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THE EFFECTS OF PRESCRIBED FIRE ON SOIL PROPERTIES

by

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I. INTRODUCTION

Over the last few decades, there has been increasing interest in the use of prescribed fire as a land management tool, both to return fire-type ecosystems to their natural state, and to reduce the hazard of wildfires. The revised Fire Management Policy adopted by the Forest Service" encourages land managers to make more use of prescription fire to protect, maintain and enhance the natural resource values and aesthetics within approved areas on the National Forest." (37)

The Society of the American Foresters defines prescribed fires as "the controlled application of fire to wildland fuels either in their natural or modified state, under such conditions of weather, fuel moisture, soil moisture, etc. as allows the fire to be confined to a predetermined area and at the same time to produce the intensity and spread needed to obtain planned objectives in fire management, silviculture, range management, wildlife management, etc."

Interest in using prescribed fire as a management tool raises questions as to the effects of prescribed fire on soil. Fire consumes organic matter and residues that eventually become soil organic matter. The organic matter can be totally removed or translocated depending on the intensity of the prescribed

fire (40). (See the next section for a discussion of fire intensity). Burning the surface organic matter reduces or removes the protective forest floor, volatilizes nitrogen and other elements, and transforms less volatile elements to soluble mineral forms that are more easily absorbed by plants or are lost by leaching or surface erosion. Heating the underlying soil alters physical and chemical properties of the soil that are dependent on the soil organic matter. It may cause the formation of a water repellant layer. The above processes often result in accelerated erosion and site degradation. The effects of prescribed fire reported in the literature are highly variable. The character of the soil, the topography of the area, the type of vegetation and amount of organic material present, the frequency, duration and intensity of the fires and the weather conditions following the fire must all be considered when assessing the impacts of prescribed fire on soil.

The main objective of this paper is to provide a detailed description of the on-site effects of prescribed fires on soil by discussing:

1. The characteristics of fire intensity
2. The effects on the chemical properties of soil, such as organic matter, pH, and nutrients.

3. The effects on physical properties of soil, such as structure, infiltration rate and capacity, water storage, and water repellancy.
4. The potential for surface, and mass erosion.

The information presented may aid in land management planning; and help improve the success and quality of prescribed burning programs, especially in relation to soil protection.

This paper represents the state of knowledge that is available at this time. Since the focus of this paper has been restricted to prescribed fire effects, careful selection of references was made to avoid complicating effects caused by logging, road building, grazing, or wildfires.

II. FIRE INTENSITY AND ASSOCIATED CHARACTERISTICS

Fire intensity is expressed in British thermal units (BTU's) per second per foot of fire front. It can be written as the simple equation $I = Hwr$, where I = fire intensity in BTU's/sec/ft of fire front, H = heat yield in BTU's/lb of fuel, w = weight of available fuel in lbs/ft^2 and r = rate of spread in ft/sec (10).

A low intensity fire in light fuels with low fuel moisture contents could have a heat yield as high as 6,500 BTU/lb of fuel (dry-weight basis). If the available fuel is 0.1 lb of fuel/ft^2, the fire intensity would be 26 BTU/sec/ft of fire front. Very few fires burning in forest fuels would have an intensity as low as 2 or 3 BTU/sec/ft of fire front. Most prescribed fires burning against the wind travel at a rate of 0.03 to 0.06 ft/sec. If the available fuel is 0.10 to 0.15 lb/ft^2 (2 to 3 tons/ac), their intensities would range from about 19 to 58 BTU/sec/ft. The burning zone would be less than a foot deep, and the flames about 12 to 20 inches high. The flame length would be around 2 1/2 feet.

Going up the scale of fire intensity, a fire spreading 0.25 ft/sec would have an intensity of about 160 BTU/sec/ft of fire front if the available fuel is 0.1 lb/ft and the heat yield

is 6500 BTU/lb. The flames would be 4 or 5 feet in length. This intensity is probably near the maximum for headfires that could be used in prescribed burning. Ordinarily, backing fires are used in prescribed burning (10).

