Seedbed Characteristics In Western Larch Forests After Prescribed Burning

Raymond C. Shearer

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INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Ogden, Utah 84401

The Northern Region and the Intermountain Forest and Range Experiment Station are jointly supporting a series of studies of prescribed fire and their applications to forest management. Groups of scientists are investigating the effects of a wide range of fire intensities on forest regeneration, watershed values, wildlife habitat, and atmospheric resources. This publication is one of a series reporting the results of these efforts.

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CONTENTS

ABSTRACT

Establishment of western larch (Larix occidentalis Nutt.) seedlings is favored by site preparation that reduces both the duff layer and the sprouting potential of competing vegetation. A cooperative study of the use of fire in silviculture in northwestern Montana provided conditions to research the effectiveness of prescribed burning of logging slash from May through October for seedbed preparation. Greatest duff reduction, nonconiferous root mortality, and soil heating occurred when water content of duff and of soil was lowest. Slash must be burned in the summer when the duff is dry to significantly reduce the organic mantle.

However, duff on north-facing slopes dries more slowly than on other aspects, and frequent summer rainfall may prevent effective preparation of seedbeds on north slopes. Burning to prepare seedbeds for establishment of regeneration can be conducted over a wider range of time on east-, south- and west-facing slopes.

INTRODUCTION

Removal of trees from western larch (*Larix occidentalis* Nutt.) forests changes the energy and moisture budgets at the ground surface (fig. 1). The volume of timber removed, the means of its removal, and the aspect of the site influence the amount of direct and indirect sunlight reaching the forest floor and thus, the amount of heating of slash, duff, and upper soil. Radiation and reflection from the slash, duff, and upper soil and convection also increase. Transpiration and interception of precipitation decrease when a timber stand is cut, particularly clearcut; so more water is temporarily available in the soil. Evaporation of soil water remains low as long as vegetation and dead organic residue protect the forest floor from direct radiation and surface wind. Because of the change in energy and water budgets, the composition of the lesser vegetation may change.

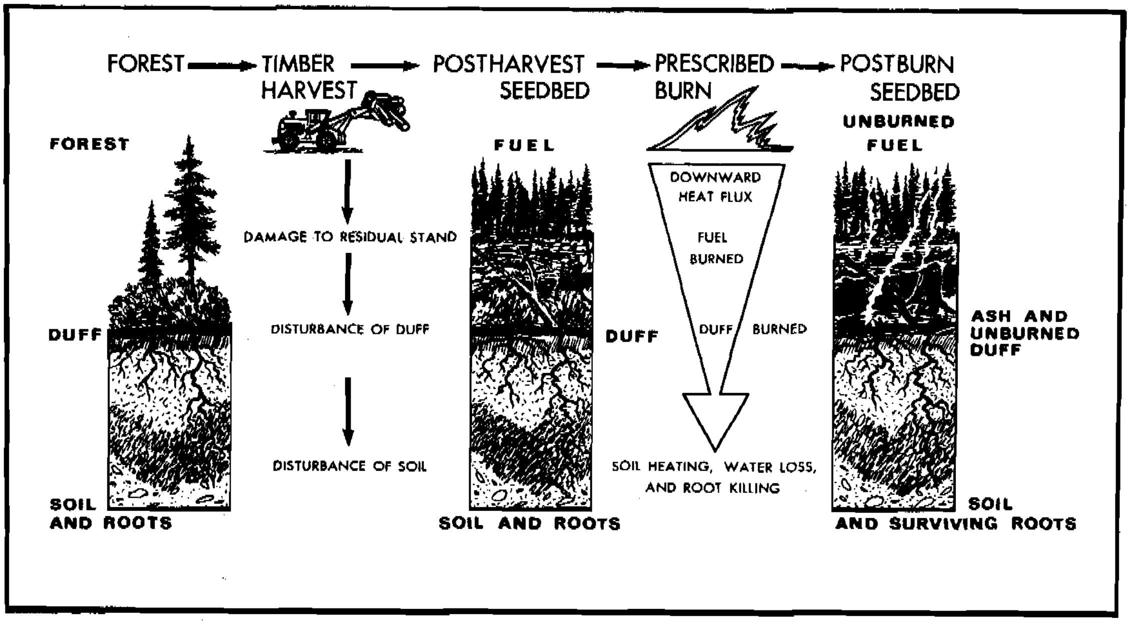

Figure 1.--Generalized sequence of changes in forest stands caused by harvest cutting and prescribed burning.

Successful establishment of western larch, a shade-intolerant tree, usually requires further alteration of the site after timber harvest through exposure of the mineral seedbed by scarification or burning and suppression of vegetative competition until seedlings attain a dominant position in the stand. Site preparation by prescribed burning should expose well-distributed patches of soil where the sprouting potential of competing vegetation is substantially reduced. If too much area is exposed, the probability of overstocking from natural regeneration increases and may require costly precommercial thinning to form a stand of desirable density at a later date.

A good initial indicator of the effectiveness of a prescribed burn to decrease competition is reduction in the number of living roots of nonconiferous species within the surface soil. The amount of root mortality is affected by several interrelated variables (fig. 1). Fire intensity is a function of the fuel load and its water content, as well as the atmospheric temperature and moisture variables at the time of burning. Downward heat flux through the duff and into the soil is dependent on the water content and the depth of duff and on the water content of the soil.

A cooperative project was begun in 1967 to study the effects of prescribed burning on (1) site preparation for conifer regeneration, (2) air and water quality, (3) erosion and runoff, (4) the nutrient status of the soil, and (5) wildlife habitat. These burn sites varied greatly by aspect, and the amount and nature (especially water content) of fuels. This variety provided a range of conditions that formed a basis for evaluating site preparation for regeneration.

This paper describes the effectiveness of several prescribed burns to reduce the amount of duff and to kill roots growing within the surface 4 inches of soil (fig. 2). In addition, soil water before and after burning and soil temperature during burning were studied to help evaluate root mortality.

Figure 2.--Portion of a 10-acre clearcut: A. The day of the prescribed burn (July 25, 1967); B. 43 days after burn (September 6, 1967); C. 14 months after burn (September 26, 1968); and D. 4 years after burn (June 7, 1971).

B

C

D

LITERATURE

Plant tissue is damaged or killed when exposed for several minutes to temperatures ranging from about 125° to 130°F (Hare 1961). Although aerial portions of plants usually are burned by fire, the roots generally are well protected from the killing effects of heat by the soil (Beadle 1940). Even dry soil has low thermal conductivity, and additional soil water further increases the energy required to raise the temperatur of the soil (Baver 1959). Thus, a greater amount of energy is necessary to heat a soil to a lethal temperature at high soil water contents than at low soil water contents. In addition, Van Wagner (1970) found that temperature increased little in mineral soil when 0.5 inch or more of duff remained unburned after a prescribed fire. The amount of bared soil was strongly related to the weight of consumed duff and, to a lesser extent, to the water content of duff (Van Wagner 1972). He also attributed nonuniformity in depth and water content of the duff layer to the amount of bared soil.

As the surface soil temperature increases from energy released during burning, hea flows along a gradient from the surface to the cooler layers below (Baver 1959). As soil temperature increases, root tissue near the surface begins to die. The intensity of the fire, coupled with the moisture content of the soil, greatly determines the success of broadcast burn in providing a seedbed.

STUDY AREA AND TREATMENT

The study area is in the adjacent Miller Creek and Martin Creek drainages on the Flathead National Forest in northwestern Montana (lat. 48°31'N., long. 114°43'W). Sixty 10-acre units, 15 on each of the four cardinal exposures, were clearcut in 1966 and 1967. Data reported in this paper were gathered from about half of these units in 1967 and 1968. The timber stands averaged 24 M bd. ft. per acre. The overmature stan was comprised mainly of western larch, Engelmann spruce (*Picea engelmannii* Parry), and Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) in nearly equal volumes. Most of the area is classified as an *Abies lasiocarpa/Pachistima myrsinites* habitat type by Daubenmire and Daubenmire (1968). While studying Miller Creek habitat types in 1971, Robert D. Pfister, Intermountain Station, recognized two phases of this habitat type: *Menziesia* phase, primarily on steep north slopes, to *Xerophyllum* phase, primarily on south-facing slopes, but also on steep west-facing slopes. (See table 1 for habitat type and burn date for each unit.)

Topography is moderately steep, with slopes ranging from 10 to 50 percent (20 percent average). Elevations range from 4,200 to 5,000 feet. The soil, derived from glacial till (10 to 25 feet in thickness) of argillite and quartzite, is gravelly loam from the Wallace (Belt) formation (R. C. McConnell unpublished data).

