Soil Fertility as Affected by Broadcast Burning Following Clearcutting In Northern Rocky Mountain Larch/Fir Forests

NORBERT V. DeBYLE [1]

INTRODUCTION

THE western larch *(Larix occidentalis)* and Douglas-fir *(Pseudotsuga menziesii)* forest in the northern Rocky Mountains is a seral type, usually growing as even-aged stands following wildfire. Fire kills some or all of the standing crop, opens up the forest, and creates a mineral soil seedbed, allowing regeneration of this type. Hence, fire can be considered a natural part of the northern coniferous forest environment (Wellner, 1970). This vegetation-soil complex has developed over thousands of years, with fire periodically perturbing the system.

Ever since their value as a wood source for our society has been realized, these forests have been protected, when possible, from wildfire. Clearcutting is the usual method of harvesting the wood produced. After harvesting, prescribed burning is often used as a convenient way of obtaining mineral soil seedbeds and reducing the wildfire

hazard created by logging residue (Steele and Beaufait, 1969). Thus, to the extent possible, man has mimicked the natural role of wild-fire in his management of this forest type.

The sudden and dramatic change from a dense conifer forest to a denuded and burned landscape has the potential of triggering other changes; for example, soil properties may be altered, either directly by heating during the fire or indirectly by the changed environment. The extent of changes in the soil depends upon such factors as: (1) climate; (2) forest type; (3) soil type; (4) site history, especially frequency and nature of previous fires; (5) intensity and behavior of current fire; (6) amount of fuel consumed; (7) amount of organic mantle remaining on soil after current fire; and (8) postfire weather.

Because of these interacting factors, other investigators following fire have reported everything from negligible change in soil properties to virtual baking of the surface soil and marked changes in its chemical and physical nature. Sometimes the written description of the listed controlling factors is sufficient for interpretation of the reported results.

In this report of chemical soil properties before and after prescribed burning, descriptions of the controlling factors and methods are given to enable the reader to interpret results and to recognize their possible applicability to the area of his interest.

STUDY AREA AND TREATMENT

An old-growth mixture of western larch, Douglas-fir, and Engelmann spruce *(Picea engelmannii)* in nearly equal volumes, totaling about 24,600 bd. ft./acre (approximately 143 m^3 /ha), was cut on sixty 10-acre (approximately 4 ha) units in 1966 and 1967 on the Miller Creek and Martin Creek drainages near Olney, Montana (Lat. 48°31' N., Long. 114°45' W.).

The broadcast logging debris was burned within a year after clear-cutting. Fuel loads averaged 257 .9 t/ha (115 tons/acre). About 88 percent of this fuel was coarse debris more than 10 cm in diameter. Burning prescriptions were such that a complete array of fire intensities was attained, from combustion of only very fine fuels to combustion of all but the coarsest slash and most of the organic soil horizons

(duff). In addition, a wildfire burned four units of standing timber and several units of adjacent slash. The fire occurred when prescribed burning was halted during a period of extreme fire danger and resulted in the most intense burns monitored.

The elevation of the study area ranges from 1,280 to 1,524 m (4,200 to 5,000 ft). Slopes average 24 percent and range from 9 to 35 percent. Soils have developed in glacial till from the argillites and quartzites of the Wallace (Belt) Formation and are mantled with a thin layer of loess. Ash from the Mount Mazama and Glacier Peak volcanic eruptions occurs in this loess (Fryxell, 1965); the remainder of the deposit probably comes from the Palouse region in eastern Washington. These soils belong to the Sherlock Series and, for the most part, are Andie Cryoboralfs with an unincorporated surface organic horizon from 2 to 8 cm thick. The surface 1 to 3 cm of mineral soil is silt loam of single-grain structure (30 percent sand, 56 percent silt, 14 percent clay). This silt loam overlies 30 cm of gravelly loam of a weak blocky structure, beneath which is very stony loam to at least a 2 m depth.

