ONSITE SEDIMENT PRODUCTION AND NUTRIENT TRANSPORT FROM A LOW SEVERITY BURN IN THE INTERIOR NORTHWEST

P.R. Robichaud, R.T. Graham, R.D. Hungerford

ABSTRACT

Postharvest residue burning is a common site preparation treatment used in the interior Northwest to reduce forest fuels and prepare sites for tree regeneration. A study was conducted to measure runoff, sediment production, and nutrient changes caused by broadcast burning of logging slash. The site was a northern Idaho mixed conifer forest of western hemlock, grand fir, western white pine, western larch and Douglas-fir. A spring burn (1992) consumed about 50 percent of the litter, 22 percent of the humus, and 79 percent of the woody fuels less than 8 cm in diameter. Heat penetration into the mineral soil was minimal due to moisture present in the lower duff and mineral soil. Temperatures at the mineral soil surface did not exceed 77°C. Four replications of three, 30-minute simulated rainfall events (50 mm/hr) were used. Low erosion rates and nutrient losses were measured from this burn treatment. These results could help land management decisions concerning timing of burning as related to onsite sediment production, fuel reduction and long-term site productivity.

Keywords: erosion, prescribed burning, nitrogen loss, soil heating, sediment yield.

INTRODUCTION

Foresters, hydrologists, and soil scientists have long been concerned with the effects of fire on soil (Arend, 1941; Wells *et al*., 1979), in particular with erosion, site productivity and water quality following fires on steep terrain (Van Lear and Kapeluck, 1989). Sediment production after fires, whether prescribed or wild, can be a serious problem. Little quantitative information is available on the effects of prescribed fires in timber harvest areas on runoff/infiltration, sedimentation and nutrient changes.

Post-harvest burning of logging residue is a common method of fire hazard reduction and site preparation used after timber harvesting. Burning is used alone and in combination with other treatments to dispose of slash, reduce the risk of insects and fire hazards, prepare seedbeds, and suppress plant competition for both natural and artificial regeneration. The amount of vegetation, residue and forest floor consumed and resulting soil heating caused by burning determines the extent to which soil properties are altered. The effects of fire on the forest floor can range from only removing the litter to total consumption of the forest floor and altering mineral soil structure (Wells *et al*., 1979). Forest floor depth (litter layer and humus layer above mineral soil), moisture content, and woody residue amounts determine forest floor consumption. When forest floor depths are shallow or moisture contents are low, fires consume more of the forest floor and have the potential to alter mineral soil (Reinhardt *et al*., 1991).

Water and sediment yields may increase as forest floor consumption increases (Wells *et al*., 1979). By consuming the forest vegetation burning reduces canopy interception and evapotranspiration. If the organic layers are consumed and mineral soil exposed, soil infiltration and water storage capacities are reduced. Such impacts may last weeks or decades, depending on the fire's severity and intensity, remedial measures, and the rate of vegetative recovery (Baker, 1990).

The effect prescribed fire has on the nutrient reserves is highly variable. Depending on fire intensity and duration, forest floor consumption, and soil heating, nitrogen (N) losses can range from 6 to 90 percent (Boerner 1982; Jurgensen *et al*., 1981; Raison, 1979). However, if the forest floor and upper mineral soil is moist N volatilized in the upper forest floor can condense in the lower forest floor and upper mineral soil layers minimizing N losses (Mroz *et al*., 1980; Stark, 1977). Similarly, phosphorus (P) and sulfur (S) are volatilized at temperatures exceeding 700°C making them less vulnerable to loss from prescribed fires (Hungerford *et al*., 1991). Probably as important as loses of nutrients from volatilization is losses of nutrients through erosion processes after burning. Both organic materials and mineral soil can be lost during storm events after burning (Hungerford *et al*., 1991). Losses of organic materials (humus and buried decayed wood) not only removes nutrients but can also remove important sources of N fixation and ectomycorrhizol fungi, two vital components of northern Rocky Mountain soils (Harvey *et al*., 1987).

