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Influence of Slash Burning on Ion Transport in a Forest Soil

Ion transport in a forest soil is an important part of the mineral cycle of a forest ecosystem. Through this process ions move downward into the soil where they are recycled by the forest, retained within the soil system, or leached from the soil profile. This transport process can be altered by various forest management practices including slash burning, clearcutting, and fertilization. Potentially, slash burning should have the most serious impact on ion transport as it directly affects (1) uptake and return of elements by the forest, (2) the nutrient capital of the soil system, and (3) the mobility of mineral elements within the soil system. In addition to these results the quantities of nutrient ions incorporated in the slash must also be considered since substantial amounts of these nutrients are released to the soil by burning.

Because of difficulties in directly measuring the transport of ions through the soil and lack of sufficient data on nutrient levels in the slash, studies concerning the effects of fire on forest soil have typically considered only the chemical and morphological changes occurring within the profile as determined by sampling before and after burning (Ahlgren and Ahlgren, 1960). Such studies are insensitive to changes in the nutrient status of the ecosystem resulting from slash burning.

This paper reports the results of a pilot study designed to evaluate changes in nutrient release and transfer following slash fires in two different fuel concentrations. A tension lysimeter system was used to examine the relationships of ion release and transfer resulting from burning. This technique permits continuous monitoring of ion concentrations in selected soil horizons. The data thus obtained permit ion transfer within the soil to be evaluated as a function of time. These data in combination with data of nutrient content of the slash material provide information on changes in the nutrient status of the ecosystem following burning.

Methods

The study was conducted at the Allen E. Thompson Research Center (formerly the Cedar River Research Area) located about 35 miles southeast of Seattle in the foothills of the Washington Cascade range. This research center is located in a 40-year-old second-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) plantation growing on an Everett series gravelly sandy loam, a brown podzolic soil (Typic Haplorthod) derived from Pleistocene glacial outwash. The climate is typical of lower elevations in western Washington, the average temperature in July is 16°C; in January it is 3°C. The average annual precipitation (ca. 144 cm) falls largely during the winter months. The research facilities have been described by Cole (1968). The soils, vegetation, geology, and climate have been described by Cole and Gessel (1968).

During spring 1969, an area about 40 x 70 m was clearcut. This area was adjacent to an existing 0.2 ha clearcut. All logs of small-end diameter greater than 12 cm were removed, and branches and tops were piled for storage. Three plots 1.5 x 2 m each (plots 1 through 3) were established on the clearcut to delineate treatment boundaries. Iron-constantan, three-junction integrating thermopiles were installed in plots 2 and 3 at the surface of the forest floor, at the surface of the mineral soil, and at 2.5, 5, 10, 20, 40, and 80 cm in the soil. Tension lysimeters 620 cm^2 in area (Cole, 1968) were installed in the three plots at the base of the forest floor (or ash layer), at the base of the A-horizon (about 7 cm), at the base of the B-horizon (about 30 cm), and in the C-horizon (1 m). Installation of the forest floor and A-horizon lysimeters in the treatment plots was deferred until after burning to avoid the possibility of heat damage to the acrylic portions of the lysimeters.

Slash composed of needles, branches, and tops was piled evenly on the treatment plots—plot 2 receiving about 7.5 kg/m^2 of slash and plot 3 receiving about 32 kg/m^2 of slash. In addition, forest floor material weighing 1.4 ± 0.04 kg/m^2 (McColl and Grier, unpublished) was left intact beneath the piles. All weights are on an oven-dry basis at 70°C. The slash piles were then covered with a polyethylene sheet until burning.

Mineral concentration of the fuel load was approximately 0.15 percent nitrogen, 0.11 percent potassium, and 0.16 percent calcium (Cole, Gessel, and Dice, 1967). The forest floor contains 0.86 percent calcium, 0.14 percent magnesium, 0.19 percent potassium, and 0.98 percent nitrogen (Grier and McColl, unpublished). All mineral contents are based on oven-dry weight.

