PRESCRIBED BURNING AND PHYSICAL REMOVAL OF FOREST FLOOR MATERIAL:

EFFECT ON FROST HEAVING OF SOUTHWESTERN PONDEROSA PINE SEEDLINGS[1]

Sally M. Haase[2]

ABSTRACT: Frost heaving is a major cause of mortality in naturally and artificially regenerated ponderosa pine on basaltic soils in the Southwest. The effect of prescribed burning and mechanical removal of forest floor material on seedling size, soil nutrients, and subsequent susceptibility to frost heaving was observed in this study. A lower percentage of seedlings frost heaved on the burned treatment (3 percent) compared to scraped treatment (6 percent). The average seedling size that frost heaved was about the same for both treatments. Seedlings that survived the first winter were larger on the burned treatment. This is most likely related to the increased available nitrogen found in the soil after burning. Seedling total nitrogen concentration (percent) was about the same for both treatments. Results indicate that prescribed burning and seedling size may influence resistance to frost heaving.
KEYWORDS: prescribed burning; ponderosa pine; regeneration

INTRODUCTION

The two primary soil types in the Southwestern United States have different requirements for restocking ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), and each has different success rates. The success of restocking is generally higher on sedimentary than basaltic soils, because initial seedling growth is greater, making seedlings less prone to frost heaving (Heidmann et al. 1977). Natural seedlings, however, have been found thriving on burned-over basaltic soils (Sackett 1983), when seedling establishment after other methods of site preparation have failed. The reasons for these differences are speculative.

Observations on prescribed burn areas indicate a relationship between seedling size and frost-heaving susceptibility (Sackett 1983), and between the number of seeds germinating and seedbed characteristics (Harrington and Kelsey 1979). The return of the nonvolatile nutrients to the soil from the burning may be the major contributor to better seedling establishment on burned areas. Burned sites under

---

[1]A paper presented at the 11th Conference on Fire and Forest Meteorology, April 16-19, 1991, at Missoula, MT.

[2]Sally M. Haase, USDA Forest Service, Pacific Southwest Research Station, Forest Fire Laboratory, 4955 Canyon Crest Drive, Riverside, CA 92507.

mature trees had significantly higher concentrations of ammonium (Harrington and Kelsey 1979, Covington and Sackett 1990, 1991), and a larger coniferous seedling has a survival advantage under frost-heaving conditions (Schramm 1958). Nutrient stimulus may produce larger seedlings that could better resist frost heaving.

After consuming forest floor material, fire leaves a seedbed of exposed mineral soil in some places and surface-charred residual duff of varying depths in others (Haase 1986). The charred material acts as a mulch, can maintain higher overall soil moisture, protect seeds from rodents, and produce an even distribution of soil temperatures. Somewhat higher soil moisture was observed on burned compared with unburned areas on basaltic soils in the Southwest (Ryan 1978, Ryan and Covington 1986, Haase 1981). The exact amount of moisture available to seedlings is not known for basaltic soils. But, in an environment where moisture is a major limiting factor in seed germination and seedling establishment, any increase in soil moisture may be significant. Soil temperatures on blackened surfaces resulting from a fire have been found to be higher than soil temperatures on unburned areas (Ahlgren and Ahlgren 1960, Isaac 1930). This temperature difference, in combination with sufficient moisture, could result in earlier seed germination and thus a longer first growing season and larger seedlings.

This paper reports a study of site preparation and frost heaving of ponderosa pine seedlings on the two primary soil types in the Southwest. Objectives of the study were to determine the relative sizes of pine seedlings on both scraped and fire-produced seedbeds, and to determine which pine seedlings on which seedbeds are most resistant to frost heaving.

METHODS

Plot Layout and Assignment of Treatments

The study area was located on the Rocky Mountain Forest and Range Experiment Station's Fort Valley Experimental Forest, northwest of Flagstaff, Arizona. Elevation is approximately 7200 feet. Sites selected had forest floor conditions that are common in a stand of mature ponderosa pine. The canopy was removed with minimal disturbance to the forest floor. Trees were felled and removed so that at least half of the area under each tree was not altered.