The study area has long, cool, wet winters and short, dry summers. Annual precipitation averages 63 cm; approximately two-thirds f alls as snow: Although high-intensity summer rainstorms occasionally occur, summer precipitation generally f alls at low intensities from Pacific maritime frontal systems. Most rainfall is recorded during April, May, and June, the months when snowmelt runoff is greatest. These are humid watershed lands that yield more than 25 cm of streamflow annually, nearly all as year-long seepage flow (Packer, 1959). When plant cover is sufficient, only a small part of the annual precipitation becomes overland flow. Most of it contributes to seepage flow or is stored in the soil mantle.

METHODS

Bulk soil samples were gathered and analyzed from 35 of the 60 clearcut units on the study area. Sampling was confined to the central 21/2 acres of each unit, in which there was a 36-point grid. Fire intensity was monitored with a water-can analog (Beaufait, 1966) at each point of the grid, and the amount of duff (surface organic

soil horizon) consumed in the fire was measured. This grid was diagonally divided and five points in each half were randomly selected for repeated soil sampling. The soil from each of the five points was composited, thus yielding two soil samples from each unit for each time and depth.

Samples were taken from the surface organic horizon (duff or, after burning, the duff-ash layer) and from the 0- to 5-, 5- to 10-, 10- to 20-, and 20- to 30-cm depths into the mineral soil. To minimize site disturbance, a 15-cm diameter core was extracted for each point and time. The first (preburn) sample core was taken 2 meters uphill from the point of fire-intensity measure. Through the time sequence, each subsequent sample core from this point was taken 1 meter to the side or below this first core hole.

Soil samples were taken before slash burning, within a few days after, 1 year after, and, in some instances, 2 years after burning. A few units also were sampled 1 year before burning.

After immediate and thorough air drying, the mineral soil samples were passed through a 2-mm sieve and the organic (duff or duff-ash) samples were ground in a Wiley mill through a 40-mesh screen before subjecting them to standard chemical analyses. The organic samples were analyzed for total contents of nitrogen (N), sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), and phosphorus (P). The mineral soil samples were analyzed for pH, organic matter, total N, available P, cation exchange capacity, and both water-soluble and exchangeable Na, K, Ca, and Mg. All cation, phosphorus, and exchange capacity analyses were done by the Soils Laboratory of the College of Agriculture, Utah State University.

A 1-gram portion of each ground organic sample was digested in a 4:1 mixture of nitric and perchloric acid. The digest, after dilution to volume with distilled water, was analyzed for Na and K by flame-emission spectrophotometry and for Ca and Mg by atomic absorption. Lathanum was added to prevent interference before any Ca and Mg analysis by atomic absorption. The spectrophotometric vanadomolybdate method (Chapman and Pratt, 1961) was used to determine the phosphorus content of this digest.

The total nitrogen contents of the organic and the mineral soil

samples were determined in finely ground 1/2-gram portions using the Dumas method (Morris et al., 1968).

A glass electrode in a paste of soil and distilled water was used to make pH determinations.

Chromic acid oxidation with spontaneous heating (Walkley-Black technique) was used to quantify organic matter content.

Thesaturation percentage of the mineral soil was measured by using method 27a in Agricultural Handbook 60 (Richards (ed.), 1954). The saturation extract, removed from the soil by vacuum filtering, was analyzed for Na and K by flame emission and for Ca and Mg by atomic absorption. The results are expressed as milliequivalents of water soluble elements per 100 grams of soil.

Cation exchange capacity was determined by sodium saturation (American Society of Agronomy, 1965:899) and the displaced sodium was quantified by flame photometry.

Available phosphorus was approximated through sodium bicarbonate extraction (Watanabe and Olsen, 1965), and the quantity of phosphorus in the extract was determined spectrophotometrically.

Ammonium acetate was used to extract the cations Na, K, Ca, and Mg from the soil exchange (method 18 in Agricultural Handbook 60). These extracts were analyzed for Na and K contents by flame emission and for Ca and Mg contents by atomic absorption. The ammonium acetate extractable content minus the water-soluble component equals the total exchangeable content of each cation.