Table 1.--*Habitat type, date burned, and average water loss from can analogs for each unit of the Miller Creek study, Flathead National Forest.*

Unit	Habitat type[1]	Date burned	Can water loss	Unit	Habitat type[1]	Date burned	Can water loss
NORTH				SOUTH			
1	AP	Control[2]	--	1	X	5/18/68	
2	AP	Control	--	2	X	5/18/68	
3	AP	Control	--	3	X	5/18/68	
4	M	8/31/68	497	4	X	7/3/68	407
5	M	10/9/67	495	5	X	9/30/68	135
6	M	9/10/68	303	6	X	8/23/67	
7	M	6/18/68	241	7	X	8/23/67	1,382
8	M	9/10/68	266	8	X	8/8/67	784
9	M	7/26/68	688	9	X	10/5/67	455
10	M	Control	--	10	X	7/3/68	615
11	M	8/3/67	1,119	11	X	Control	
12	M	8/3/67	1,062	12	X	8/23/67	
13	M	7/8/68	609	13	X	8/23/67	
14	M	10/3/68	126	14	X	8/23/67	
15	M	10/3/68	137	15	X	8/23/67	
EAST				WEST			
1	AP	10/10/67	827	1	AP	7/25/67	799
2	M	Control	--	2	X	8/23/67	1,473
3	M	8/7/68	940	3	X	9/30/68	423
4	M	7/18/68	480	4	X	9/5/68	53
5	M	7/5/68	525	5	X	8/23/67	1,610
6	AP	10/2/67	243	6	X	8/23/67	
7	AP	7/18/67	728	7	X	8/23/67	1,926
8	AP	10/1/70	--	8	X	7/24/68	513
9	AP	10/1/70	--	9	AP	10/7/67	737
10	AP	9/9/68	415	10	X	7/16/68	519
11	AP	8/23/67		11	AP	6/6/68	47
12	AP	8/23/67		12	AP	8/30/68	556
13	AP	8/23/67	1,251	13	AP	8/30/68	266
14	AP	9/9/68	379	14	AP	10/2/68	264
15	AP	7/18/67	286	15	AP	10/2/68	228

[1] Classified by Robert D. Pfister: AP = *Abies lasiocarpa/Pachistima myrsinites*; M = AP, *Menziesia* phase; X = AP, *Xerophyllum* phase.

[2] Control = unit not burned.

METHODS

Root Mortality

ty of nonconiferous vegetation was measured at six points within the s of each unit. At each sample point, a vertical face about 10 inches inches in depth was exposed. Then, excess soil around the roots was away; so roots were fully visible. If the roots had not been cut, they sectioned.

by 4-inch grid was pressed against this face and nonconiferous roots either as living or dead by means of a chemical test similar to that e (1965) and Steel and Henderson (1967). A solution of 1 percent (by idine $[(-C_6H_3-4NH_2-3-CH_3)_2]$ in 95 percent methanol was mixed and stored y bottle. A second spray bottle contained a solution of USP 3 percent e (H_2O_2). These solutions react with the enzyme peroxidase in living form a dark-blue product. Because peroxidase denatures when the cell hange occurs when these chemicals are sprayed on dead cells.

lidine and hydrogen peroxide solutions were sprayed on the surface grid. Immediately, living roots turned blue. Those that exhibited no e classified as "dead." From 10 to 30 seconds were allowed for the the alcoholic orthotolidine to disperse before the roots were counted. roots over 1 mm in size were counted at six levels.

l intent of the study was to compare the number of living roots on getation before and after burning on the blocks. Preburn samples on ocks showed that over 99 percent of these roots were alive. Subse- stburn root sampling was done, and all roots were considered to be alive Although some natural root mortality probably occurred through the hought to be minimal because soil moisture was not a limiting factor on eas before burning. Separate identification of nonconiferous plant roots was not attempted.

Soil Water

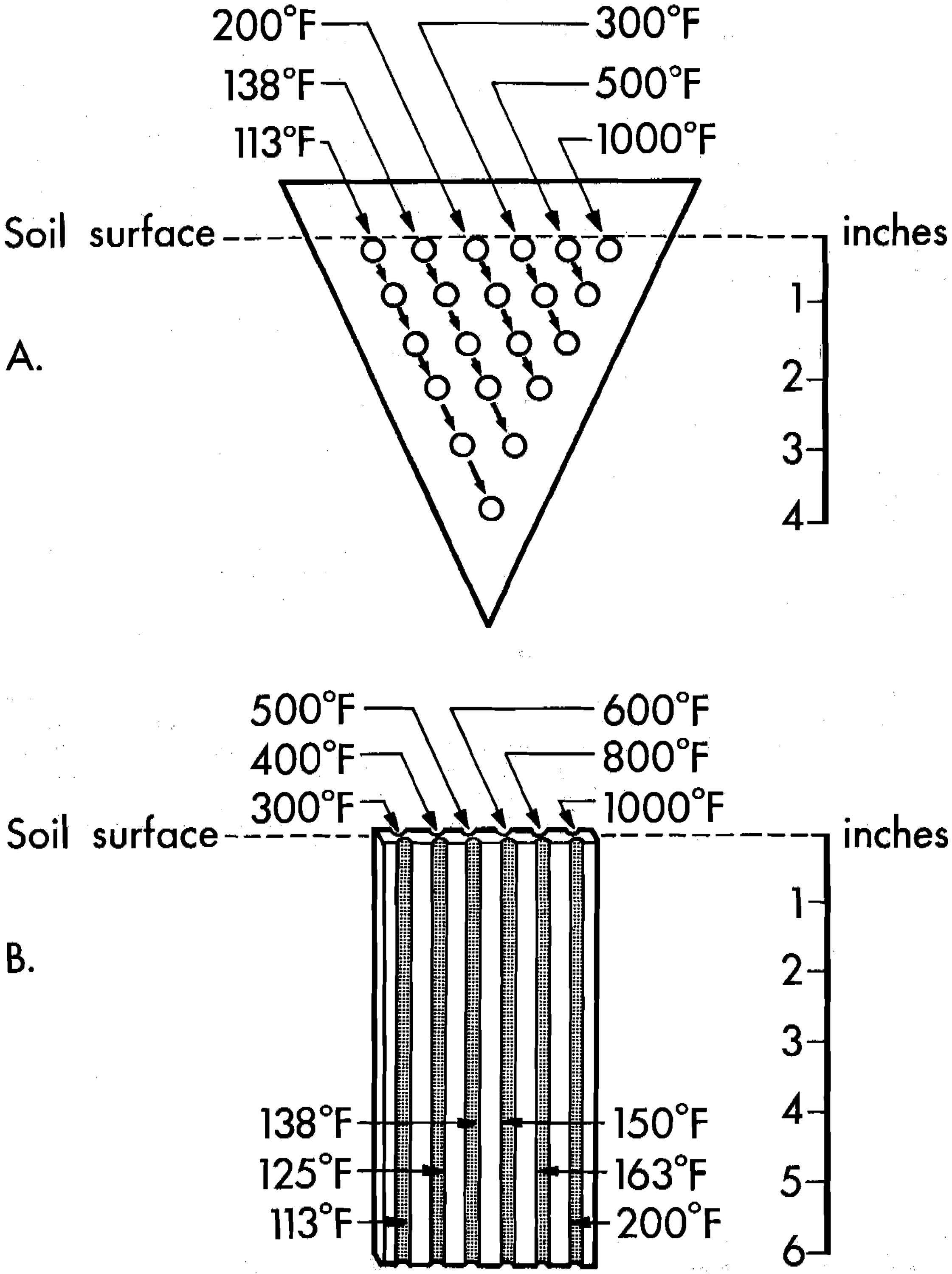

Figure 3.--Schematic showing depth of insertion of asbestos wedges and strips used to indicate the temperature gradient within the soil during prescribed burning. (A) Triangular wedge used in 1967 showing placement and melting points of Tempils. (B) Rectangular strip used in 1968 showing spacing of depressions and melting points of Tempilaq.

Soil Temperature

The maximum temperature within the upper 4 to 6 inches of soil was estimated by using Tempil Pellets or Tempilaq (Tempil Division, Big Three Industries, Inc., South Plainfield, N. J.) with melting points ranging from 113° to 1000°F. Tempil Pellets are temperature-sensitive tablets (7/16-inch diameter and 1/8-inch high) and Tempilaq is a temperature-sensitive material suspended in an inert, volatile, nonflammable vehicle. In 1967, triangular asbestos wedges were used to hold Tempil Pellets of six melting points (fig. 3a). From 25 to 36 wedges were placed within a central 2.5-acre study plot on each unit prior to burning so that the upper edges of the top row of Tempil Pellets were at the mineral soil-duff interface. Tempil Pellets indicated the approximate maximum temperature at various levels within the soil. Rectangular asbestos strips were used in 1968 that had six full-length depressions scored on both sides. Each depression was filled with a Tempilaq of a different melting point that dried in about 1 minute (fig. 3b). The strips were evenly spaced at 36 points within the central 2.5-acre study plot on each burn in 1968 and the upper edge of the asbestos was positioned along the soil-duff surface. These strips gave a better indication of the temperature gradient within the soil during burning than the wedges used in 1967 and were easier to insert in the soil and to maintain.