Each plot consisted of four 1 by 1-m subplots that were located and marked after the overstory was removed. Each of the four subplots were placed so that the forest floor accumulation depth gradient was adequately sampled. The first 1 m^2 subplot was placed near the base of the tree to sample maximum litter accumulation, while the next two were placed at the middle and minimum litter accumulation under the canopy. The fourth subplot was placed outside the dripline. All four were on a single radius from the tree.

Once the 10 plots and 40 subplots were located and marked, 5 plots were randomly selected for burning, and the remaining 5 plots were designated for scraping.

Treatment Application

The five chosen plots were burned November 11, 1984. Daytime temperatures were in the high 50's (^oF), with a maximum temperature of 61 ^oF. Relative humidity ranged from 16 to 21 percent, and winds were 2 to 8 mi/h from the south, southwest. The last precipitation on the study area was 0.27 inch of rain on October 17, and 0.16 inch on October 21. Forest floor moisture content ranged from 4.8 to 5.7

percent (L layer), 4.3 to 36.6 percent (F layer), and 24.6 to 46.8 percent (H layer).

Forest floor fuel loadings were estimated by using nine duff pins in a 3 by 3 grid pattern in each subplot before burning. Each duff pin was inserted so that the top was level with the top of the L layer. After the burn, the exposed portion and the total length above mineral soil were measured. These depths were used in the prediction equation that was determined for this particular site to estimate the total forest floor loadings and consumption.

$$\text{Tons/acre} = 16.825 * \text{depth (inches)} - 11.645 \quad (R^2 = 0.90)$$

Forest floor material on the remaining five plots was removed with pitchforks and rakes, down to mineral soil, with minimum disturbance to the soil surface.

Seeding

Fresh ponderosa pine seed, collected in the study area, was found to be 99 percent viable. Forty-nine seeds were placed on each subplot in a 7 by 7 grid with a 12.5 cm spacing in May 1985. On scraped plots, each seed was pushed into the soil so that the top of the seed was level with the soil surface. On burned plots, seeds were pushed into the seedbed until they came into contact with mineral soil. All plots had to be reseeded because birds removed an unknown number of seeds. Immediately after reseeding, the subplots were protected with chicken wire.

Seedling Measurements

Seed germination was followed with weekly observations starting mid-July 1985. Each germinate was mapped to follow its survival. In April 1986, after the snow had melted, seedling survival was checked weekly on each plot.

Seedling characteristics (crown length, stem length, and stem diameter) were measured in April 1986. Crown length was measured from the base of the cotyledon whirl to the end of the cotyledons. Diameter was measured at the root collar. Stem length was the distance between the root collar and the base of the cotyledon whirl. We were careful not to disturb the soil around the base of each seedling before the seedlings were exposed to frost heaving conditions.

Frost-heaved seedlings were easily identified laying on the surface or pushed up out of the ground, exposing the root system. Seedling characteristics were measured the same way as for the not-heaved seedling.

In August 1986, 22 of the largest seedlings from each treatment were washed out of the ground. Total nitrogen was determined on the root, stem, and top portion of each. Some stems had to be combined to have a sample large enough to analyze. Only those from the same subplot were combined. One seedling from the burn treatment was analyzed combining all three parts.

Seedling tissue samples of about 200 milligrams were ovendried for 12 hours at 65 $^{\circ}$C. These samples were digested, using the methods outlined in Parkinson and Allen (1975). Samples were then prepared for colorimetric analysis with a Technicon AutoAnalyzer II following methods reported in Schuman et al. (1973). (Mention of trade names or products is for information only and does not imply endorsement by the U.S. Department of Agriculture.)

Soil Nitrogen Measurements

Soil ammonium-N and nitrate-N were measured before and after the burn in November 1984 and then again in June and August 1985. A composite sample of seven cores from each subplot was divided into two samples from 0-5 cm depth and 5-15 cm depth.

Chemical analysis procedures used by Covington and Sackett (1986) were used to determine the mineral N content of the soil on both treatments.

RESULTS

Seedling Survival and Characteristics

The original germination counts were 671 seedlings on the burned plots and 1,071 seedlings on the scraped plots. Survival counts by season and status of seedlings after snow melted in 1986 are shown in Table 1.

Table 1. Status of seedlings found after snow melted in April 1986 and at the end of the study, by treatment.