Because the effects of prescribed fire on forest floor dynamics, water infiltration, soil erosion, and nutrient losses in not fully understood a study was initiated on prescribed fire effects in a northern Idaho mixed conifer forest.

METHODS AND SITE DESCRIPTION

The study was conducted on the Fernan Ranger District of the Idaho Panhandle National Forest, near Coeur d'Alene, Idaho during the spring of 1992. Slopes within the study area (16 ha) ranged from 12 to 55 percent with a west-southwestern aspect. The predominant soil type is Typic Vitrandept, a silt loam, derived from volcanic ash influenced loess 28 to 45 cm thick. This is over a Eutirc Glossoboralfs soil, a mixed loamy-skeletal formed from Precambrian Belt rock.

Vegetation of the area was typical of the western hemlock/queencup beadlilly (*Tsuga heterophylla/Clintonia uniflora*) habitat type (Cooper *et al*., 1991). The overstory was dominated by 100 year or older western hemlock (*Tsuga heterophylla* [Raf.] Sarg.), grand fir (*Abies grandis* [Doug. exD. Don] Lindl.), Douglas-fir (*Pseudotsuga menziseii* [Mirb.] Franco), western larch (*Larix occidentalis* Nutt.), and western white pine (*Pinus monticola* Dougl.ex D. Don). The understory was relatively sparse because of the high stand density but did contain some low shrubs (*Vaccinium* ssp., *Pachistima mysinities* [Pursh] Raf.) and forbs (*Clintonia uniflora* [Schult.] Kunth., *Coptis* spp.).

The 16 ha study site was clearcut and cable yarded in the spring of 1991. In the spring of 1992 thirty-six plots were established on a systematic grid (15 m by 15 m) in the harvested area. Two random 15-m transects were directed radially from each plot center for woody fuel measurements (Brown, 1974). Eight steel pins were installed flush with the forest floor surface in each plot (total of 288 pins) for estimating forest floor consumption. A sample of the forest floor and mineral soil was taken in each plot using a 10 cm diameter core sampler driven 30 cm into the soil profile. Each horizon (litter, humus, decayed wood, and shallow mineral (10 cm) and deep mineral (11 to 30 cm)) was identified, depth noted, and a sample taken for nutrient analysis. Pre-burn and post-burn total N in the soil profile was determined on the 30 cm cores. Total N was analyzed after Kjeldahl digestion using the salicylic acid-sodium thiosulfate modification (Bremner and Mulvaney, 1982) and assayed on a Alpkem Rapid Flow Analyzer.

Six paired 1 m^2 plots were systematically selected in the study area representing the average fuel condition with one plot used for rainfall simulation and the other for soil temperature measurements. Pre-burn fuels were measured in each of the paired plots on 1.8 m diagonal transects. Fuel loading on each pair were equalized before the burn. Four steel pins were installed flush with the forest floor surface in each plot to estimate forest floor consumption. In the temperature measurement plots, these forest floor pins were located near thermocouples. Temperatures during the fire were recorded with eight chromel-alumel thermocouples located at the litter surface, in the humus, at the humus-mineral soil interface and in the mineral soil at 1, 2, 4, 8 and 10 cm below the interface. Immediately prior to burning, samples of the woody fuels, forest floor and mineral soil were collected to determine moisture content. Temperatures during the burn began when the surface temperature reached 80°C and continued every minute for 36 hrs.

Ignition of the harvested unit began in the early afternoon on April 25, as part of the operational burn program of the Fernan Ranger District. A heli-torch was used for ignition by strip headfire starting at the top of the slope and placing fire strips about every 40 m down the slope. Ignition was very rapid and the entire unit ignited within 30 minutes.

Post burn measurements were taken several days after burning, this allowed for the ash to disperse or settle before measurements were taken. Plots were re-located, fuel transects re-measured, soil cores extracted, and the forest floor consumption was estimated using the forest floor pins in each plot. Differences between the two surveys were used to determine total fuel and forest floor consumption.