Wildfire intensities will usually range from 100 to 1,000 BTU's/sec/ft^2. Flame lengths can be a few feet to up to 50± feet. In prescribed burning, it is usually desirable to have as low intensity fire as possible yet still achieve the resource management or fire management objectives. It is unfortunate that so few measurements of fire intensity have been made during prescribed burns, because whether effects on soils are adverse or not are so highly dependent on intensity of the burn.

The intensity of a fire can be determined subjectively by the appearance of the residual litter, soil and remaining vegetation after burning (40).

A low intensity burn scorches the litter and duff layer in spots but does not alter the layer over the entire depth. A lightly burned area would have less than 2 percent of the total area severely burned, less than 15 percent moderately burned and the rest lightly burned or non-burned. Less than 40 percent of the brush canopy remains. Irregular and spotty burning occurs and some leaves and small twigs remain on the plants either slightly singed or unharmed.

A moderate intensity burn chars but not ashes the litter and duff in spots. It does not visibly alter the underlying mineral soil. Less than 10 percent of the total area is severely burned, but over 15 percent is moderately burned. Between 40 and 80 percent of the plant canopy is burned by the fire and the remaining charred twigs are greater than 0.25–0.50 inches in diameter.

On severely burned spots all the organic layer is consumed and the mineral soil structure and color are visibly altered. More than 10 percent of the area has spots that are severely burned, more than 80 percent moderately or severely burned, and the rest lightly burned. After a severe fire, only ashes remain on the soil surface. The area is completely burned and the plant stems remaining are 0.5 inches or greater in diameter. In many cases, only charred remains of the large stubs of the main plant stems are left (40).

This same type of visual estimation has been used to classify burn intensity after chaparral fires in southern California (7). The visual appearance of the seedbed has been related to the soil temperatures generated during a fire. The lightly burned condition was characterized by charred leaf litter. Some greyish ash was present immediately after the fire but soon became inconspicuous. The maximum soil

temperatures during a burn producing "black ash" conditions were 177°C at the soil surface and 121°C at 0.3 inches downward in the soil. A moderate burn produced a "bare-soil" seedbed. Some charred material remained but was very sparse. The ash became inconspicuous soon after the fire. The maximum temperatures at the mineral surfaces were 399°C and 288°C at 0.3 inches. The most severely burned areas were characterized by a "white ash" seedbed. This was identified by a fluffy ash layer where large branches or main stems of trees or shrubs had burned. Temperatures at the surface exceeded 510°C and 399°C at 0.3 inches (7).

III. SOIL CHEMICAL PROPERTIES AND NUTRIENT CYCLING

Both soil chemical properties and nutrient availability are affected by fire soil properties affected by burning include organic matter, pH, cation exchange capacity, nitrogen, phosphorus, sulfur and divalent cations (19).

These properties are affected due to the burning and subsequent ashing of both the organic residues and the organic materials contained in the aboveground vegetation. The ash on the surface of the soil often alters the pH and the concentration of soluble elements. These elements can react with the soil or become dissolved in the soil solution following precipitation. Variable amounts of the ash can be lost from the site due to wind or water processes. Elements can be lost as soluble ions leaching into the soil and ultimately moving into the ground water (40).

A. Organic Matter

The soil organic matter consists of the surface layers, forest floor, litter or duff and organic matter incorporated with mineral soil. The organic matter in the soil improves aeration and water infiltration rates. In addition, the surface organic matter protects the soil from erosion by wind

and water. Organic matter on the surface and in the soil provides and retains nutrients. When fires, heat or burn the organic matter, various changes result (40).

The change in organic matter is a function of fire intensity. Many wildfires have sufficient intensities to destroy all the surface litter. This is contrasted by several prescribed fire studies where minor reductions of the organic matter were found. Periodic prescribed burns at 4-or 5-year intervals for 20 years in the South Carolina coastal plain caused no visible changes in the organic matter, except for the first year or two after burning (39). In Georgia's Piedmont loblolly pine stands it was found that prescribed burning did not remove all of the forest floor, and that under some conditions, a single burn removed only a small percentage of the litter (9). Light burning was found to cause no detectable change in the total amount of organic matter in surface soils (27).