	Number of Seedlings, April 1986			Survival Totals		
Treatment	Heaved	Living/not-heaved	Dead/not-heaved	November 1985	April 1986	August 1986
Burned	8 (3%)	164 (54%)	130 (43%)	302	164	58
Scraped	42 (6%)	306 (45%)	340 (49%)	688	306	124

The average size of frost-heaved seedlings were almost the same for both treatments. Mean size of seedlings heaved and not-heaved are shown in Table 2.

Ovendry weights of the washed-out seedlings showed a large difference between treatments. Table 3 shows weight and percent nitrogen concentration of the washed-out seedlings. The percent nitrogen concentrations of seedling parts, except for the root section, were almost identical between treatments.

Soil Nitrogen

Seasonal increases are shown in both ammonium-N and nitrate-N levels on both treatments (Table 4). Changes are most pronounced on the burned sites.

Table 4. Mean soil ammonium-N and nitrate-N concentration (± SD) by treatment and sample period.

Depth (cm)	Treatment	Sample Period: November 1984 Before burn	November 1984 After burn	June 1985	August 1985
		ug/g ± SD			
Ammonium-N					
0-5	Burned	2.27 ± .86	29.21 ± 31.17	40.12 ± 43.15	57.29 ± 76.21
	Scraped	N/A	1.43 ± .45	3.09 ± 1.39	8.98 ± 7.12
5-15	Burned	1.83 ± .68	11.15 ± 13.16	10.69 ± 13.87	6.98 ± 8.50
	Scraped	N/A	1.08 ± .37	1.64 ± .44	2.57 ± 1.16
Nitrate-N					
0-5	Burned	.026 ± .040	.050 ± .042	3.915 ± 5.055	16.535 ± 17.322
	Scraped	N/A	.037 ± .031	.685 ± 1.055	14.049 ± 15.850
5-15	Burned	.035 ± .048	.061 ± .075	1.794 ± 2.972	3.701 ± 4.542
	Scraped	N/A	.022 ± .019	.256 ± 0.354	2.586 ± 4.186

DISCUSSION

No separate control was included in this study, because an earlier long-term study has documented that if forest floor material is not removed, there will be no regeneration under mature ponderosa pines (Sackett 1983, Haase 1986). Therefore, the scraped treatment was considered a control in the original design of this study.

The number of established seedlings monitored on the scraped site was higher than on the burned sites. One would expect this difference, since every seed was in contact with mineral soil, and moisture was uniform over the entire subplot. On the burned treatment plots, the surface area with unconsumed forest floor material was variable, and the depth of this material ranged from 1 to 3 cm. The subplots on which the forest floor had been completely consumed by burning had the lowest number of seedlings. This suggests that small amounts of charred or partially consumed forest floor material may be beneficial to natural regeneration. This is corroborated by an earlier study (Haase 1986).

The percentages of frost-heaved seedlings on both treatments were relatively low, and sizes of heaved seedlings were almost identical between treatments. Seedlings killed by frost heaving had smaller crowns and diameters than the average

Table 2. Mean stem length, crown length, and diameter of heaved and not-heaved seedlings in April 1986.

Seedling characteristic	Burned	Scraped
	mm ± SD	
Heaved		
Stem length	22.63 ± 5.3	22.98 ± 4.9
Crown length	19.87 ± 5.0	21.45 ± 3.9
Diameter	1.00 ± .24	1.05 ± .22
Not-heaved		
Stem length	23.17 ± 5.7	21.25 ± 5.9
Crown length	26.94 ± 7.1	26.43 ± 5.8
Diameter	1.37 ± .29	1.32 ± .27

Table 3. Mean seedling weight and nitrogen concentration (%) of seedlings (± SD) in August 1986.

	Burned Treatment		Scraped Treatment	
Seedling part	Nitrogen concentration (percent ± SD) n = 21[1]	Ovendry weight (grams ± SD) n = 22	Nitrogen concentration (percent ± SD) n = 22	Ovendry weight (grams ± SD) n = 22
Foliage	2.04 ± .35	.50 ± .42	2.03 ± .30	.23 ± .09
Stem	1.36	.07 ± .05	1.36	.04 ± .01
Root	1.60 ± .49	.31 ± .21	1.46 ± .25	.18 ± .07
Total		.88		.45

[1]One seedling was analyzed as a whole seedling instead of by portions to have a sample large enough to analyze.

seedling that did not heave on both treatments. This suggests that resistance to frost heaving may be related to seedling size. The proportion of heaved seedlings in each treatment differed significantly when evaluated using a normal approximation to the binomial distribution when compared with the number of living seedlings ($p = .0035$) and with the total number of seedlings (November 1985, $p = 0.014$).