After appropriate grouping of the data generated from these laboratory analyses, statistical tests were performed todetermine significance of any differences found through time. All possible time pairs were used for each subunit sampled. Paired Student "t" tests were run to determine significance; differences were considered significant at 0.05 confidence level and highly significant at the 0.01 confidence level. Each sampled parameter was statistically treated as a separate and independent entity.

RESULTS

The preburn data for all applicable parameters are sorted by aspect and depth and presented in Table 1. These average values for the

Table 1.Preburn characteristics of the mineral soil by aspect and depth.

Variable	Soil depth (cm)	Aspect				Average
		North	East	South	West	
pH	0-5	5.6	5.5	5.6	5.6	5.6
	5-10	6.1	5.7	5.7	5.8	5.8
	10-20	6.1	5.9	5.8	6.0	6.0
	20-30	6.5	6.0	5.9	6.1	6.1
Organic matter	0-5	4.9	5.2	4.9	5.5	5.2
(9£)	5-10	3.1	4.3	3.1	3.3	3.4
Total nitrogen	0-5	.10	.12	.08	.10	.10
(9£)	5-10	.08	.09	.06	.07	.07
Available	0-5	77.7	77.9	78.5	78.3	78.1
phosphorus	5-10	54.5	73.5	76.4	64.9	66.8
(ppm)	10-20	27.5	46.5	55.8	44.3	43.1
	20-30	16.5	38.7	36.1	27.6	29.5
Cation exchange	0-5	22.5	21.5	18.3	24.0	21.9
capacity	5-10	21.5	20.3	16.8	21.5	20.3
{meq/lOO g	10-20	18.6	18.3	14.6	18.3	17.7
of soil)	20-30	14.7	14.7	12.9	16.4	14.9
Exchangeable	0-5	.15	.12	.10	.12	.12
sodium	5-10	.16	.14	.12	.13	.13
(meq/100 g	10-20	.16	.14	.12	.13	.14
of soil)	20-30	.15	.14	.11	.12	.13
Exchangeable	0-5	.34	.36	.35	.42	.38
potassium	5-10	.29	.34	.36	.40	.35
{meq/lOO g	10-20	.22	.34	.33	.38	.32
of soil)	20-30	.19	.22	.22	.26	.23
Exchangeable	0-5	6.62	6.81	7.69	6.44	6.80
calcium	5-10	6.43	5.00	5.49	4.93	5.39
{meq/lOO g	10-20	7.44	5.13	5.44	4.73	5.58
of soil)	20-30	6.78	5.57	5.40	5.08	5.66
Exchangeable	0-5	.91	1.07	1.05	.97	.99
magnesium	5-10	.79	.90	.80	.87	.85
{meq/100 g	10-20	.93	.90	.95	.87	.91
of soil)	20-30	.80	.93	.96	.88	.89

sampled plots on each of the four cardinal aspects characterize the mineral soil on the study area. The organic surface horizon (duff) was analyzed only for total nutrient content. Results are presented in Table 2.

These data may nearly represent prelogging conditions. However, the preburn samples were taken af ter logging, which, in most in-

Table 2. Preburn nutrient content of surface organic soil horizon.
contents are given in percent by weight and in grams per square meter.

Variable	Aspect								Average	
	North		East		South		West			
	%	gfm2	%	g/m2	%	g/m2	%	gfm2	%	g/m2
Nitrogen	0.95	62.3	1.01	95.7	0.96	46.0	0.84	36.5	0.92	56.1
Phosphorus	.10	6.3	.10	9.1	.07	3.6	.08	3.7	.09	5.4
Sodium	.05	3.0	.05	3.9	.04	1.9	.05	2.2	.05	2.7
Potassium	.23	13.8	.27	25.9	.21	9.9	.25	11.4	.24	14.9
Calcium	1.18	81.6	1.06	100.9	1.08	51.6	1.07	49.5	1.10	67.6
Magnesium	.18	11.7	.28	27.5	.19	8.8	.23	10.7	.22	14.4

stances, was within the same season. We know that logging increased organic matter content of the surface mineral soil (DeByle and Packer, 1972) which, in turn, would increase the nitrogen content and perhaps the content of other nutrients, too. Logging physically disrupted the layers of the surface organic soil horizon in some places and sometimes mixed mineral soil into it. Perhaps most important, logging interrupted the pumping of nutrients from the soil by the foresttrees. This interruption, even over a season, coupled with markedly reduced evapotranspirational water loss from these soils, may have induced some changes in soil characteristics. Therefore, the data in Tables 1and 2 include any immediate changes due to timber harvest and may also include some relatively rapid, time-dependent changes, too. Nevertheless, significance of change due to fire or the change over a year or two from clearcutting and fire combined are measured against these data.