Tempils and Tempilaq indicate instantaneous maximum temperature, but give no information on the duration of that temperature. Temperature duration was estimated on a few burns by using battery-operated recorders connected to thermocouples installed at two locations at 0.2, 0.4, 0.8, and 1.6 inches in the soil. At the 0.2-inch depth, chromal/alumel thermocouple probes were used and at all other depths, iron/constantan thermocouple probes were used.

Analysis

The relations of soil temperature, soil water loss, and nonconiferous root mortality to preburn soil water content and water loss from water can analogs were all explored and expressed mathematically (appendix) by using techniques specified by Jensen and Homeyer (1970, 1971) and Jensen (1973). The same techniques were used to develop the relation between duff reduction and duff moisture content. It is anticipated that some or all of these mathematical models will be pertinent input to larger information systems currently being assembled for the use of land managers.

RESULTS

Root Mortality

Reduction of roots of competing nonconiferous species by heat from prescribed fires was generally low at depths greater than 2 inches (table 2) except in dry soil.

Time of Burning

Root mortality caused by soil heating during burning increased within the surface 4 inches of soil as the hot, dry summer of 1967 progressed; mortality decreased rapidly after rainfall started in October (fig. 4). In contrast, root mortality was lower throughout the cool, wet summer of 1968 than at any time in 1967.

Table 2.--*Root mortality by depth for units where data was taken, Miller Creek Study, Flathead National Forest.*

	Root mortality by depth (inches)					
Unit	0-1/2	1/2-1-1/4	1-1/4-1-3/4	1-3/4-2-1/4	2-1/4-3	3-4
	Percent					
NORTH						
5	55	24	15	13	16	15
7	54	56	38	21	6	0
8	0	0	0	0	0	0
9	13	22	11	14	0	0
11	100	86	63	20	5	4
13	12	0	0	0	0	0
EAST						
3	40	19	0	0	0	0
5	7	12	0	0	0	0
6	86	85	69	30	0	0
7	36	22	6	12	4	0
10	36	0	25	0	0	0
13	100	83	88	78	89	50
SOUTH						
4	20	23	12	0	0	0
8	100	67	46	18	6	4
10	11	30	6	6	9	0
WEST						
1	68	30	15	6	0	0
4	7	0	0	0	0	0
8	27	17	0	0	0	0
9	86	74	42	15	19	5
10	36	17	0	0	0	0
12	14	12	0	14	0	0

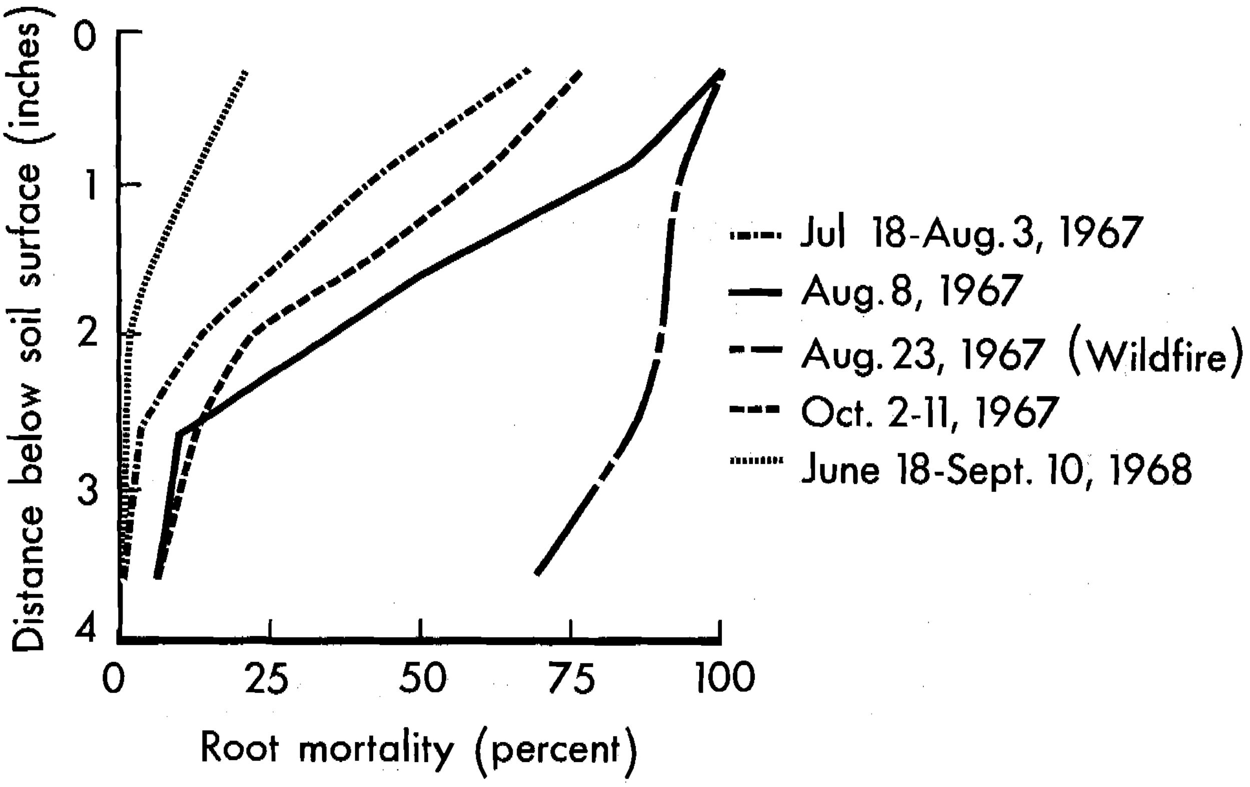

Figure 4.--Root mortality within the surface 4 inches of soil by date of burn following burning of slash on cutover blocks.

Except for areas burned by the wildfire on August 23, most root mortality in 1967 was confined to the surface 2 inches of soil and to the surface 1 inch in 1968 (fig. 4). Heat from the August 23 wildfire, which burned when soil conditions were extremely hot and dry, caused the only significant reduction of roots as deep as 4 inches below the soil surface. Over 90 percent of the roots died within the upper 2.4 inches and 70 percent of the roots died within the 3.3- to 4.0-inch layer (fig. 4). In addition, the wildfire reburned a unit initially burned 1 month earlier and consumed nearly all remaining duff and some partially burned fuels. Root survival dropped from 80 to 11 percent within the surface 2.5 inches and from 98 to 38 percent within the 2.5- to 4-inch level.

After rainfall began in October 1967, root losses decreased on each successively burned unit. Root mortality was much more variable in the fall than in July and early August. Samples taken from points that burned to the soil surface generally showed high root mortality; soil water greatly influenced the depth of root kill.

Considerable sprouting began immediately after burning in June, July, and August when root kill was generally low (fig. 5). Alder (*Alnus sinuata* (Regel) Rydb.) frequently sprouted vigorously (fig. 5a), as did mountain maple (*Acer glabrum* Torr.) and Scouler willow (*Salix scouleriana* Barratt). Beargrass (*Xerophyllum tenax* (Pursh) Nutt.) leaves continued to elongate without any apparent interruption despite the fire (fig. 5b).