The slash was burned on September 17, 1969. Fuel moisture content then averaged 20 percent of oven-dry weight. Soil temperatures during the fire and for 24 hours after were recorded. The thermopiles were then removed from the soil profile, the vacuum system for the lysimeters installed, and a 0.1 bar tension was established at the lysimeter plates. Plots 2 and 3 were then covered with open-ended polyethylene tents.

To allow examination and comparison of wetting cycles between the treatment plots, they were irrigated every three days (beginning September 28) with uniform water volumes consisting of sprinkled applications of 1.5 cm of water. Eleven days elapsed between burning and the first irrigation. Leachates were collected during the irrigations in separate 100-ml to 200-ml increments. The time required for each sample to accumulate and the sample volume were recorded.

After five irrigations, the treatment plots were uncovered, and weekly bulk collections of solutions from all plots were made. During the irrigation period, precipitation roughly equal to the irrigation fell on the control plot, so total soil solution flow through all plots was about equal. Errors of total ion amount due to different flow rates between the treatment and control plots are small due to the much lower ion concentrations in the control plot solutions.

Measurements of leachate pH, electrical conductivity, and total alkalinity (carbonate plus bicarbonate) were made within 12 hours of collection, using the techniques of Rainwater and Thatcher (1960).

Total dissolved salt content of the solution samples was calculated from electrical conductivity, using an empirical estimation method (Logan, 1961).

Selected samples were digested, using a sulfuric acid and hydrogen peroxide digest, after which calcium, magnesium, and sodium were determined by atomic absorption spectrophotometry. Organic nitrogen and ammonium in the digest samples were determined by the micro-Kjeldahl method (Jackson, 1958). Phosphorus was determined by colorimetry using the chlorostannous-reduced, molybdophosphoric blue color method of Jackson (1958).

The measured volumes of solutions collected from the different lysimeter plots in the burned plots exhibited higher variability than previously noted at this site (Cole and Machno, in press). This increased variability is partly due to channeling of water by the uneven soil surface and also to water-repellent layers in the upper soil horizons of the burned plots. Because of the high variability, the cumulative leachate flow in Figure 1 and Table 1 was estimated from measurements of water entering the soil. Error introduced by this estimation should be small since evapotranspiration losses at this site are negligible during the cool, wet autumn season.

Results and Discussion

Slash burning substantially alters both the magnitude of ion transport and the proportions of the various ionic species in the soil solution. In this study, the influx of ions to the mineral soil was enormously increased by water leaching through the ash layer (Table 1). Concentrations as high as 80 meq/liter were observed in solutions