Seedling sizes on the burned plots were generally larger than those on the scraped plots. Soil ammonium-N and nitrate-N levels were also higher on the burned plots. But this increase in soil nitrogen is not reflected in the percent nitrogen concentration in seedlings when sampled. The increase in soil nitrogen on the scraped treatment was unexpected and could have been explained more accurately if a totally undisturbed site (no removal of forest floor material) had been sampled simultaneously. Soil nitrogen should also have been measured in 1986 when seedling tissue was analyzed for nitrogen.

CONCLUSION

The effect of prescribed burning and the increase in soil nitrogen on seedling resistance to frost heaving during that initial growing season is still speculative. Seedlings growing on the burned treatment apparently were healthier. The root systems were more developed with extensive secondary and tertiary roots. Mycorrhizae were present also on some of the burned treatment root systems. These differences were more evident after the second growing season. The effect of better soil moisture and temperature should be greater also during the second year. From the perspective of the manager, it may be more significant to evaluate the effect of these two site preparation methods on subsequent survival rates rather than on the first year survival.

Literature Cited

Ahlgren, I.F., and C.E. Ahlgren. 1960. Ecological effects of forest fires. Bot. Rev. 26:483-533.

Covington, W.W., and S.S. Sackett. 1986. Effect of periodic burning on soil nitrogen concentrations in ponderosa pine. Soil Sci. Soc. America 50:452-457.

Covington, W.W., and S.S. Sackett. 1990. Fire effects on ponderosa pine soils and their management implications. P. 105-111 in Proc. Symposium on Effects of fire management of southwestern natural resources. USDA For. Serv. Gen. Tech. Rep. RM-191. p. 105-111.

Covington, W.W., and S.S. Sackett. 1991. Patterns of soluble mineral soil nitrogen following prescribed burning in ponderosa pine. For. Ecol. Mgmt. In press.

Haase, S.M. 1981. Effects of prescribed burning on ponderosa pine seed germination in the Southwest. M.S. Thesis, Northern Arizona University, Flagstaff; 67 p.

Haase, S.M. 1986. Effect of prescribed burning on soil moisture and germination of southwestern ponderosa pine seed on basaltic soils. USDA For. Serv. Res. Note RM-462. 6 p.

Harrington, M.G., and R.G. Kelsey. 1979. Influence of some environmental factors on initial establishment and growth of ponderosa pine seedlings. USDA For. Serv. Res. Pap. INT-230. 26 p.

Heidmann, L.J., F.R. Larson, and W.J. Reitveld. 1977. Evaluation of ponderosa pine reforestation in central Arizona. USDA Forest Serv. Res. Pap. RM-190. 10 p.

Isaac, L.A. 1930. Seedling survival on burned and unburned surfaces. J. For. 28:569-571.

Parkinson, J.A., and S.E. Allen. 1975. A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological material. Commun. Soil Sci. Plant Analy. 6(1):1-11.

Ryan, M.G. 1978. The effect of prescribed burning in ponderosa pine on the inorganic nitrogen content of the soil. M.S. Thesis, Northern Arizona University, Flagstaff; 64 p.

Ryan, M.G., and W.W. Covington. 1986. The effect of a prescribed burn in ponderosa pine on inorganic nitrogen concentrations of mineral soil. USDA For. Serv. Res. Note RM-464. 5 p.

Sackett, S.S. 1983. Observations on natural regeneration in ponderosa pine following a prescribed fire in Arizona. USDA For. Serv. Res. Note RM-435. 8 p.

Schramm, J.R. 1958. The mechanism of frost heaving of tree seedlings. American Philo. Soc. 102(4):333-350.

Schuman, G.E., M.A. Stanley, and D. Knudsen. 1973. Automated total nitrogen analysis of soil and plant samples. Soil Sci. Soc. Amer. J. 37(3):480-481.