*Figure 5.--A. Sprouting of alder (*Alnus sinuata *(Regel) Rydb.) about 1 month after the prescribed fire that burned the old crown. B. Leaf elongation of beargrass (*Xerophyllum tenax *(Pursh) Nutt.) after a prescribed fire.*

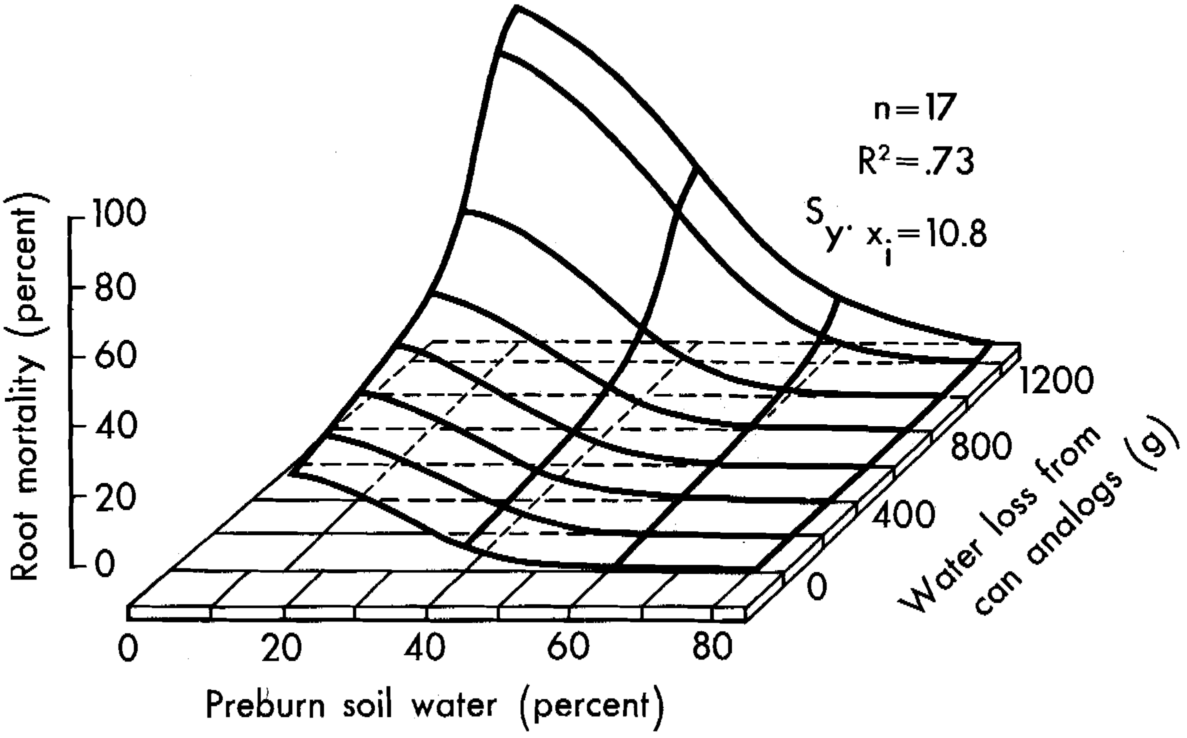

Figure 6.--Average root mortality within the upper 4 inches of soil during prescribed burning as related to the preburn soil water within the surface inch and average water loss from can analogs (a measure of fire intensity).

Influence of Fire Intensity and Soil Water

Root mortality varied from 0 to 100 percent (fig. 6) according to the interaction of the amount of water in the soil and the energy released from prescribed fires (represented by water loss from cans placed in direct contact with the surface of the soil (Beaufait 1966)). In the spring or sometimes late fall, when soil water was near or at field capacity (about 50 percent on the more sheltered sites), root mortality ranged from 0 to 30 percent, regardless of fire intensity. From midsummer to late summer of drier years when soil water declined to about 15 percent on the more exposed sites, root mortality ranged from 30 to nearly 100 percent.

Mortality varies greatly according to the depth at which roots grow in the soil. When soil water is high, most root mortality occurs within the surface half inch, regardless of fire intensity. However, when soil water is low, high-intensity burns kill most roots within the surface 4 inches of soil. Burns of lower intensity on dry soils cause high root mortality in the surface 1 or 2 inches, but have little effect on roots at lower depths.

Soil Water

Within the surface 4 inches of soil, water varied (table 3) with the amount and pattern of summer precipitation, with soil texture, and with such management practices as harvest cutting and seedbed preparation.

Table 3.--*Soil water before (B), and after (A), burning by depth for units where data were taken, Miller Creek Study, Flathead National Forest*

	Soil water by depth (inches)							
	0 to 1/2		1/2 to 1		1 to 2-1/4		2-1/4 to 4	
Unit	B	A	B	A	B	A	B	A
	Percent							
NORTH								
7	45	50	47	39	44	38	47	40
8	49	49	41	44	41	46	40	47
9	40	37	37	32	36	34	33	38
11	41	31	40	34	43	36	36	38
13	43	42	42	36	39	38	39	37
EAST								
3	33	32	32	32	31	32	31	31
5	48	45	52	42	49	41	52	42
6	22	12	17	17	18	17	18	17
7	32	25	28	25	28	26	30	27
10	44	39	38	35	40	38	38	41
13	25	11	29	21	28	25	27	26
SOUTH								
7	--	2	--	5	--	8	--	10
8	11	10	13	13	12	13	12	14
9	28	19	23	19	22	20	18	20
10	43	42	47	40	44	42	44	41
WEST								
1	43	43	42	40	41	42	43	40
2	--	11	--	12	--	12	--	12
4	37	29	33	28	34	29	35	27
5	--	9	--	10	--	12	--	13
6	--	2	--	2	--	3	--	4
7	--	8	--	10	--	12	--	12
8	31	30	27	26	26	26	23	24
9	36	26	30	31	30	30	32	34
10	32	37	33	27	30	28	32	26
12	42	36	30	33	31	33	32	33
13	36	38	30	32	28	28	32	27
14	46	--	42	--	41	--	44	--

Summer Precipitation

Frequent precipitation was needed to maintain soil water during the summer months when vegetation required large amounts of water to support growth. In 1967, the water in the upper 4 inches of soil decreased rapidly in the uncut stands from June through September and in cutover, but unburned, units from late July through September. In 1968, however, soil water failed to decline as it had the previous year because of frequent rain showers. Less than half as much rain fell on the Keith Mountain study area 20 miles south of Fortine, Montana, from June through September 1967, as was recorded during the same period in 1968:

Month	*Precipitation (inches)*	
	1967	*1968*
June	3.91	3.05
July	.14	.36
August	.00	1.99
September	.30	3.74
Total	4.35	9.14

This amount was only about 30 percent of average in 1967, but nearly 160 percent of normal in 1968 (U.S. Environmental Science Services Admin. 1967, 1968).

Soils

Paul E. Packer, Intermountain Station, found that the water-holding capacity of the soils at Miller Creek varied with the proportion of soil particles greater than 2 mm in size. These soil features are also closely related to habitat type and to aspect:

Water-holding capacity (tension, cm)		*Proportion of soil particles >2 mm in size*	*Aspect*	*Habitat type*
20	*60*			
- - - - *Percent* - - - -				
48	42	28	N, E	*Abies/Pachistima (Menziesia* phase*)*
44	39	40	N, E, W	*Abies/Pachistima*
38	32	53	W, S	*Abies/Pachistima (Xerophyllum* phase*)*

In May, soon after snowmelt, when the upper 4 inches of soil was at or near saturation, soil water was greatest on units with the *Abies/Pachistima* habitat type *(Menziesia* phase) and was least on units with the *Abies/Pachistima* habitat type (*Xerophyllum* phase). Later, soil water depletion was more severe on the *Abies/Pachistima* habitat type (*Xerophyllum* phase) than on either of the other cover conditions. When fall rains began in 1967, soil water on unburned units had declined to about 15 or 20 percent on the *Abies/Pachistima* habitat type (19 percent on unit East 6). Soil water was estimated to be about 25 to 30 percent on unburned units with *Menziesia* and about 5 to 15 percent on units with *Xerophyllum.* In contrast to 1967 totals, soil water on most unburned units remained high during the wet summer of 1968.

The amount of water within the surface 4 inches of soil also varied by the topographic position of the unit on the slope. As indicated in the previous tabulation, there was an overlapping of soil characteristics by aspect. Some upper north- and east-facing sites had greater water-holding capacity and fewer coarse fragments than those lower on the same slopes, as evident by a change in habitat type. Some lower, less steep, west-facing slopes held more water than upper or steeper west aspects and showed distinct habitat type differences also.

Effect of Cutting

Depletion of water in the upper 4 inches of soil by vegetation is considerably reduced on clearcut and slashed areas when compared with adjacent uncut stands (table 4). This results because transpiration is drastically decreased when the timber and other

Table 4.--*Soil water within two undisturbed stands compared with that within the cutover and slashed unit adjacent to each, August 2, 1968*

Soil depth (inches)	Soil Water					
	Unit North 9			Unit East 3		
	Uncut	Cut	Difference	Uncut	Cut	Difference
	Percent					
0-1/2	18	40	22	23	33	10
1/2-1	18	37	19	22	32	10
1-4	18	35	17	21	31	10
Average	18	35	17	21	31	10

vegetation are removed by logging and slashing operations. In addition, evaporation from the surface does not increase greatly as long as logging slash shades the ground and physically suppresses the low vegetation. Large differences were evident in early August (table 4) but before remeasurements were made on these units later in 1968, heavy summer rainfall recharged the upper soil on both cut and uncut plots and eliminated the differences. Similar measurements were not taken in 1967, but soil water differences between cut and uncut stands probably would have shown greater divergence later in the summer.

