8" Dark brown to very dark grayish-brown (10YR 4/3, dry; 10YR 3/2, moist) sandy loam; weak subangular blocky, breaking to single grain structure; firm, friable; boundary diffuse; wavy; numerous roots.

8-15" Brown to dark brown (10YR 5/3, dry; 10YR 4/3, moist) coarse loamy sand; very weak subangular blocky; firm in place when dry, loose when wet; boundary clear, wavy, numerous roots.

Site 12 (Cont'd)

15-16" Variegated sands and gravels, few roots.

Site 13

Location: SW. 1/4 Sec. 21, T13S, R5E. Clear cut in lodgepole pine forest, 60 ft. north of timber, slash piled and burned. West Yellowstone, Montana.

Elevation: 6630 ft.

Vegetation: Sparsely vegetated with yellow Eriogonium (Eriogonium flavum), pusseytoes (Antennaria rosea), bitterbrush (Pursha tridentata), yarrow (Archillea lanulosa), and green needlegrass (Stipa virdula).

Description by Stermitz

Description same as site 12.

Site 14

Location: NE. 1/4 Sec. 30, T13S, R5E. Clear cut area in lodgepole pine forest, slash piled and burned. 50 ft. west of timber. West Yellowstone, Montana.

Elevation: 6630 ft.

Vegetation: Same as site 13.

Description by Stermitz

0-2"	Very dark grayish-brown to black (10YR 3/2, dry; 10YR 2/1, moist) sandy loam, mixed with fine gravel; no structure; little mulch on surface; boundary clear, wavy; numerous roots.
2-8"	Grayish-brown to dark brown (10YR 5/2, dry; 10YR 4/3, moist) loamy sand; weak, subangular blocky breaking to single grain; firm in place, friable; boundary diffuse, wavy; numerous roots.
8-13"	Light grayish-brown to dark brown (10YR 6/2, dry; 10YR 4/3, moist) loamy sand; same as above except lacks firmness in place; boundary clear, wavy; few roots.
13-48"	Variegated sands and gravels of obsidian and rhyolite.

Site 16

Location: SE. 1/4 Sec. 32, T13S, R5E. Clear cut area in lodgepole pine forest, north slope; brush piled and burned. West Yellowstone, Montana

Elevation: 6660 ft.

Vegetation: Densely vegetated with sedge (Carex rossii), strawberry (Fragaria virginiana), low huckleberry (Vaccinium scoparium), glacier lily (Erythronium grandiflorum), and kinnikinnick (Aretostaphylos ura-rusi).

Description by Southard and Stermitz

0-4" Gray (10YR 5/1) with dark yellowish-brown (10YR 4/4) mottles; very fine sandy loam; moderate-medium plates; firm, friable; nonsticky, nonplastic; gradual boundary; abundant roots.

4-14" Grayish-brown (10YR 5/2) loam; weak fine platy; slightly firm, friable; nonsticky, nonplastic; boundary clear, wavy; few roots.

14-29" Dark gray (10YR 4/1) with dark grayish-brown (10YR 4/2) mottles; very fine sandy loam; coarse prisms; firm in place, also firm out of place; nonsticky, nonplastic; boundary abrupt; few roots.

Site 16 (Cont'd)

29-40" Dark brown (10YR 4/3) silt loam; weak thick platy; firm; sticky, plastic; some fine gravels, stones; few roots.

Site 17

Location: SW. 1/4 Sec. 3, T14S, R5E. Large clear cut area in lodgepole pine forest, south slope, brush piled and burned. West Yellowstone, Montana.

Elevation: 6660 ft.

Vegetation: Same as site 16.

Description by Southard and Klages

0-6" A_1 Very dark grayish-brown (10YR 3/2) silt loam; moderate-medium granular; friable; many medium and fine roots; clear, wavy boundary.

6-14" B_{21} Dark grayish-brown (10YR 4/2) silt loam; moderate-medium platy; friable; few roots; abrupt boundary.