The data from the burned units were grouped in several ways to detect and possibly to illustrate treatment effects. The groups are:

1. All observations on logged and burned units sorted by time and depth;

2. All the above observations divided into cardinal aspects;

3. A selection of the 5 hottest and another of the 10 hottest burns, based upon data from all the water-can analogs on whole units;

4. Selection of the 10 hottest sampling replications (subunits), based upon data from water-can analog measures at the soil sampling points;

5. The six units with 2-year postburn data;
6. The four units of standing timber burned in the wildfire.

Paired observation "t" tests were run on available data within each of the seven groups to test for changes in each measured parameter. The surface organic soil horizon is included in the statistical analyses for only the first two groups.

SOIL PH

The hydrogen ion activity of the soils decreased as a result of burning and continued to decrease over the next year. This is reflected in a highly significant pH increase in the surface 10 cm of mineral soil (Table 3). The change in the 10- to 20-cm depth is statistically significant, but the slight increase in the lowest depth is not. A maximum of 56 observations were used to compute each of the pH values in Table 3, because all logged and burned units were included. The changes appeared to be consistent on all cardinal exposures.

Even though the number of observations was much reduced, there was a significant pH. rise in all sampled depths under the hottest burns during the first postburn year. However, the immediate changes in mineral soil pH. caused by burning were inconsistent and usually not significant under the hot burns. Initial pH values and the magnitude of changes under hot burns were similar to those for all units (Table 3), and, therefore, are not illustrated.

The soil samples taken from six units 2 years after burning had pH values that were statistically similar to those taken 1 year after burning. Apparently, no further consistent change had occurred.

Four units of standing timber burned in a wildfire were sampled after burning and 1 year later; two of these were sampled 2 years after burning. There was a highly significant rise in pH at all depths in the mineral soil during the first postburn year, but changes during the second year were inconsistent and insignificant (Table 4).

Table 3. Soil pH under all logged and burned units.

Depth (cm)	Preburn	Postburn	One-year postburn
0-5	5.57	5.76	6.06
5-10	5.83	5.91	6.00
10-20	5.97		6.13
20-30	6.13		6.18

Table -t. Soil pH under uncut units after wildfire.

Depth (cm)	Postbum	One-year postburn	Two-year postburn
0-5	5.42	6.27	6.20
5-10	5.57	5.99	5.88
10-20	5.74	6.12	5.85
20-30	5.82	6.27	5.95

ORGANIC MATTER

Organic matter content was measured in only the surface 10 cm of most mineral soil samples. In the surface 5 cm of all logged and burned units, it was reduced from 5.18 to 4.54 percent by burning, a highly significant decrease. The following year, it was at 4.94 percent, an increase, but not one that is statistically acceptable. In the 5- to 10-cm depth, these values were 3.42, 3.46, and 3.39 percent during the same time sequence. On the six units sampled for a second postburn year, the organic matter content continued to increase, particularly in the surface layer, returning to approximately its preburn values in 2 years.

Selection of the hottest slash burns illustrates organic matter changes that are compatible with the findings of DeByle and Packer (1972). On these units, there was not only a decrease from 4.2 to 3.9 percent organic matter in the surface mineral soil caused by burning, but a highly significant decrease to 2.8 percent during the following year.