Effect of Burning

Prescribed burning in June and July reduced soil water only slightly because all but the fine fuels were wet and the soils were near field capacity (table 3). By late July, only soils sampled on north-facing slopes (*Menziesia* phase of the *Abies/Pachistima* habitat type) remained near field capacity; those on the south-facing slopes (*Xerophyllum* phase of the *Abies/Pachistima* habitat type) were much drier. In addition to being droughtier, the soils on southerly exposures had a higher evaporation rate because of greater insolation.

The effect of topographic position was evident on units East 7 and West 1. Both support the *Abies/Pachistima* habitat type and were burned a week apart in 1967. A similar amount of energy was released during each fire. However, the effects of burning were different (table 5) because unit East 7 is on an upper, exposed, and steep, east-facing slope that has slightly coarser soil of lower water-holding capacity than unit West 1, which is on a lower, moist, and gentle west-facing slope. Snowmelt occurred about 2 weeks earlier on unit East 7 than on unit West 1. Because less water was held in the lower duff and soil of East 7, nearly 2.5 times more duff was burned (table 6) and considerably more water was removed from the surface 1 inch of soil (table 3) on unit East 7 than on unit West 1.

In 1967, the soil continued to dry through August and September. A wildfire burned unit East 13 on August 23 and the soil moisture decreased 14 and 8 percentage points within the 0 to 0.5 and 0.5 to 1-inch levels (table 3). This reduction was greater than that following any other prescribed fire measured at Miller Creek.

After the fall rains began in 1967, burning reduced soil water mainly in the upper one-half inch. At first, the rain had relatively little effect on the upper soil because it was intercepted by the fuels and then either evaporated or was absorbed by the slash and duff. These wet fuels burned poorly except where they were concentrated. As water increased within the duff and soil following additional rainfall, burning became less effective in reducing overall surface moisture.

Table 5.--*Effect of soil water on the depth of heat conduction during prescribed burns of similar intensity*[1]

Units	Water		Depth of soil heating	
	Soil (Surface inch)	Duff (Lower half inch)	138°F	200°F
	Percent by weight		*Inches*	
South 10 and North 13	44	195	0.2	0.0
North 9	38	96	.4	.0
West 9 and East 7	31	53	.8	.2
South 8	12	28	1.6+	.5

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[1] Water loss from can analogs averaged between 609 and 784 g.

Table 6.--*Maximum, minimum, and average duff depth before burning, average depth of unburned duff after burning, and average reduction for units where data were collected, Miller Creek study, Flathead National Forest*

Unit	Duff Depth				Reduction
	Before burning			After burning	
	Maximum	Minimum	Average	Average	
	Inches				*Percent*[1]
NORTH					
4	5.1	1.6	3.0	1.6	46
7	4.0	1.4	2.6	1.7	35
8	8.5	1.1	--	--	--
9	5.9	0.7	2.4	1.2	51
11	4.5	1.1	2.6	0.9	66
13	4.7	0.8	2.8	1.9	35
EAST					
3	4.9	0.6	2.7	1.0	63
5	4.5	0.8	3.1	2.1	32
6	4.1	1.4	2.4	1.0	56
7	4.8	1.0	2.7	0.6	78
10	6.7	0.1	2.7	1.6	42
13	4.1	1.9	3.2	0.0	100
SOUTH					
4	7.1	1.0	3.4	2.1	38
8	4.1	1.4	2.7	0.4	84
9	2.3	0.8	1.4	0.1	93
10	3.8	0.0	2.0	1.5	25
WEST					
1	3.0	1.6	2.3	1.5	33
4	4.1	0.2	--	--	--
8	4.4	0.0	1.8	1.1	40
9	3.7	1.7	2.2	0.3	86
10	4.7	0.4	2.6	1.4	46
12	4.3	0.2	2.5	1.5	43
13	3.9	1.0	2.7	1.8	34

---

[1] Determined from unrounded data.

In 1968, frequent rainfall occurred after August 10 and the surface 4 inches of soil was quickly recharged. Soil water was little reduced by burning (table 3) at any time in 1968.

The wildfire of August 23, 1967, burned when fuels were dry and moisture in the upper 1 inch was low. The lowest postburn soil water recorded in this study occurred on four cutover units located on west- and south-facing slopes and on one uncut unit located on a west-facing slope. The wildfire burned nearly all the duff and probably reduced soil water substantially. As shown in the following tabulation, postburn soil water in the 1- to 4-inch level averaged 11 percent on the cutover units South 7, West 2, West 5, and West 7, and 4 percent on the uncut unit, West 6:

	Soil depth (inches)		
	0-1/2	*1/2-1*	*1-4*
	- - - - - *Percent* - - - - -		
Cutover units	8	9	11
Uncut unit	2	2	4
Difference	6	7	7

The uncut unit averaged 6 percent less water content after the wildfire than the two cutover and slashed units bordering it on either side. This or a larger difference probably existed before the fire because of greater use of water by undisturbed vegetation growing on the uncut stand.

Fire intensity and preburn soil water content within the surfce 1 inch of soil interacted to cause varying responses in soil water loss during prescribed burning (fig. 7). This loss of soil water ranged from 0 to 11 percent during the course of

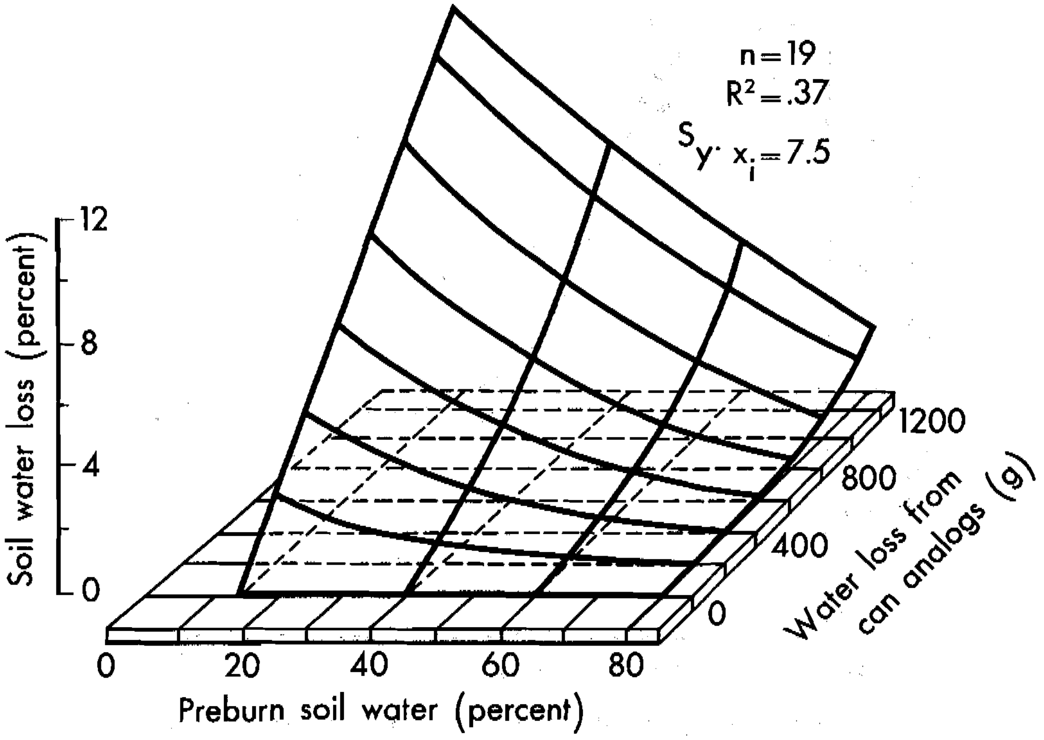

Figure 7.--Average loss of water during prescribed burning as related to preburn soil water within the surface 1 inch and can analogs (a measure of intensity).

prescribed burning at Miller Creek. When the soil was nearly saturated (about 50 percent by weight) soon after snowmelt, the water regime in the surface 1 inch of soil decreased only 6 percent during the most intense fire (fig. 7). However, later in the summer after evapotranspiration had depleted much of this water, fire in dry fuel released enough energy to burn off nearly all the duff and dry the surface 1 inch of soil. For example, at 15 percent soil water, intense fires decreased soil water by 12 percent. Once the slash and upper duff were moistened by rain, usually in late summer or early fall, the energy released by prescribed fires diminished. Although the heat flux decreased, water loss was considerable within the upper 1 inch of soil where the surface soil and lower duff remained relatively dry, as in early October 1967. Later, soil water depletion occurred primarily under fuel concentrations or other conditions that protected the soil from the rain.