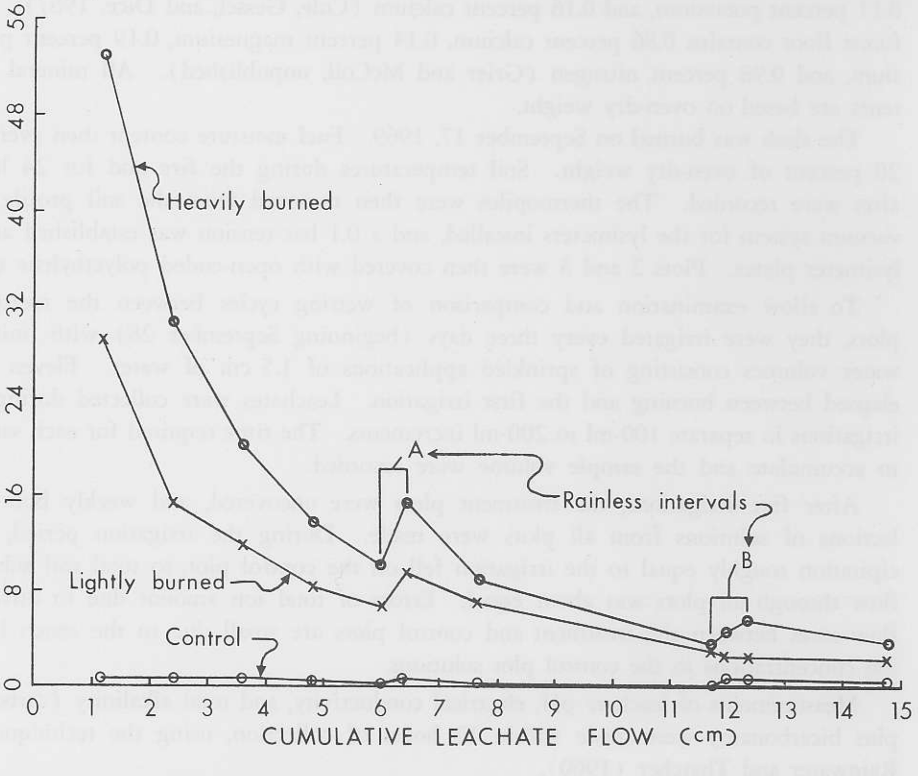

Figure 1. Relationship between cumulative leachate flow (cm) and ion concentration in leachates (meq/liter) from the ash layer or forest floor. The time interval is from 28 September to 23 November 1969. Rainless intervals noted on figure actually represent the first wetting cycle following dry period. Rainless interval A was 14 days, B was two 3-day dry periods with small wetting front between.

entering the soil of the heavily burned plot during the first wetting of the soil after burning. This represents an increase of about 250 percent over concentrations in the control plot. An increase in ion loss through leaching was also noted deep in the soil profile. For example, leaching losses from the 1-m soil depth increased 3.3 times on the lightly burned plot and 4.5 times on the heavily burned plot over leaching losses from the control plot (Table 1).

TABLE 1. Total ion amount collected from soil horizons subjected to various treatments from 25 September to 23 November 1969.

	Total ion (meq)*		
Horizon	Control	Light burn	Heavy burn
Forest floor**	5.3	76.9	128.0
A-horizon	5.6	85.1	78.8
B-horizon	2.1	7.2	16.2
C-horizon	2.4	7.8	11.4

* Total ion estimated on basis of uniform flow through soil and measured ion concentrations.
** Forest floor or ash layer.

Leaching of the soluble ash constituents from the ash layer was the major contributor of ions to the soil solution. There was little if any addition of ions to the leachates as they passed through the heated portion of the mineral soil. This result could be expected since heat flux from the fire did not substantially increase the temperature of the underlying mineral soil. The maximum surface temperatures were about 410°C on both plots, while at the 2.5-cm soil depth the maximum temperatures were 41°C on the lightly burned and 84°C on the heavily burned treatment plots. Soil moisture in the upper 10 cm of soil ranged between 10 and 30 percent before the fire. Higher or lower soil moisture could produce different results by changing the thermal conductivity of the soil.

The mineral soil played an important role in regulating the downward movement of ions released by the ash layer. The A- and B-horizons adsorbed 70 to 90 percent of the ions entering the soil from the ash layer (Table 1). In the two months under discussion, the A- and B-horizons of the lightly and heavily burned plots adsorbed about 1.1 equiv/m^2 and 1.8 equiv/m^2, respectively, from the soil solution.

The ion concentration of the solution that was leached from the ash layer decreased rapidly as a function of total flow (Fig. 1), indicating that much of the ash was readily soluble and rapidly depleted. However, the ion concentrations of the ash leachates remained above those of the forest floor leachates from the control plot throughout the period reported, indicating the presence of less soluble ash components. This finding suggests a differential release of ions from the ash layer, the more soluble constituents comprising a major portion of the ion content of the early wetting cycles.