TOTAL NITROGEN

Most of the nitrogen in soils is in the organic fraction. This relationship was tested with 390 pairs of total nitrogen-organic matter observations in a linear regression analysis. The resultant formula was $Y=0.03+68.9X$. The relationship was reasonably good (R^2 of 0.64). Since some nitrogen would be in mineral form, it seems reasonable that 0.03 percent nitrogen would exist when no organic matter remains in the soil; this was the Y intercept of the regression line. It also appears reasonable that, with an increase to 70 percent organic matter, there would be about 1 percent nitrogen in the soil, since there is about 1 percent nitrogen in the surface organic soil horizon.

Most organically held nitrogen is volatilized by burning and is lost as gas (DeBell and Ralston, 1970). Hence, consumption by the fires

of the surface organic soil horizon and a small amount of organic matter in the surface mineral soil caused some nitrogen loss from the site. In the surface organic layer, nitrogen was reduced from 60 g/m² before burning to 40 g/m² after burning, a highly significant loss of 20 g/m² on all burned units measured. A year later, nitrogen had further declined to 36 g/m² . Thus, more than one-third of the nitrogen held in the organic layer on top of the mineral soil was lost directly or indirectly by burning.

The nitrogen content of the mineral soil was not significantly altered by burning or during the following year. It remained at approximately 0.10 percent in the surface 5 cm and at 0.08 percent in the 5- to 10-cm layer.

AVAILABLE PHOSPHORUS

The content of phosphorus in the mineral soil ostensibly available for plant uptake changed little. When the data from all logged and burned units are grouped, there appears to be a slight increase immediately after burning and during the subsequent year (Table 5). The only increase statistically significant was that from 78 to 84 ppm in the surface 5 cm from before burning to 1 year after burning. When these units were grouped by aspect, the increases of available phosphorus in the surface 5 cm from before burning to after burning were significant on east and west exposures. No other groupings showed significant changes in phosphorus content. The available phosphorus data varied greatly; so the increases, if real, were masked into statistical insignificance by high variation.

Total phosphorus content of the surface organic layer increased insignificantly from 5.6 g/m² before burning to 6.5 g/m² after burning. This increase could have come from ashfall from burned logging de-

Table 5. Available phosphorus under all logged and burned units.

Depth (cm)	Preburn	Postburn	One-year postburn
	----------------------- ppm ----------------------		
0-5	78.1	81.3	83.9
5-10	66.8	67.8	71.7
10-20	43.1		49.1
20-30	29.5		33.4

bris. During the next year, total phosphorus content was reduced to 4.0 g/m^2. This highly significant reduction could be due to leaching or erosion. Thogh much leaching of phosphorus is unlikely, leaching from the duff-ash layer could have accounted for some of the apparent increase of available phosphorus in the mineral soil.

CATION EXCHANGE CAPACITY

No statistically valid changes in cation exchange capacity of the mineral soil were caused by logging and burning treatments. Capacity for cation exchange remained near 20 meq/100 g of soil in the surface 10 cm and near 18 meq/100 g and 15 meq/100 g in the 10- to 20- and 20- to 30-cm depths, respectively (Table 1).

SODIUM

Total sodium content of the surface organic soil horizon as well as the amounts of water-soluble, exchangeable, and total extractable (soluble plus exchangeable) sodium in the mineral soil are discussed.

The sodium content of the surface organic layer was increased slightly, from 2.8 to 2.9 g/m^2, by burning. It declined to 2.1 g/m^2 after a year. No doubt, this highly significant decrease was caused by leaching of the soluble components in the ash layer and by some erosion.

These humid forest soils contain little soluble sodium; percolating water would normally carry it away. There was between 0.03 and 1.5 meq/100 g present in the mineral soil before burning. Burning and the leaching process during the subsequent year caused statistically significant decreases in soluble sodium contents, particularly in the surface mineral soil layers.

Of thecations analyzed, sodium was least abundant on the exchange, too (Table 1).There was, however, about three times as much sodium on the base exchange as in the water-soluble form. Neither burning nor conditions the following year caused any significant changes in exchangeable sodium content of the mineral soil.

The content of total extractable sodium (available sodium) sometimes showed a significant decrease because of treatment. For the group of all logged and burned units, all four mineral soil depths showed statistically valid decreases from the preburn sampling to

the I-year postburn sampling. Even though small, soluble sodium loss probably accounted for much of the significant reduction in extractable sodium.