Effect of Duff

Forest litter ameliorates the effect on the soil surface of desiccation by wind and heating by incoming radiation. At Miller Creek, this layer averaged about 2.5 inches in depth (see table 6 for the average, the maximum, and the minimum depth of litter measured on each unit). In May, June, and most of July, this layer of decomposing organic matter was moist and insulated the surface soil from the drying effects of prescribed fires. On units where litter averaged more than 2 inches in depth and where the water content of the lower half of the duff was above 110 percent, less than 40 percent of the duff depth was burned during prescribed fires (fig. 8). As the water content of the litter decreased, prescribed fires consumed more of this layer and caused greater water depletion of the upper soil. When the lower half of the duff layer reached about 50 percent water content, prescribed fires burned off most of the duff layer. Concurrently, surface soil water was reduced to the lowest point.

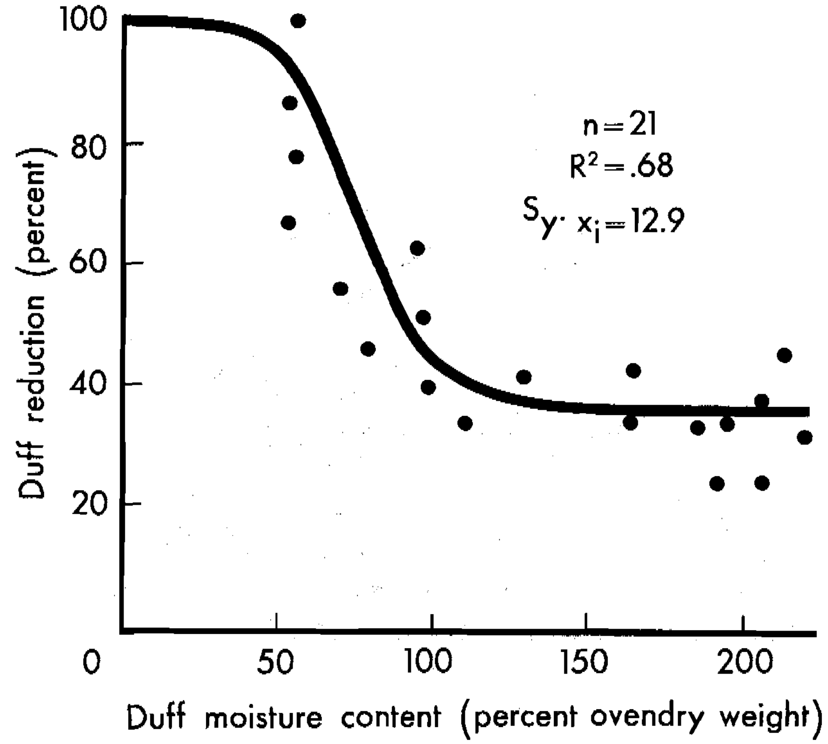

Figure 8.—Duff reduction related to the water content of the lower half of the duff layer.

Soil Temperature

The downward heat flux from the combustion of forest fuels penetrates the soil surface and heats the upper soil mantle. The increase in soil temperature varies considerably during the burning of slash.

Conduction

Usually as logging slash and duff dried and soil water decreased during the summer, each successive prescribed fire became more intense and a steep temperature gradient developed within the surface soil (fig. 9). In 1967, this condition continued into the fall; extreme fire conditions forced a halt to burning from the end of August to early October. However, in 1968 frequent heavy rains, from mid-August on, replenished soil water and stopped further soil drying. Except at scattered points where fuels were concentrated, the effectiveness of fires in reducing duff layers and heating the surface

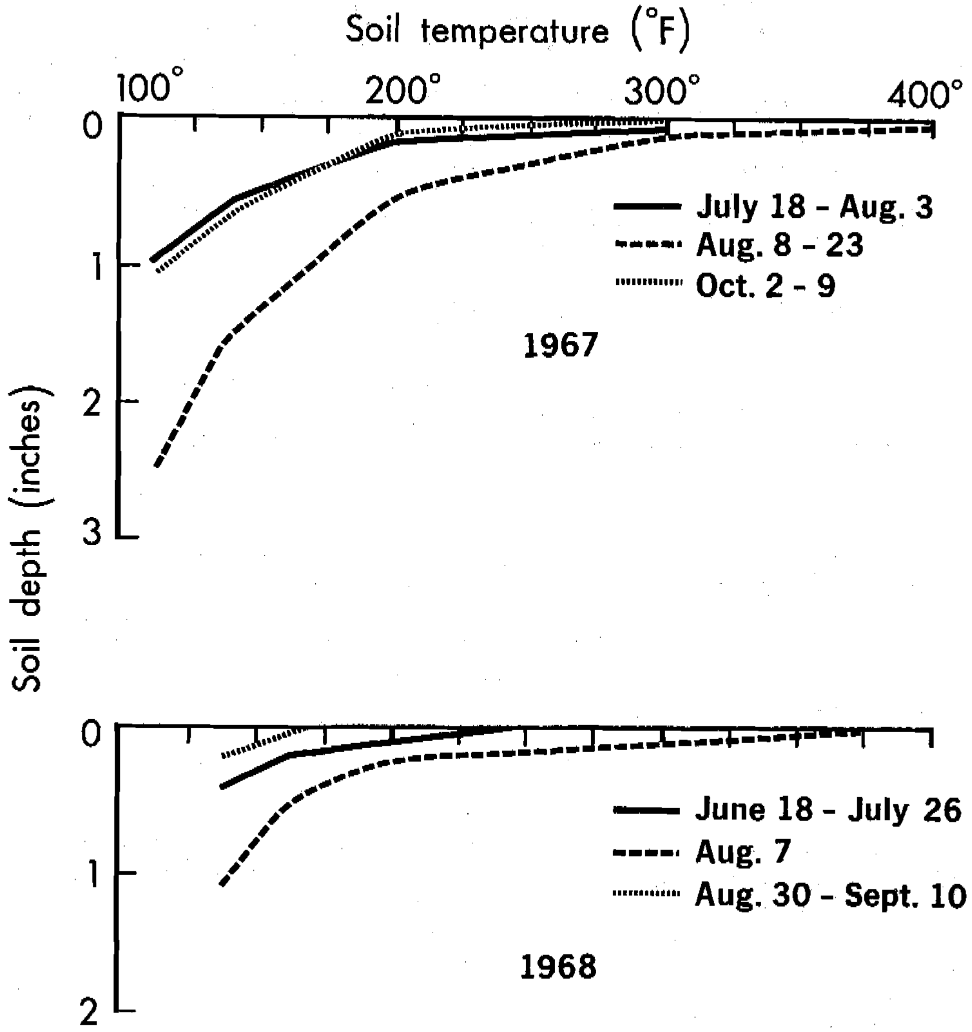

Figure 9.--Average depth temperatures were recorded during prescribed burns in 1967 and 1968.