Two environmental factors also appeared to influence the ion concentration of the soil solution, these being soil solution flow rates and the length of time between wetting cycles. The flow rate of the soil solution, which in this well-drained soil is governed by precipitation rate, was inversely related to ion concentration (Fig. 2). The inverse relationship suggests that chemical equilibrium between soil and solution was not achieved in the soil system under conditions of high flow.

The time elapsed between wetting cycles also influenced ion concentration in the soil solution. Figure 1 shows that increases in ion concentration coincident with rainless periods occurred between 6 and 7 cm of total flow and again between 11 and 13

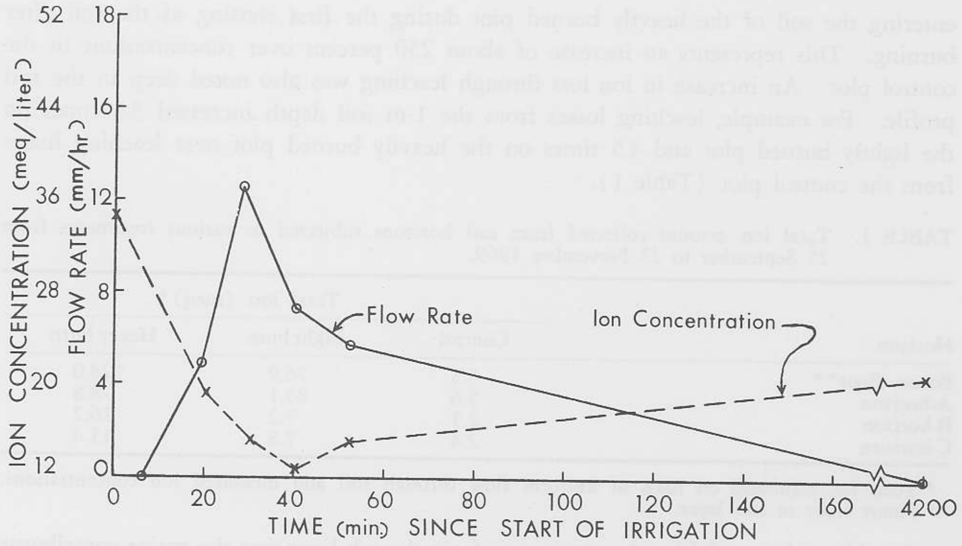

Figure 2. Ion concentration and flow rate of leachates from the A-horizon of the lightly burned plot as a function of time elapsed since the beginning of irrigation.

cm of total flow. This phenomenon was also noted by McColl (1969) in an undisturbed Douglas-fir ecosystem at this research site. He found that the length of the period preceding the wetting front was a major component increasing the ion concentration in the soil solution, and he also found an inverse relationship between flow rate and ion concentration in the soil solution.

In addition to changing the total ion concentration of the soil solution, burning also altered the concentration and proportion of various ions in the soil solution (Table 2). Potassium, for example, was present in the forest floor leachates from the control plot on September 28 at 0.1 meq/liter, or about 30 percent of the total cations. In the leachates from the burned plots of the same date, potassium comprised 60 to 80 percent of the total cations and was present in concentrations as high as 25.3 meq/liter. Only trace amounts of potassium were lost from the rooting zone, however. Magnesium, on the other hand, comprised only 15 to 20 percent of the cations entering the soil from the ash, but comprised as much as 50 to 60 percent of the cations lost from the rooting zone. Calcium was the major cation in the unburned fuel (Cole, Gessel, and Dice, 1967) and presumably also in the ash, but it was only a minor constituent of the soil solution from the burned plots (Table 2). The small amount of calcium in the soil solution can probably be explained by the physical-chemical behavior of calcium salts in high pH ranges.