POTASSIUM

Total potassium content in the surface organic soil horizon on all logged and burned units tested was 14.7 g/m^2 before burning. Ash-fall from burning the overlying logging debris significantly increased this amount to 19.6 g/m^2 · During the subsequent year, leaching and erosion removed more than half of this highly mobile element and reduced the residual content to 8.8 g/m^2 in the duff-ash layer, a highly significant change. This change was also significant on the two aspects (north and south exposures), which were analyzed separately.

Soluble potassium, like sodium, exists in small amounts in humid forest soils. Here, it averaged between 0.03 and 0.01 meq/100 g of the mineral soil under the group of all logged and burned units. Both soluble sodium and potassium declined in quantity with depth. No consistent nor significant changes in the soluble contents of potassium in the mineral soils under the large group of all sampled logged and burned units could be attributed to treatments. However, there were significant decreases in soluble potassium content of soils under some groups of units. Soluble potassium content decreased at all depths under the five hottest burns during the first postburn year and continued to decrease in the top 10 cm under the six units sampled during the second year.

As a result of burning, exchangeable potassium increased in the surface 10 cm of mineral soil under all logged and burned units (Table 6). This highly significant increase was further augmented du ring t he subsequent year. The increases shown in Table 6 for the

Tahll' B. Exehangl'ahk• potassium in minl'ral soil u nder all logged and burned u nits.

Depth (cm)	Preburn	Postburn	One-year postburn
	- meq/100 g -
0-5	◐8	0.44	0.47

10- to 20- to 30-cm depths from before the fire to 1 year after the fire also are significant.

It is doubtful that the changes in exchangeable potassium from preburn to postburn samples in the mineral soil can be attributed to burning alone. This highly soluble element was more likely leached from the ash by rains that fell on severaf of the burned units before postburn soil sampling was accomplished. This leached potassium would then have been tied onto the exchange in the upper layers of mineral soil.

Analyses of data from the six units sampled 2 years after burning showed a significant decline in the content of soluble potassium in the upper 10 cm during the second postburn year. During this same period, a significant increase in the exchangeable and total extractable contents of potassium occurred in the 10- to 30-cm layers.

Mineral soil data from the four units of standing timber consumed by wildfire showed some significant increases in exchangeable and extractable potassium contents. There were increases during each year; and, when added, the accumulated change over 2 years became statistically significant.

CALCIUM

Calcium was the most abundant cation analyzed in the surface organic horizon or in the mineral soil. Calcium content averaged 72 g/m^2 in the surface organic layer before burning. An insignificant reduction to 69 g/m^2 occurred during burning. A year later, calcium content averaged 66 g/m^2 in the duff-ash layer, statistically the same as before burning. These small decreases, if real, were masked by large natural variation in calcium content among the samples.

Table 7 shows soluble calcium contents in the mineral soil under

Table 7. Soluble calcium in mineral soil under all logged and burned u nits.

Depth (cm)	Preburn	Postburn	One-year postburn
	---------------------- meq/100 g ----------------------		
0-5	0.24	0.24	0.20
5-10	.16	.16	.12
10-20	.13		.10
20-30	.10		.09

the large group of all logged and burned units. This constituent was about twice as abundant in the surface 5 cm as below. Burning caused no immediate change. One year later, there were statistically significant declines at all depths.

Similar changes in soluble calcium contents of mineral soil under smaller, more select groups of units also occurred. On the five hottest burns, soluble calcium content at the three lowest depths declined significantly during the first postburn year. The six units with 2-year postburn data showed some significant reductions through the second year after burning. Significant calcium decreases also occurred in the mineral soil under the standing timber burned in the wildfire.

Exchangeable and total extractable calcium contents in the mineral soil did not statistically change as a result of the logging and burning treatments imposed. Variation among the samples was much too great; no trends could be inferred from these data.

MAGNESIUM

Total magnesium content in the surface organic horizon averaged 15.4 g/m^2 before burning and 15.2 g/m^2 after burning, an insignificant change. One year later, there had been a highly significant decline to 8.0 g/m^2 ; almost one-half of the total magnesium content had been lost to leaching and erosion.