In some studies, prescribed fire caused an increase of organic matter in subsurface soil layers. In South Carolina, prescribed burning increased the organic matter in the 0-2 inch layer of mineral soil, but had no effect in the 2-4 inch layer. Burning caused the redistribution of organic matter within the profile, but no actual reduction of organic matter occurred (39). Prescribed burning in loblolly pine in South Carolina resulted

in an increase of organic matter in the surface 4 inches of the burned plots (25).

In contrast to this, a loss in organic matter due to erosion was found to occur in California chaparral following prescribed fire. In the Los Padres National Forest, organic matter made up 5.6 percent of the debris leaving 50 percent slopes, and 10.9 percent of the debris leaving 20 percent slopes. There was more organic matter in the debris from the gentle slopes because the runoff water had less transporting ability and carried higher portions of the less dense organic matter. Despite the difference in the organic matter content of the debris, the steep slopes lost 88 lbs/ac (99 kg/ha) more organic matter than did the gentle slopes (16).

An additional factor associated with the alteration or loss of organic matter is a change in the cation exchange capacity. It can be decreased by burning and may remain low for at least one year because the exchange sites on the organic matter are destroyed (11).

B. Soil pH

Soil acidity in the upper soil and ash layers is reduced by burning as a result of an excess of basic cations (K^{+},Ca^{++}, Mg^{++}) over anions (PO_4,SO_4) in the ash (40). The

cations are released by the combustion of organic matter, and the chemical effects of heating on organic matter and minerals. The soil pH is raised temporarily, depending on the amount of ash released, the original soil pH, the chemical composition of the ash and the wetness of the climate (39,11).

Burning tends to change the acidity of a highly buffered clay soil high in organic matter less than if the burning occurred on sandy soils low in organic matter (40).

Soils are highly variable in chemical properties, and the release of relatively large amounts of basic elements by fire would not significantly change the soil if it were already rich in those elements (40).

C. Nutrient Changes

When organic matter is consumed by fire, the nutrients from the leaves, twigs and stems are left in a highly soluble form in the ash. Thus, the nutrients are readily available for plant growth, but are also susceptible to leaching and surface runoff (21,15). Burning materials high in a mineral element increases the concentration of that element in the soil. Conversely, burning the same amount of material low in that element may not measurably change the element in the soil (39,40).

After a prescribed fire, there often are trends toward higher concentrations of (N,P,K,Ca, and Mg in the upper few inches of mineral soil and a decrease in those elements in the forest floor. The immediate flush of those elements following fire is followed by a slower release (40). Mineral elements and N increased in the surface 4 inches after burning in loblolly pine in South Carolina (25). A study on burned and unburned soil under chamise showed the concentration of acetate-soluble sulfate, K, P, total N, ammonia N and nitrate N were higher in burned soils (11). Prescribed burning of mature pine in South Carolina resulted in small increases in N, P and exchangeable Ca and Mg in the surface 2-4 inches of mineral soil (39).

D. Nutrient Losses

Increased nutrient losses from burned sites are caused by several mechanisms. Soil nutrients may be lost by leaching, water erosion, wind erosion or by volatilization. Volatile elements (N,S,P,Cl) are lost when burning temperatures exceed the temperature of volatilization. N and S are most important because they are often the limiting factor in many ecosystems. They also have a low volatilization temperature. Surface erosion removes nutrients closely associated with organic

matter (N,P,S), while mass erosion removes the entire soil with its nutrients. Surface erosion causes greater nutrient losses because it affects larger areas. Leaching losses of cations depend upon the formation of mobile anions HCO_3, NO_3, SO_4, and organic acids in solution. Cation losses will remain high until anion concentrations are lowered by physical and biological processes on site (40).

After prescribed burning in chaparral in the Los Padres National Forest, plots with 50 percent slopes lost larger amounts of nutrients during the first rainy season than did plots on 20 percent slopes. The nutrients loss included N, P, Ca, Mg, K and Na. Most of the nutrients lost were in the debris with smaller amounts lost in the runoff water. The nutrients removed with the debris were probably contained in the organic matter. Immediately after the fire, the nutrients lost represented less than 6 percent of the total nutrients found in the upper 0.79 inches of the soil and litter layer (15,16).