14-19" B_{22} Grayish-brown (10YR 5/2) with yellowish-brown (10YR 5/4) common distinct mottles; silt loam; firm; coarse prisms breaking to moderate to medium blocky; abrupt smooth boundary.

19-26" IIC_1 Dark grayish-brown and grayish-brown (10YR 4/2 and 10YR 5/2) clay loam; weak fine blocky; firm; sticky and plastic; abrupt boundary.

26-39" IIC_2 Yellowish-brown (10YR 5/4) sticky clay - auger sample.

Site 17 (Cont'd)

39"+ $IIIC_3$ Dark brown (7.5 YR 4/4) clay.

Site 18

Location: NE. 1/4 Sec. 32, T13S, R5E. Clear cut area in lodgepole pine forest, 200 ft. east of timber, West Yellowstone, Montana.

Elevation: 6640 ft.

Vegetation: Some natural regeneration of lodgepole pine (slow growth), sedge (Carex rossii), yarrow (Achillea lanulosa) green needlegrass (Stipa viridula).

Description by Southard and Klages

0-2" A_1 Very dark grayish-brown (10YR 3/2) gravelly sandy loam; weak fine granular; friable; many medium and fine roots; porous; loam material coating the sand and gravel; clear wavy boundary.

2-5" B_{21} Dark brown (10YR 3/3) sandy loam; weak fine granular; friable; many medium and fine roots; porous, clear boundary.

5-10" B_{22} Dark brown (10YR 4/3) gravelly sandy loam; single grain; loam material coating sand and gravels; abundant obsidian; clear boundary.

10-14" C_1 Variegated gravel and sand (obsidian and rhyolite); few roots; increase in obsidian gravels.

14-22" C_2 Same as above except increase in obsidian gravels.

Site 18 (Cont'd)

22-32" C_3 Gravels are larger than in above horizons.

Site 19

Location: SW. 1/4 Sec. 21, T12S, R5E. Clear cut area in lodgepole pine forest, slash not piled or burned. West Yellowstone, Montana.

Elevation: 6560 ft.

Vegetation: Good natural regeneration of lodgepole pine in area. Sparse vegetation of sandburg bluegrass (Poa secunda), yellow Eriogonum (Eriogonum flavum), foxtail (Hordeum jubatum) and bitterbrush (Pursha tridentata).

Description by Stermitz

0-3"	Very dark grayish-brown (10YR 3/2) loose loamy sand; no structure; gravel and mulch on surface; boundary clear, wavy; abundant roots.
3-11"	Brown (10YR 5/3, dry; 10YR 4/3, moist) loamy sand; very weak subangular blocky; firm, friable; boundary diffuse, wavy; abundant roots.
11-20"	Brown (10YR 5/3, dry; 10YR 4/3, moist) loamy sand; same as above except lacks firmness in place; few roots.
20-45"	Loamy sand; single grain structure; increasing amounts of obsidian gravels.

Site 20

Location: SE. 1/4 Sec. 21, T12S, R5E. Clear cut in lodgepole pine forest, slash not piled or burned. West Yellowstone, Montana. Immediate area of plots appears to be a small lake bottom. Partially inundated until August.

Elevation: 6560 ft.

Vegetation: Good natural regeneration of lodgepole pine in area. Vegetation of sedges, rushes and ticklegrass (Agrostis scabra).

Description by Stermitz

0-3"	Light brownish-gray (10YR 6/2) sandy loam; loose, no mulch on surface; some fine gravels; boundary clear, numerous roots.
3-9"	Light gray (10YR 7/2) with dark grayish-brown (10YR 4/2) common, distinct mottles; fine sandy loam; coarse prisms breaking to moderate to medium blocky; firm in place, firm out of place; nonsticky, nonplastic; has appearance of pan; clear, wavy boundary; few roots.
9-24"	Variegated sands and gravels; saturated with water.

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