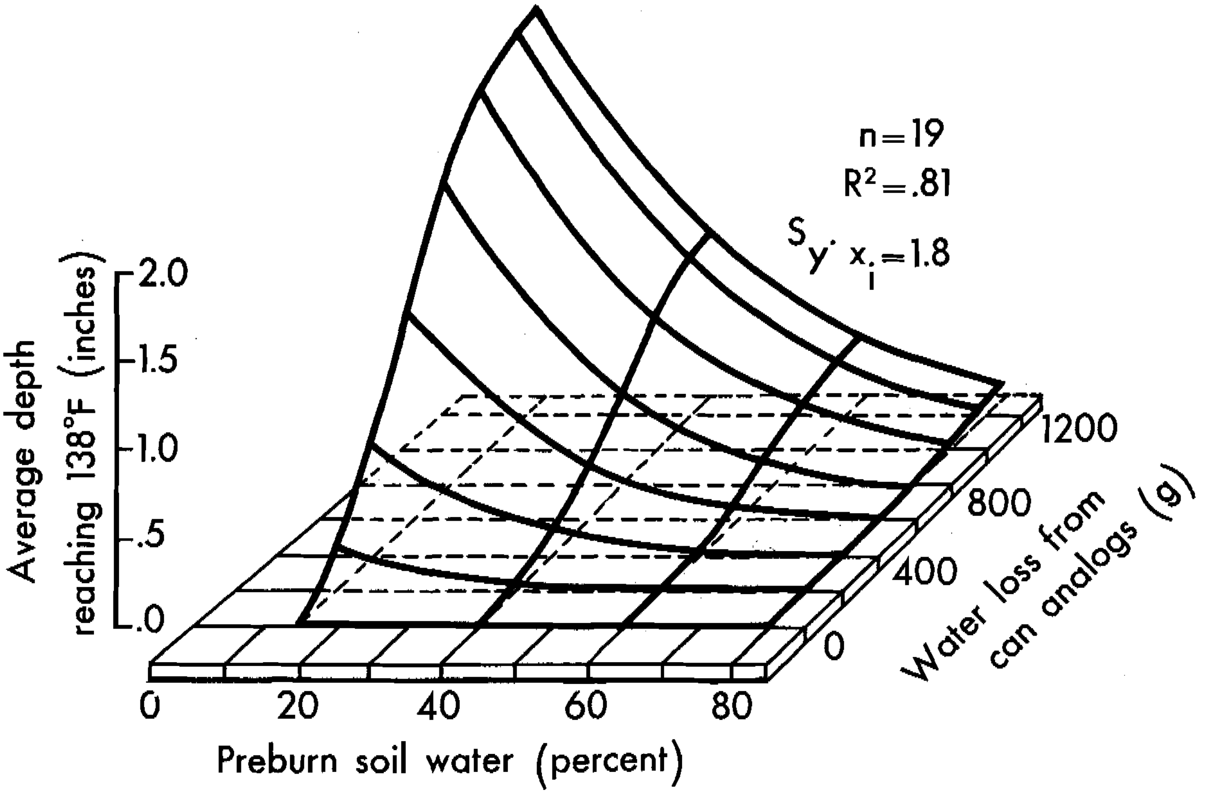

Figure 10.--Average depth that reached 138°F during prescribed burning as related to preburn soil water within the surface 1 inch and average water loss from can analogs (a measure of fire intensity).

soil diminished rapidly after heavy rainfall began. Fires in June and July caused few spots to be heated above 200°F, and then only in the surface one-fourth inch (fig. 9); temperatures over 113°F were rare below 1.5 inches. Prescribed burning in early August caused the greatest soil heating. After the heavy rains subsided and fuel dried enough to burn, the level of heat penetration decreased to or below that caused by fires ignited in June and July.

Temperature Variation

Heating of the surface soil varied according to the interaction of fire intensity and the amount of soil water (fig. 10). Variability was evident both within individual units and between units (table 7). Maximum soil temperatures were usually recorded at points of high fuel concentration, low soil water, or both. Living cells usually are killed at 138°F. In this study, the average depth that reached 138°F increased as preburn soil water decreased at any given fire intensity (fig. 10). However, the depth reaching this temperature increased rapidly with greater fire intensities. In the spring, when soil water was near field capacity (about 50 percent on the more sheltered slopes), the depth that reached 138°F increased from 0 to 0.6 inch over the extremes of fire intensity shown in figure 10. In middle to late summer, when soil water reached about 15 percent on the driest slopes, the soil was heated to 138°F from 0 to 2.2 inches depending on the intensity of prescribed fires.

Table 7.--*Maximum, minimum,*[1] *and average depths that Templaq melted for several temperatures on units where data were taken, Miller Creek study, Flathead National Forest*

Unit	Depth of Templilaq melt																	
	113°F			125°F			138°F			150°F		163°F		200°F			300°F	
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Ave.	Max.	Ave.	Max.	Min.	Ave.	Max.	Ave.
	Inches																	
NORTH																		
4	--	--	--	1.2	0.0	0.2	0.9	0.0	0.2	0.9	0.1	0.2	0.0	--	--	--	--	--
5	4.0	0.0	0.3	--	--	--	3.0	.0	.7	--	--	--	--	0.6	--	0.1	0.3	0.0
7	--	--	--	.7	.0	.1	.4	.0	.1	.1	.0	.1	.0	--	--	--	--	--
8	--	--	--	.7	.0	.2	.6	.0	.1	.6	.1	.3	.0	--	--	--	--	--
9	--	--	--	1.4	.0	.5	1.2	.0	.4	.9	.2	.6	.1	.4	--	.0	--	--
11	3.7	.0	.9	--	--	--	1.9	.0	.5	--	--	--	--	.6	--	.1	.0	.0
13	--	--	--	--	--	--	.3	.0	.2	.7	.2	.1	.1	--	--	--	--	--
EAST																		
3	--	--	--	2.1	.0	1.0	2.2	.0	1.1	.9	.9	1.1	.6	.9	--	.2	.8	.1
5	--	--	--	1.4	.0	.3	1.3	.0	.2	1.0	.1	.7	.1	--	--	--	--	--
6	4.2+	.0	.9+	--	--	--	3.3+	.0	.6	--	--	--	--	1.1+	--	.2+	.3	.0
7	2.1	.4	1.1	--	--	--	1.4	.2	.7	--	--	--	--	1.0	--	.2	.6	.1
10	--	--	--	1.2	.0	.2	1.0	.0	.1	1.0	.1	.3	.0	.2	--	.0	.2	.0
13	4.2+	.7	2.5+	--	--	--	3.0+	.5	1.6+	--	--	--	--	1.4	--	.6	1.2	.2
SOUTH																		
4	--	--	--	2.4	.0	.4	1.6	.0	.3	1.5	.2	.8	.1	.0	--	.0	.0	.0
8	4.5+	.4	2.5+	--	--	--	3.6+	.2	1.6+	--	--	--	--	1.5	--	.5	.6	.1
9	1.6	.0	.6	--	--	--	.8	.0	.2	--	--	--	--	.1	--	.0	.0	.0
10	--	--	--	1.7	.0	.4	1.4	.0	.3	1.0	.2	.0	.1	--	--	--	--	--
WEST																		
1	2.0	.0	.9	--	--	--	1.5	.0	.6	--	--	--	--	.9	--	.2	.6	.0
4	--	--	--	.6	.0	.0	.2	.0	.0	.0	.0	.0	.0	--	--	--	--	--
8	--	--	--	1.3	.0	.4	1.2	.0	.2	1.2	.1	.7	.0	.6	--	.0	--	--
9	3.9+	.0	1.5	--	--	--	2.9	.0	.8	--	--	--	--	1.3	--	.3	.6	.0
10	--	--	--	--	--	--	1.3	.0	.6	1.3	.5	.6	.1	--	--	--	--	--
12	--	--	--	1.2	.0	.2	1.0	.0	.2	1.0	.2	1.1	.4	--	--	--	--	--
13	--	--	--	.5	.0	.0	.4	.0	.0	.5	.0	.0	.0	--	--	--	--	--

[1] Minimum values are all 0.0 for 150°F and greater.

The magnitude of heat penetration into the soil is also influenced by the amount of water in the duff. In early August 1967, on a moist north-facing slope, a prescribed fire caused the soil surface temperature to increase from about 50°F to between 138°F and 200°F with 113°F recorded to a depth of about 1 inch. Heat conduction increased as the lower one-half inch of duff and the surface 1 inch of soil dried (table 5). The maximum temperature at the surface varied from 200° to 500°F, with 113°F recorded at an average depth of about 3 inches and a maximum depth of about 5 inches.

In August 1967, maximum soil temperatures to 200°F ranged from 0 to 1.5 inches in depth, with an average depth of 0.5 inch, which was twice that on any other burn. About 80 percent of the units were burned when the soil water within the surface 1 inch was greater than 30 percent. Temperatures greater than 138°F were seldom recorded below a depth of 3 inches even during the hottest burns, and 200°F was rarely measured below the surface 0.5 inch of soil.

In 1967, little rain fell from mid-July through September to recharge the upper soil. Soil heating was greatest during this period. Even after rains began in early October, interception by slash, vegetation, and the duff layer prevented most of the initial moisture from entering the surface soil. Hence, surface soil water remained fairly low and fires, even fires of low intensity, heated the soil considerably.

During this period, water within the lower 0.5 inch of duff averaged 28 percent and water within the surface 1 inch of soil averaged 20 percent. In contrast, when water content of duff and soil was high and fires similarly low in intensity burned, little or no increase in soil temperature occurred.

Duration

To some extent, the length of time that high temperatures are maintained in the soil surface causes physical and biotic changes within that layer. As soils dry, the heat flux from fires causes greater and longer heating within the surface soil. The most extreme soil heating measured at Miller Creek is shown in figure 11, point 4. This figure illustrates the increase and duration of temperature in the upper 1.8 inch of soil and the variability measured at two points on a south-facing slope burned in early August. Soil temperature maximums varied from 130° and 360°F at the 0.4-inch depth, to 103° and 155°F at the 1.6-inch depth. The sudden rise to 621° and 252°F at the 0.4-inch and 0.8-inch depths, respectively (fig. 11), shows the influence of the ignition of a root within the soil--temperature was not increased at 1.6 inches. While the temperature at the 0.4-inch depth just reached 130°F at point 27 (fig. 11), it was greater than 130°F at point 4 for about 6, 5, and 3-1/2 hours at depths of 0.4, 0.8, and 1.6 inches, respectively. The soils had not returned to ambience by the time the instruments were removed the next morning.