Nitrogen is the main nutrient lost during fires, and if a replacement mechanism such as biological N fixation is not present, site quality would decrease in areas subjected to repeated fires (40). Measurements taken before a prescribed burn in chaparral in the Los Padres National Forest showed that about 132 lbs/ac (150 kg/ha) of nitrogen were contained in the

litter (16). Most of this N would be volatilized during an intense fire. N loss during a fire of moderate intensity could account for 75 percent of the N in the litter. In the upper inch of soil, only small amounts of N would be lost. During light intensity fires, less than 50 percent of the N at the soil surface is lost (16).

Although total N is lost during a prescribed burn, higher concentrations of N and other nutrients have been reported on burned areas than on unburned sites. This contradiction occurs because N is expressed in concentration, rather than in amount per unit area. If N is based on ash material remaining after fire, then the concentration will increase; but if this same amount of N is based on the initial weight of unburned material, then percent N is usually decreased by fire. Another reason N appears more abundant after fire is because N availability increases, and plant growth is much more rapid. Total N on the site, however, may have decreased (19).

IV. SOIL PHYSICAL PROPERTIES

The degree that soil physical properties are influenced by fire depends on the intensity of the fire, the amount of the overstory and understory vegetation removed, forest floor consumed, soil heating, proportion of the area burned, fire frequency, topography, condition of the soil, and climate.

The effects of fire lessen overtime. The duration of effects varies from one season to many decades, depending on the extent of the fire and the rate of recovery as influenced by natural conditions, post fire use and remedial measures applied by man (40).

A. Soil Structure

Soil physical properties change when organic matter is altered or destroyed during burning. Organic matter improves the aggregation and structure of soil by binding individual soil particles together. The creation of large pores allows better water penetration and aeration. When organic matter is destroyed by fire, soil structure also deteriorates (19).

The majority of prescribed fire studies indicate that the fires were not intense enough to produce direct effects upon the structure of the soils. The exception to this is where complete removal of litter and subsequent exposure of mineral

soil to rain results in puddling and baking of the surface (40).

B. Infiltration Capacity

Where organic layers of the forest floor are removed and mineral soil exposed, infiltration may be immediately reduced (40). A study of infiltration rates on seven types of soils revealed that burning reduced infiltration rates 38 percent, compared to an 18 percent reduction when litter was removed by raking (6). Infiltration on land prescribed burned annually was one-fourth the rate on unburned land (23). At North Fork, California on the central Sierra foothills, repeated burning of mixed chaparral and woodland progressively decreased the infiltration capacity of the soil during the first years of the experiment. It took more than three years after burning to bring the infiltration capacity up to levels high enough to cope with rain rates associated with heavy storms (29). Water repellancy in the upper layers of the soil causes reduced infiltration (21).

If sufficient organic matter remains after burning, infiltration rates can be maintained. At Hoberg's in the Coast Ranges of Northern California, partially decomposed duff and debris remaining after prescribed burning of second-growth ponderosa pine were effective in maintaining high infiltration capacity (8).

C. Water Storage

Prescribed fires may increase, decrease or have no effect on soil water storage depending on the amount of canopy removed, the amount of litter remaining, the invasion of vegetation after fire, and the formation of water repellant layers. Where much of the overstory foliage is destroyed, interception and evapotranspiration will be reduced, resulting in increased soil water storage (3). In brushfields of Northern California at the end of the first dry season after burning, more water remained in the lower soil depths in the burned plots than in the adjacent unburned plots (1). No difference in relative moisture holding capacity of the humus layers was found in burned and unburned soils, as long as they were similar in content of incorporated mineral matter (13). Soil moisture in the upper 3–12 inches of soil under chaparral was depleted more rapidly on burned than on unburned soils due to its removal by invading weeds, root sprouts, and evaporation. At depths beyond the reach of vegetation, burned plots had more moisture than unburned plots. After summer drought, the upper levels of the soil on both the burned and unburned plots had the same moisture (31). Fire reduces the capacity for soil–water storage when humus layers and organic materials in mineral layers are burned, or when soil exposure increases the oxidation

of organic matter by solar radiation. When an overlying 2-inch layer of humus has been destroyed, the total reduction of the water storage capacity was found to be about one (1) inch (5). Soil water storage also may be reduced by fire-induced repellancy in the surface soil (20).