A simulated rainfall event was applied to selected plots with a USDA-Forest Service oscillating nozzle rainfall simulator. These plots were isolated by 15-cm sheet metal placed vertically 5 cm into the ground. The simulator produced an average rainfall intensity of 50 mm/hr, which represents a 15-yr event for 25 mm of rainfall (Miller *et al.*, 1973; Weather Bureau, 1955). Seven rain gauges located around the 1 m^2 plots verified the rainfall amount. Each plot received three 30-min rainfall events (Runs). Run 1 was conducted with the existing soil moisture condition. Afterwards, the plots were covered with plastic tarps and Run 2 was conducted the following day. Run 3 was conducted about 30 minutes after Run 2. This sequence is used to determine characteristics affecting soil infiltration and runoff under various soil moisture conditions.

A covered trough at the lower end of each plot conducted runoff (water and sediment) through an outlet tube for timed volume samples, collected manually in 1000 ml bottles. At the end of each run, any sediment in the trough was washed into bottles. All runoff samples were weighed and oven-dried to determine runoff rates and sediment concentrations. Additional samples were taken throughout each rainfall event to determine total N in the runoff. Total N in the water was determined by Kjeldahl digestion and assayed on a Alpkem Rapid Flow Analyzer. A water sample from the rainfall simulator was also analyzed for N. This value was used to adjust the N values found in the runoff.

RESULTS AND DISCUSSION

Ignition technique, fuel moisture, and weather during the burn produced an intense fast moving fire (Tables 1 and 2). Flame lengths averaged 2 to 6 m and the fireline intensity averaged 965 to 13200 Kw/m. Moisture conditions of the woody fuel was 19 to 22 percent for the fine fuels and 34 to 54 percent for the large fuels.

Forest floor and soil temperatures confirmed the residence time of the fire was short and resulted in minimal soil heating (Table 2). The flame front temperature on the plots lasted from 5 to 16 min and some smoldering occurred for 10 to 40 min. Temperatures at the litter surface during flaming varied from 660 to 854°C (Figure 1).

Temperatures within the humus varied from 26 to 423°C, with the maximum temperature of 423°C lasting only 15 min. These temperatures would result in minimal loss of N from the humus layer because of the low temperatures and the short duration (Hungerford *et al.*, 1991). The humus layer provided a barrier to heat flow allowing the maximum temperature at the humus-mineral interface to reach only 77°C with most temperatures between 60 and 70°C. Surface mineral soil temperature on one plot never exceeded 23°C. Similar to the temperatures observed in the humus, temperatures in the mineral soil were far below the level where N is volatilized or where organic matter is destructively distilled.

After the burn, the forest floor had a blackened appearance with minimal destruction of the humus layer indicating a light char fire as described by Ryan-Noste (1985), or a low-severity burn (Phillips and Abercrombie, 1987). Fifty percent of the surface litter was consumed and about 20 percent of the humus was consumed (Table 3). The residual forest floor thickness averaged 3.6 cm over the study area following burning. The low consumption of litter and humus can be attributed to their high moisture contents (litter and humus, 64 and 125 percent, respectively) (Table 1). The forest floor after burning provides an adequate site for planting of artificial regeneration (Graham *et al.*, 1993) and because burned over surfaces are good sites for natural regeneration in these habitat types (Haig *et al*., 1941).

By retaining a large proportion of the humus this prescribed burn did an excellent job of maintaining total N, sites for N fixation and ectomycorrhizal activities, all important factors for maintaining productive forest soils (Harvey *et al*., 1987). After the burn 240 kg/ha of N was left in the litter layer and 370 kg/ha of N was left in the humus layer (Table 3). Burning of the litter and humus layers caused a total loss of 16 percent N from the rooting zone down to 30 cm. If the fire would have been severe, and consumed all of the humus and litter layers and some of the organic matter in the mineral soil, up to 40 percent of the total N in the rooting zone soil profile could have been lost (Little *et al*., 1988) or redistributed (Covington *et al*., 1991). Even though 16 percent of the total N was lost through burning a considerable amount of the available forms of N (NH_4, NO_3) are usually condensed in the humus and upper mineral layers especially if they are moist as they were in this study (Harvey *et al*.,1989).