The bicarbonate ion was the major anion in the leachates from the treatment and control plots. The carbonate ion was also present in the initial leachate collections from the surface horizons of the treatment plots, but in all cases was less than 10 percent of the total anions. Phosphate concentrations were highest in the leachates of the lightly burned treatment plot and lowest in the heavily burned treatment. Although reported as PO_4^{3-} in Table 2, the $H_2PO_4^-$ and HPO_4^{2-} forms are probably dominant in the solutions. This conclusion could explain part of the discrepancy between calculated total ion and the analytical total in the control plot leachates. Qualitative tests

TABLE 2. Ion concentration (meq/liter) of soil solution from different soil horizons for wetting cycles on 28 September (I) and 23 November 1969 (II).

		Total ion (calculated)		Ca^{2+}		Mg^{2+}		K^+		Na^+		pH		Alkalinity (total)		$(PO_4)^{3-}$	
Treatment	Horizon*	I	II	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Control	F	0.28	0.28	0.09	0.16	0.10	0.13	0.10	T	0.01	0.04	6.2	6.0	0.18	0.16	0.92	0.03
	A	0.27	0.27	0.05	0.08	0.14	0.10	0.12	T	0.01	0.06	6.2	6.7	0.17	0.14	0.35	T
	B	**	0.19	**	0.07	**	0.07	**	T	**	0.05	**	6.4	**	0.14	0.23	T
	C	**	0.23	**	0.10	**	0.10	**	T	**	0.04	**	6.7	**	0.20	0.17	T
Lightly burned	F	17.10	2.52	0.09	0.02	1.08	0.36	13.65	1.60	0.41	0.04	8.1	7.6	5.89	1.42	1.34	0.01
	A	18.70	2.42	0.07	0.03	1.70	0.77	13.06	1.10	0.49	0.04	7.9	7.4	6.05	1.76	1.15	0.01
	B	**	0.37	**	0.01	**	0.18	**	T	**	0.02	**	6.6	**	0.14	**	T
	C	**	0.52	**	0.01	**	0.32	**	T	**	0.04	**	7.0	**	0.40	**	T
Heavily burned	F	34.10	4.00	0.17	0.08	7.24	3.13	25.29	1.80	1.02	0.12	8.9	8.1	14.16	3.60	0.59	0.01
	A	19.70	2.63	0.14	0.03	3.34	0.70	12.17	1.40	0.57	0.06	8.0	7.7	9.83	1.76	0.48	0.01
	B	**	1.47	**	0.03	**	0.82	**	T	**	0.08	**	7.2	**	0.72	**	T
	C	**	0.97	**	0.03	**	0.64	**	T	**	0.06	**	6.8	**	0.70	**	T

$T<0.01$ meq/liter.
*F=forest floor or ash layer.
A=A-horizon (7 cm).
B=B-horizon (30 cm).
C=C-horizon (1 m).
**Wetting front had not reached these depths on 28 September 1969.

showed that substantial amounts of sulfate and silicate were present in the solutions from the treatment plots, but tests for nitrate and chloride were negative.

Organic nitrogen and ammonium nitrogen were present only in trace amounts in the soil solution of the treatment plots. Tests for nitrate were negative, so it is concluded that little nitrogen was released to the soil solution as a result of burning.

Conclusions

Slash burning produced the following changes in the ion regime of this soil.

1. Burning caused substantial increases in the concentrations of ions entering the soil. Ion loss from the rooting zone also increased. These increases are related to the weight of fuel on the soil surface.
2. Leaching of ions from the ash layer caused the major chemical changes occurring in the soil. There was no evidence that heating of the mineral soil appreciably affected the chemical composition of the leachates.
3. Most of the ions leached from the ash layer were adsorbed in the A- and B-horizons of this soil.
4. Total flow, flow rate, and time between wetting fronts influence the amount of ion transport after burning.
5. The principal anion in the soil solution of the treatment plots was bicarbonate, but carbonate, sulfate, phosphate, and silicate were also present. Leaching loss of nitrogen occurred only in trace amounts and at concentrations less than in the control plot.
6. Calcium was the major cation in the fuel while potassium was the major cation leached from the ash layer, and magnesium was the major cation leached from the rooting zone.

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