D. Water Repellancy

Some soils are naturally repellant, while in other soils, repellancy is induced by fire. Soils which resist wetting during rainfall yield greater overland flow and readily erode. Water repellancy is indicated when water droplets form beads on the soil surface that do not penetrate for at least 5 seconds (34).

The mechanism of water repellancy has been discussed by many scientists. This phenomenon is caused by organic materials, mainly aliphatic hydrocarbons, which coat soil particles and reduce the attraction between water molecules and soil particles (34). Organic substances in the litter layer or in the mineral soil are vaporized during hot fires. Some of the vaporized material is lost to the atmosphere, but part of it migrates downward along steep temperature gradients. It condenses in cooler soil layers where it causes water repellancy (17). The substances condensing in the cooler soil are possibly pyrolytic products of the heated litter layer rather

than organic materials translocated after volatilization (33).

Studies relating to the formation of water repellant layers in soils have provided much useful information. One study, for example, showed that after burning, heat moves down through underlying sand, "fixing" some of the more polar hydrophobic substances and revolatilizing the less polar substances, broadening the repellant layer. The surface temperature required for "fixing" and revolatilization is greater than 250°C (32). Relatively cool fires cause water repellancy in the surface layer, while hot fires produce repellancy at a greater depth. Under hot fires, the surface layer is completely wettable. Organic matter decreases at higher temperatures due to volatilization and subsequent loss to the atmosphere. The volatilized material causing water repellancy is completely lost above surface temperatures of 270°C. Below this temperature, enough material is trapped and condensed on exchange sites to produce water repellancy (34). (The section on fire intensity presents an example of soil temperatures generated during different intensity fires.) The formation of a water repellant layer in the underlying soil increases as percent silt and clay decrease. The effect of texture on water repellancy is attributed to differences in specific surfaces of the soils. The degree of water repellancy was found to increase as the amount

of translocated organic matter increased in a given soil (18).

Soil water affects the translocation of organic substances by altering the temperature gradients in soil during a fire. The nature of the particle surface is also modified by soil water. Therefore, prescribed burning should be done when the soil is moist in areas where repellancy is a problem (20). Soil erosion due to water repellant layers may be the most serious problem associated with it. Two ways in which prescribed burning can be used to lower the possibility of hazard from soil erosion caused by repellancy are suggested:

1. burning of dense brush fuels when the soil is wet and heat penetration into the soil is minimal; and
2. conversion of brush cover to grass having a much lower fuel volume and limited heat production when burned (22).

V. EROSION

The effects of prescribed burning on erosion depend on the severity of the burn, the erodibility of the soil, the potential for recovery of the vegetation, and the kinds of storms that follow the fire (5).

The process of erosion often begins with increased overland flow. Overland flow occurs when the infiltration rate or capacity of a soil has been exceeded by the amount of incoming precipitation. Independent variables include all the soil and plant factors that influence infiltration rate, intensity and duration of the rain, and the steepness of slope (40). In northern Mississippi, prescribed burning on steep slopes caused increased overland flow. The most significant changes occurred on loess soils, the least on sandy soils. Small changes in vegetation cover could greatly influence hydrologic responses of small headwater basins. Stormflow responses were related to the presence or absence of a fragipan (35,36).

A. Surface Erosion

Surface erosion includes sheet erosion and rilling. It can be defined as the movement of individual soil particles by wind or water. It is a function of forces available, protection of the soil surface and the erodibility of the soil. Fire

increases the available forces by increasing effective precipitation, wind movement, and overland flow. Protection of the soil surface is reduced by losses of surface litter. Soil erodibility is increased because of the destruction of soil aggregates and the volatilization of soil organic matter. The net effect of burning is toward increased surface erosion (40). When overstory trees, surface vegetation and forest floor are completely destroyed by fire, high-intensity rainfall usually produces great quantities of sediment (5).