The plots used for rainfall simulation represented the overall area fairly well. Preburn fine fuel loadings were 55 Mg/ha on the rain plots and averaged 43 Mg/ha over the entire area (Table 4 and 5). Fine fuels were reduced 88 percent on the rain plots and 78 percent overall by the prescribed fire. Forest floor reduction was 34 percent on the plots and averaged 42 percent reduction overall. Therefore, we feel data collected on the rain plots represents the entire burn area.

Because the slopes varied from 13 to 27 percent, they were adjusted to convert runoff depths and sediment yield values to a uniform slope of 30 percent (McCool *et al*., 1987).

After adjustment, runoff depths (mm) and sediment yield (kg/ha) were low compared to similar studies (Robichaud and Waldrop, 1992; Shahlaee *et al*., 1991) for a low severity burn. Average runoff depth was 7 mm after the first rainfall event (Run 1) and decreased to 6.2 mm after the third rainfall event (Run 3) (Figure 2). Likewise, average sediment yield decreased from 276 kg/ha for Run 1 to 64 kg/ha for Run 3. In contrast, Robichaud and Waldrop (1992) found that after a high severity burn, sediment yields averaged 1260 kg/ha and 113 kg/ha for a low severity burn for 100 mm/hr, 30-min event. Thus, low rates of sediment yield and rapid decline found in this study can be attributed to the 3.6 cm of forest floor that remained after the burn which provided a medium for high infiltration and protection from raindrop splash and overland flow detachment.

In addition to small amounts of sediment being removed from the plots after simulated rainfall events, losses of N from the plots were also very minimal. After the first rainfall event (Run 1), only 0.26 kg/ha of total N was lost from the plots, and only 0.65 kg/ha of total N would have been lost from the plots if all of the rain events were combined (Figure 2). Because of the relatively small total N losses from runoff and the amount conserved by retaining 68 percent of the forest floor, this burn conserved much of the N capital of the site.

Fuel moisture and burning conditions allowed for 79 percent consumption of the fine fuels (<8 cm) and a 33 percent consumption of all fuels (Table 5). Only 9 percent of the large fuels were consumed leaving 73 Mg/ha of large woody debris across the site. This amount of material easily exceeds the 36 to 58 Mg/ha minimum of large woody materials that Graham *et al*. (1993) recommend leaving after timber harvesting for the maintenance of forest productivity. In addition, this amount of woody debris does not exceed the maximum amount (112 Mg/ha) recommended by Reinhardt *et al*. (1991) for minimizing fire hazard. Also, by removing the majority of the fine fuels on the site the fire hazard is greatly reduced. The 9.1 Mg/ha of fine fuels left after this burn easily meet the recommendations of Reinhardt *et al*. (1991) for reducing fine fuels to less than 22 Mg/ha for minimizing fire hazard. By removing the fine fuels the site can easily be planted. Access for planters is good and little ground clearing is necessary for successful planting.

CONCLUSIONS

Prescribed fire is an excellent tool in preparing sites for regeneration and reducing fuel loadings in the mixed conifer forests of northern Idaho. This study shows that fires conducted under relatively moist conditions (litter moisture 64 percent and humus moisture 124 percent) resulted in little soil heating. Most of the fine fuels and 50 percent of the litter were consumed, which reduce fire hazard and increased planting ease. Only 22 percent of the humus was consumed, which resulted in minimal amounts of nutrients or sediment to be lost from the site even after three rainfall events. The residual forest floor, after a low severity burn, provides excellent protection for the mineral soil from raindrop splash, overland flow detachment, and rill development.

This burn shows that if the objectives of post-timber harvest fuel treatments are to retain the majority of the forest floor yet remove the fine fuels from a forest site they can be accomplished on an operational basis. The burn in this study did an excellent job of conserving the forest floor, reducing the fire hazard and maintaining a large amount of coarse woody material on the site.