Soluble magnesium followed much the same pattern as calcium. However, the soil contained only about one-fourth as much magnesium as calcium (Table 8). The decreases shown for soluble magnesium content during the first postburn year are highly significant in all four depths of mineral soil. Similar decreases occurred on the five hottest burns and on the four unlogged wildfire units. And, where measured, declines continued through the second postburn year.

Table 8. Soluble magnesium in mineral soil under all logged and burned units.

Depth (cm)	Preburn	Postburn	One-year postburn
	---------------------- meq/100 g ----------------------		
0-5	0.071	0.077	0.062

Exchangeable magnesium increased significantly during the first postburn year in the surface 10 cm on the large group of all logged and burned units (Table 9) and on the smaller group of five hottest burns. On the wildfire units, there was an increase in exchangeable magnesium during that year in the lower depths, but not in the upper 10 cm. Since approximately 95 percent of the extractable magnesium in the soil exists in the exchangeable state, changes in extractable magnesium contents were similar to those for exchangeable magnesium.

Table 9. Exchangeable magnesium in mineral soil under all logged and burned units.

Depth (cm)	Preburn	Postburn	One-year postburn
	---------------------- meq/100 g ------------------------		
0-5	0.99	0.93	1.06
5-10	.85	.83	.91
10-20	l		l
20-30	.89		.97

ExCHANGE SATURATION

The cation exchange capacity of the soil did not change as a result of treatment. The amounts of this capacity occupied by the four cations tested are shown in Table 10. Changes apparent in this table were not statistically tested. There appears to be a slight increase in saturation with Ca, Mg, K, and Na during the first postburn year. The rise in soil pH, the loss of cations from the overlying duff-ash layer, and the increase in contents of some cations on the exchange during this timespan all support the validity of this apparent increase in exchange saturation.

Table 10. Saturation of cation exchange capacity in mineral soil under all logged and burned units with calcium, magnesium, potassium, and sodium.

Depth (cm)	Preburn	Postburn	One-year postburn
0-5	37.8	38.9	40.5
5-10	33.1	33.4	34.2
10-20	39.2		38.4
20-30	46.2		48.9

DISCUSSION

Clearcutting removed the primary nutrient and water pumps from these forested soils. It opened the soil surface to increased insolation and an altered microclimate. Removal of the trees also interrupted the annual cyclic return of litter and nutrients to the soil surface. Logging activity caused some mixing of surface soils, some break up of the continuity and layering of the surface organic horizon, and some incorporation of this material into the mineral soil. In addition to all these disturbances, 258 t/ha of logging debris was dumped onto the site in a broadcast layer about a meter deep. This layer temporarily protected the soil surface from direct insolation. The debris could be considered a large increment of litter, poorly applied by natural standards, to the soil surface. This was the first treatment and the time of preburn soil sampling.

The second treatment, broadcast burning of logging debris, was superimposed upon the first. A complete array of fire intensities was attained and measured. Burning removed most of the carbon, hydrogen, oxygen, and nitrogen, and fractions of other elements from the consumed material as gas or as smoke particulates. The remainder was reduced to ash. With the insulating effect of logging debris gone, increased insolation could act on the blackened soil surface to alter the microclimate and increase evaporation from the upper layers of soil. A layer of ash was added to the top of the remaining surface organic soil horizon. This ash and the nutrients it contained came from logging debris and from burning part or all of the surface soil horizon. This was the second treatment; the time of postburn soil sampling.

Soil samples were next taken 1year later. During the interim, wind moved some of the fine ash. Most was redeposited within the unit but some was blown elsewhere.

Precipitation, runoff, and percolating water had an even greater influence. Precipitation dissolved the readily soluble compounds in the ash. These were then moved downward into the mineral soil by percolating water or were transported downhill in the overland flow. The amounts of soil and nutrients eroded by overland flow on some of these units were measured by DeByle and Packer (1972). Most of the nutrients dissolved in the percolating water from snowmelt and rain-

storms probably moved into the mineral soil to be held within the rooting zone. The rise in pH and the increases in available phosphorus, exchangeable potassium, exchangeable magnesium, and base saturation of the cation exchange in the upper layers of mineral soil during the first postburn year are indicators of this process.