Surface erosion is often caused by prescribed burning of various forest types. Sediment yields increased by burning mixed conifer forests in the South Sierra Nevada. The increases in sediment were highly correlated to a decrease in the forest floor (2). Significant increases in erosion were found following prescribed burning of ponderosa pine on basaltic soils on 35 percent slopes in the Fort Apache Indian Reservation in Arizona (13). In the Payette National Forest in Central Idaho, the effects of fire on erosion on loose granitic slopes was evaluated in relation to burn intensity, and slope gradient. Erosion increased with both slope gradient and burn intensity (12).

Several references are available which cite erosion following prescribed burning of chaparral. Annually burned plots of woodland chaparral in central California produced 249,165 lbs/acre (113 tons) in 9 years. Twice burned plots yielded 8820

lbs/ac (4 tons). The erosion accompanying the increased run-off was due to the reduction of infiltration capacity and to the intensity and duration of the rainfall (30). The first year after a prescribed burn of chaparral in the Los Padres National Forest, 2.6 times more surface erosion occurred on 50 percent slopes than on 20 percent slopes. On the 50 percent slopes, about 35 times as much erosion occurred on the burned areas as on the similar unburned sites. The erosion rates for the burned and unburned sites were 6,500 and 186 lbs/acre respectively (15). Chaparral in Arizona was strip burned after treatment with a herbicide. Erosion was greatest on steep slopes adjacent to main channels; however, lightly burned areas with 70 percent or more litter had slight or no erosion. Areas with less than 60 percent litter remaining had moderate erosion during periods of high precipitation. The average sediment movement during the 5 year period of study was 2394 lbs/ac (695 tons/mi^2) (26). The first winter after burning of woodland chaparral at North Fork, in the central Sierra foothills of California, annually burned plots yielded greater than 5,000 lbs/ac of eroded soil. In the next 8 years, annual erosion ranged from 148 to 171,000 lbs/ac. Plots burned at 6-year intervals yielded 5000 lbs/ac the first year and smaller quantities the next 3 years (29). The effect of chaparral burning on

erosion was studied at the Chamise Experimental Pastures in Northern California. The average results of the study were that soil movement was significantly greater on burned areas than on unburned areas, and that greater erosion occurred per unit increase in slope the first year, followed by lesser soil loss in proportion to the number of years after the fire. The amount of soil movement was directly related to slope; i.e., the steeper the slope the greater the erosion. The same results were found in a similar study near Ukiah on the North Coast of California (31).

In contrast, initial and repeat prescribed burning did not increase soil movement as shown in one study in the Georgia Piedmont. The burning was done on the Hitchiti Experimental Forest, where erosive soils on 10–20 percent slopes support a loblolly pine forest. It was concluded that the degree of slope, the ground surface disturbance, the amount of protection rendered by the overstory canopy and the amount of litter left on the site are key factors in erosion on Piedmont forest sites (9). Similarly, one prescribed burn in a Piedmont pine communities in the Sumter National Forest in South Carolina did not have a measurable effect on soil movement in 25 established gullies (14). Most studies in the Southeastern Coastal Plain conclude that periodic prescribed fire has little impact on soil

physical properties that affect infiltration rates or erosion. Large pore space may decrease and percolation may slow with short interval (1 to 2 year) burns, but erosional consequences are negligible (40).

In western United States, it was found that where the forest floor depth exceeded 0.51 inches (1.3 cm), erosion is adequately controlled (28). Sufficient litter was left after prescribed burning of ponderosa pine at Hoberg's in the coast ranges of Northern California to prevent observable erosion on 43 percent slopes (8). On the Fort Apache Indian Reservation in Arizona, the first prescribed burn led to no observable accelerated erosion (38).

B. Mass Erosion

Mass erosion is the downslope movement of a portion of the landscape caused by gravitational forces. The principal elements responsible for mass erosion in most areas are elimination of stability provided by roots of vegetation and high soil pore water pressures resulting from the removal of transpiration draft. Mass movement either develops or is accelerated during periods of abnormally high rainfall (40). Massive soil slips are likely to occur on steep slopes following the removal of chaparral by fire. Chaparral has deep tap roots, and when it is

killed by repeated fires, erosion removes the ash and top layers of the soil. This results in the thinning of the soil mantle and the reduction of site productivity. The only kind of vegetation that can exist under these conditions is that with shallow roots. Shallow roots do not have the capacity to hold soil as well as deep tap roots, thus landslides result (24).