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Authors

P.R. Robichaud, Research Engineer, Engineering Technology, Intermountain Research Station, Moscow, Idaho.

R.T. Graham, Research Forester, Silviculture and Genetics, Intermountain Research Station, Moscow, Idaho.

R.D. Hungerford, Research Forester, Fire Effects, Intermountain Research Station, Missoula, Montana.

Table 1.—Fuel and weather conditions at the time of ignition.

Measurement / Woody fuel size class	Moisture content (%) Mean	S.E.[1]
0.0-0.6 cm (diam.)	19	5.8
0.6-2.5 cm	19	3.0
2.5-8 cm	22	2.0
8-15 cm	34	2.7
15-23 cm	34	3.6
23-50 cm	54	5.0
Litter	64	10.5
Humus	125	5.5
Soil		
0-2 cm	69	3.3
2-5 cm	61	1.3
5-8 cm	57	1.6
Ambient temperature	22 °C	
Windspeed	8-15 kph	
Relative humidity	15%	

[1]Standard error of the mean.

Table 2.—Selected fire behavior parameters.

Measurement	Max. temperature
Litter	660-854 °C
Humus	26-423 °C
Mineral soil surface	23-77 °C
1 cm below mineral soil interface	41-68 °C
2 cm below mineral soil interface	20-60 °C
4 cm below mineral soil interface	20-35 °C
8 cm below mineral soil interface	14-20 °C
Flame length	2-6 m
Fireline intensity	965-13,220 kw/m

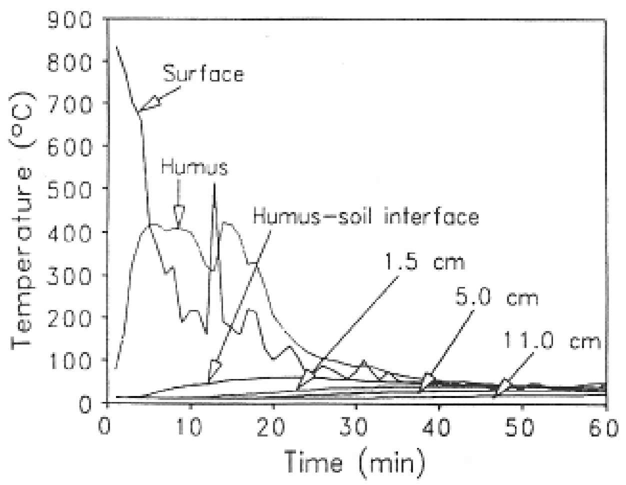

Figure 1. Typical temperature profile showing litter, humus, and soil temperatures during the burn.

Table 3. —Summary of forest floor conditions and total N changes from the soil profile.

Horizon	Preburn Depth (cm) Mean	S.E.	Preburn Total weight (Mg/ha) Mean	S.E.	Preburn Total N (%) Mean	S.E.	Preburn Weight of N (kg/ha) Mean	Postburn Depth (cm) Mean	S.E.	Postburn Total weight (Mg/ha) Mean	S.E.	Postburn Total N (%) Mean	S.E.	Postburn Weight of N (kg/ha) Mean	Total N loss (Kg/ha)	Total N change (%)
Litter	2.5	0.2	75.5	8.1	0.69	0.0	520	1.1	0.1	37.3	5.0	0.65	0.0	240	280	-53.6
Humus	3.7	0.4	111.1	11.1	0.46	0.3	510	2.5	0.2	89.2	7.4	0.42	0.0	370	140	-26.9
Total	6.2	0.4	186.6	16.6			1030	3.6	0.3	126.5	10.8			610	420	-59.2
Mineral Soil																
0-10 cm			680.0		0.10	0.01	660			680.0		0.10	0.0	650	10	-1.5
10-30 cm			1360.0		0.07	0.00	990			1360.0		0.07	0.0	970	20	-2.0
Total profile							2680							2230	450	-16.5

Rain plot	Fuel loading (<8 cm) (Mg/ha) Pre-burn	Post-burn	Forest floor depths (cm) Pre-burn	Post-burn
2	49	0.7	3.6	2.6
3	42	0.2	3.8	2.4
4	94	25	—[1]	—[1]
6	35	0	4.8	3.1
Rain plots average	55	6.5	4.1	2.7
Burn area average	42.8	9.1	6.2	3.6

[1]No data available.