Other factors may have influenced these mineral soil changes, too. During the first few postburn years, pumping of nutrients and water by vegetation was much reduced, much less litter fall occurred, and the microclimate affecting the soil surface probably altered the biological and chemical processes within it. Some or all of these factors, along with the flush of soluble nutrients from the ash, could have been responsible for the changes measured in the mineral soil.

CONCLUSIONS

Clearcutting and the subsequent burning of logging debris in the larch-Douglas-fir forests of western Montana caused some measurable changes in soil chemistry and nutrient availability. Nutrient cycling was interrupted, the soil environment was altered, and a layer of debris and ash was deposited on the soil surface. Burning volatilized about one-third of the nitrogen in the organic horizon lying on the mineral soil surface. Leaching and erosion of the ash-duff layer during the next year or two markedly reduced the amounts of nutrients held in this horizon. This reduction was offset by some increases in available nutrients held in the mineral soil. The pH of the mineral soil also increased.

Clearcutting and burning did not cause any alarming alterations in soil chemistry. These relatively fine-textured soils probably trapped most of the released nutrients within the rooting zone. Nitrogen loss through volatilization by combustion of organic matter is great but total nitrogen is not a measure of the nitrogen supply actually available to plants. Available nitrogen supplies were not assessed. A profusion of herbaceous vegetation covered these burns within a couple years and woody vegetation has since become increasingly dominant. Thus, the cycling of nutrients has been renewed and the soil surface is again protected. None of the nutrient changes measured should have an adverse affect on site quality.

LITERATURE CITED

American Society of Agronomy. 1965. Methods of soil analysis. Agron. Monogr. 9. 1572 p. Beaufait, William R. 1966. An integrating device for evaluating prescribed fires. For. Sci. 12(1):27-29.

Chapman, Homer D., and Parker F. Pratt. 1961. Methods of analysis for soils, plants, and wa- ters. Div. Agric. Sci., Univ. Calif. 309 p.

DeBell, D. S., and C. W. Ralston. 1970. Release of nitrogen by burning light forest fuels. Soil Sci. Soc. Am. Proc. 34(6):936-938.

DeByle, Norbert V., and Paul E. Packer. 1972. Plant nutrient and soil losses in overland flow from burned forest clearcuts. AWRA Nat!. Symp. Watersheds in Transition Proc. p. 296- 307.

Fryxell, Roald. 1965.Mazama and Glacier Peak volcanic ash layers: Relative ages. Science 147 (3663):1288-1290.

Morris, G. F., R. B. Carson, D. A. Schearer, and W. T. Jopkiewicz.1968. Comparison of the automatic Dumas (Coleman Model 29A Nitrogen Analyzer II) and Kjeldahl methods for the determination of total nitrogen in agricultural materials. J. AOAC, 51(1):216- 219.

Packer, Paul E. 1959. Watershed management problems in the northern Rocky Mountain re- gion. USDA For. Serv., Intermt. For. and Range Exp. Stn. Res. Pap. 57. 28 p.

Richards, L. A. (ed.).1954. Diagnosis and improvement of saline and alkali soils.USDA Agric. Handb. 60. 160 p.

Steele, Robert W., and William R. Beaufait. 1969. Spring and autumn broadcast burning of interior Douglas-fir slash. Mont. For. and Cons. Exp. Stn., Univ. Mont. Bull. 36. 12 p.

Watanabe, F. S., and S. R. Olsen. 1965. Test of ascorbic acid method for determining phos- phorus in water and NaHC03 extracts from soil. Soil Sci. Soc. Am. Proc. 29(6):677-678.

Wellner, Charles A. 1970. Fire history in the northern Rocky Mountains. *In:* The Role of Fire in the Intermountain West. Intermt. Fire Res. Counc. Proc. p. 42-64.