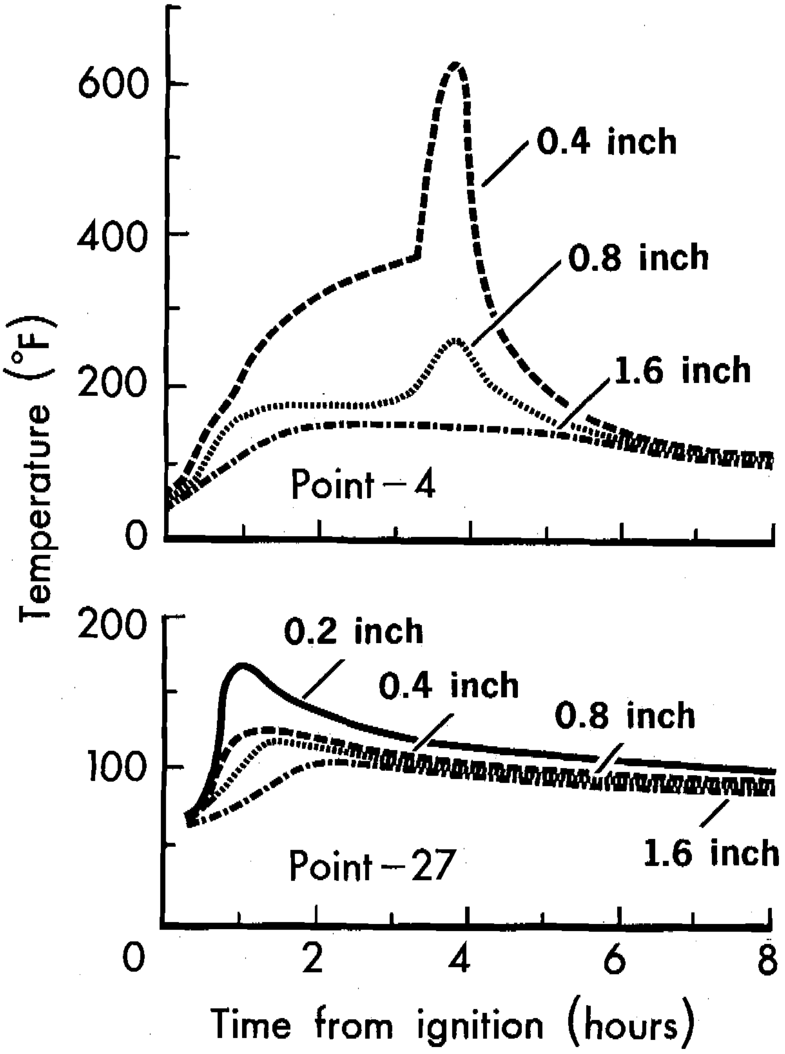

Figure 11.--Soil temperatures recorded at four depths at two points during burning of unit South 8, August 8, 1967.

DISCUSSION

Because establishment of coniferous seedlings, particularly western larch, is enhanced on soil that is free from excessive competition, the successful burn must create receptive seedbed mosaic. Exposure of too much mineral soil seedbed may result in severe overstocking, a problem in many young larch stands. At least three levels of seedbed conditions resulted from 2 years of burning at Miller Creek. Seedbed condition corresponded to the date an area was burned and to the moisture content of the soil.

1.--The first three 1967 burns and nearly all 1968 burns exposed little mineral soil. Usually, litter and duff were not completely burned. Soil water was high and root mortality was low, confirmation that soil temperatures seldom reached the lethal level, especially below 2 inches in depth. Sprouting began within 2 weeks after burning in June, July, and August, and emergent species will grow rapidly and compete with new tree seedlings for light and moisture.

2.--The 1967 wildfire consumed most of the duff on burned units. Postfire soil water was low. These units had little root survival because soils commonly reached lethal temperatures as deep as 4 inches. Occasional sprouting occurred in early September on these areas.

3.--Distribution of exposed mineral soil on units burned in October 1967 was spotty and was limited to areas that sustained high soil temperatures. Frequent rains increased soil water during the period these blocks were burned. Heat penetration was highly variable between areas, particularly on the first burns, where some killing temperatures reached as deep as 4 inches after the fall rains.

APPLICATIONS

These results suggest that if natural regeneration is to be limited by regulating the amount of mineral soil exposed, then prescribed burning must be timed with duff and soil moisture. The best seedbeds on south-, east-, and west-facing slopes apparently resulted from the October 1967 fires. Data are lacking as to when the most root mortality would have resulted on north-facing slopes, but summer burning before the fall rains begin probably will be required.

Stocking control becomes less of a problem when artificial regeneration is used to renew a stand. Lightly to heavily burned seedbeds can be planted or spot seeded without fear of overstocking. These methods also permit selection of microsites where competition is minimized. Based on chance, natural or broadcast seeding offers no such choice. Planting allows the greatest flexibility in seedbed preparation since vigorous, well-planted growing stock initially has a 1- to 3-year growth advantage over newly germinated seedlings.

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APPENDIX

Formulas used to develop surfaces shown in figures 6, 7, and 10 and the curve shown in figure 8.

Figure 6

$$\text{Root mortality, percent } (\widehat{RM}) = 0.99523 \text{ YP} \left\{ \frac{e^{-\left|\frac{\frac{(100 - PW)}{100} - 1}{1 - I}\right|^{2.8}} - e^{-\left(\frac{1}{1 - I}\right)^{2.8}}}{1 - e^{-\left(\frac{1}{1 - I}\right)^{2.8}}} \right\}$$

where:

$$YP = 31 + 2.6191 \text{ X } 10^{-5} \text{ } (WL)^{1.95} + 38.07 \text{ } e^{-\left|\frac{\frac{(WL)}{1300} - 1}{0.2}\right|^{3}}$$

$I = 0.65 - 8.7172 \text{ X } 10^{-15} \text{ } (WL)^{4.2}$

WL = Water loss (percent), $0 \leq WL \leq 1300$

PW = Preburn soil water (percent), $0 \leq PW \leq 100$

Figure 7

Soil water loss, percent $(\widehat{SWL}) = (YP/(85)^{N}) \text{ } (100\text{-}PB)^{N} \text{ } (0.96262)$

where:

$YP = .0096473 \text{ } (CWL)$

$N = 2.65 - 5.223 \text{ X } 10^{-6} \text{ } (CWL)^{1.75}$

PB = Preburn soil water (percent), $15 \leq PB \leq 100$

CWL = Can water loss (g), $0 \leq CWL \leq 1300$

Figure 8

Duff reduction, percent $(\widehat{DR}) = 100 - 63.772\ e^{-\left|\frac{\frac{MC}{220} - 1}{0.7}\right|^{8}}$

where:

MC = Duff moisture content, $0 \leq MC \leq 220$

Figure 10

Depth, inches $(\hat{D}) = \left(\frac{YP}{(75)^{N}}\right) (100-PW)^{N} (0.97118)$

where:

$$YP = 1.72906\ e^{-\left|\frac{\frac{(CWL)}{1300} - 1}{0.63}\right|^{2.2}} - 0.10906$$

$$N = 4.0 - 1.5\ e^{-\left|\frac{\frac{(CWL)}{1300} - 1}{0.4}\right|^{2.2}}$$

PB = Preburn soil water (percent), $15 \leq PB \leq 100$

CWL = Can water loss (g), $0 \leq CWL \leq 1300$

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SHEARER, RAYMOND C.
1975. Seedbed characteristics in western larch forests after prescribed burning. USDA For. Serv. Res. Pap. INT-167, 26 p., illus. (Intermountain Forest & Range Experiment Station, Ogden, Utah 84401.)

The effectiveness of prescribed broadcast burning for seedbed preparation during the months of May through October was studied on several 10-acre clearcuts on all aspects in western larch forests of northwest Montana. On north-facing slopes, nearly complete duff reduction only occurred during the summer before heavy rains. Other aspects had a broader time range in which to burn for adequate duff reduction. Spring burns did not significantly decrease this layer on any aspect.

OXFORD: 114.122, 114.354, 232.322.6, 436.
KEYWORDS: prescribed burning, western larch, fire use seedbed preparation, soil heating, moisture content (soil), duff reduction, root mortality.

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Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

- Boise, Idaho
- Bozeman, Montana (in cooperation with Montana State University)
- Logan, Utah (in cooperation with Utah State University)
- Missoula, Montana (in cooperation with University of Montana)
- Moscow, Idaho (in cooperation with the University of Idaho)
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