Table 4. Preburn and postburn fuel loading and forest floor consumption for the 1-m^2 plots.

Woody fuel size class (cm)	Preburn Weight (Mg/ha) Mean	S.E.	Postburn Weight (Mg/ha) Mean	S.E.	Consumed (Mg/ha)
0.0 - 0.6	4.0	0.3	0.1	0.0	4.0
0.6 - 2.5	17.5	0.8	1.8	0.6	15.7
2.5 - 8	21.3	0.8	7.2	0.9	14.1
8 - 15	15.5	0.7	15.5[1]	3.2	0.0
15 - 23	28.7	1.5	24.7	3.7	4.0
23 - 50	24.2	1.3	21.3	3.2	2.9
>50	11.2	0.6	11.2[1]	3.2	0.0
Total	122.4	6.0	81.8	14.7	40.7

[1] Because of fuel moving during the fire, the 8-15 cm and >50 cm size classes showed increases after the burn. The postburn values were set to the preburn amounts.

Table 5—Woody fuel consumption characteristics.

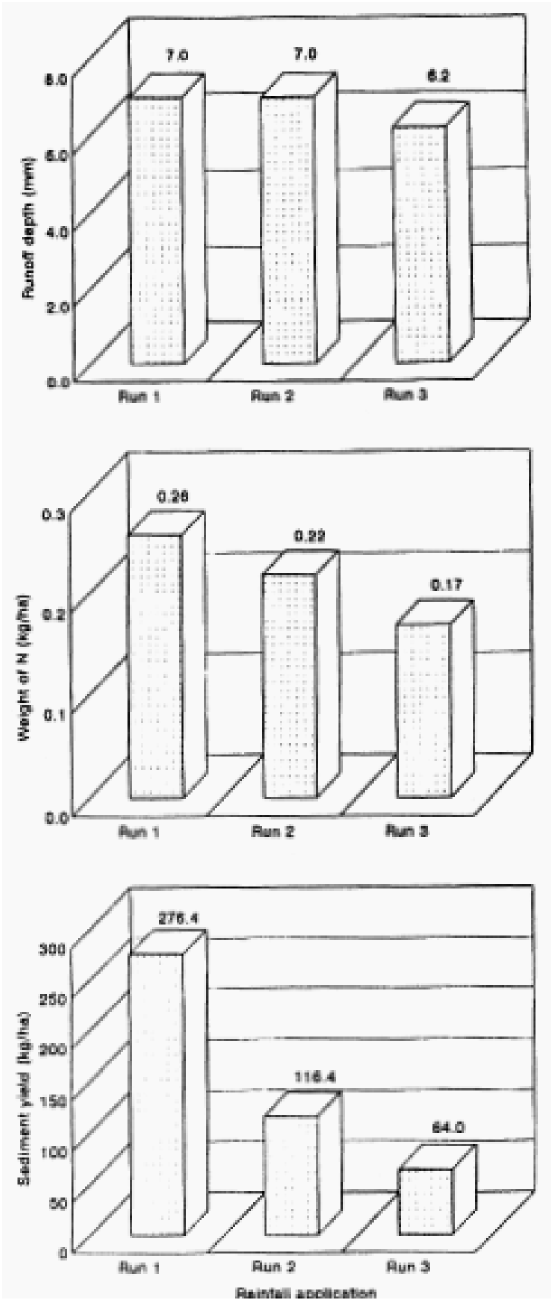

Figure 2 - Average runoff, total N in runoff, and sediment yield from the 1-m^2 plots.

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Moscow Forestry Sciences Laboratory
Rocky Mountain Research Station
USDA Forest Service
1221 South Main Street
Moscow, ID 83843

http://forest.moscowfsl.wsu.edu/engr/