Debris production from chaparral seems to be a two-phased process. After fires, erosion from sideslopes is primarily gravity activated landslides and dry ravel (4). Dry ravel or dry creep occurs on steep slopes with soils that are high in coarse materials and low in cohesion. Removal of protective litter by fire allows the soil particles to easily move downslope under the influence of gravity (40). On steep slopes, dry ravel may occur during and after fire, even before the start of the rainy season. Dry ravel from steep unburned chaparral slopes can amount to about 200-3,800 lbs/acre. This amount can significantly increase after fire (4).

In addition, soil nonwettability has been identified as an important contributing factor in debris flows (40).

VI. SUMMARY

The change in organic matter during and following fire is a function of fire intensity and erosive forces. Some studies found no visible change in organic matter following prescribed fire, while others found an increase of organic matter in subsurface layers. One study reported a substantial loss of organic matter due to runoff and erosion. Burning was found to decrease the cation exchange capacity due to the loss of exchange sites on the organic matter.

Depending on the concentration of basic elements in the soil, burning can cause the pH to increase. The change in pH is more pronounced in sandy soils than in clay soils high in organic matter.

Soil nutrients (P,K,Mg,Ca) in the upper layers of the soil are increased immediately after fire. Volatile elements (N,S,P, Cl) are lost when burning temperatures exceed the temperature of volatilization. Surface erosion removes nutrients closely associated with organic matter and soil debris (N,P,S,Ca,Mg,K, Na). Nitrogen is the main element lost during fires.

Some soil physical properties can be affected by prescribed fires. According to the studies reported, most prescribed fires are not intense enough to affect soil structure, except where

the litter is completely removed and intense rainfall causes compaction of the soil. Infiltration capacity is generally reduced by fire and can remain so up to 3 years following a fire. Soil water storage is often decreased in surface soils, but is increased in subsurface layers due to reduction in vegetation draft. However, if 2 inches of humus is destroyed, the total reduction of water storage capacity is 1 inch. The formation of water repellant layers can cause a reduction in infiltration and soil water storage. This leads to increased overland flow and subsequent erosion. Cool (low intensity) fires cause repellancy in the surface layer of soil. while hot (high intensity) fires produce repellancy at greater depths. No repellancyis produced if surface temperatures exceed 270°C during the fire. The thickness of the repellant layer decreases with increased soil moisture, and increases as the percent silt and clay decrease.

The net effect of prescribed burning is towards surface erosion. The degree of erosion depends upon the fire intensity, the amount of vegetation and litter removed, soil type, slope, and the formation of non-wettable layers. Generally, on slopes greater than 30 percent, erosion can be expected unless sufficient litter remains after the fire to protect the soil. Mass

erosion can occur on steep slopes following prescribed fires if all the vegetation is destroyed. Chaparral areas have significant soil loss due to dry ravel following fires.

VII. CONCLUSIONS

Prescribed fires can adversely affect land productivity and soil stability. Intense fires volatilize nutrients, destroy organic matter, disrupt soil structure and may cause water repellancy. These effects can subject the soil to accelerated erosion and cause site degradation. However, low intensity fires aid in nutrient cycling, do not affect soil structure and generally don't increase soil erosion.

The factors which must be considered when planning prescribed fires and when assessing the impacts of fire include:

1. the character of the soil
2. the topography of the area
3. the type of vegetation and amount of organic material present
4. the frequency, duration and intensity of each fire

When planning a prescribed fire, it is important to make a decision concerning the desired fire intensity which will achieve the management goals, yet minimize adverse effects. Once the fire intensity is chosen, measurements should be taken during the prescribed burn. The results of the fire can then be correlated to the fire intensity. This process would provide valuable information to be used when planning the next prescribed fire.

A very important area that is not covered in this paper is the off-site effects of prescribed fire. The reduction of infiltration capacity, soil water storage, and the formation of water repellant layers lead to increased runoff, surface erosion and mass wasting. These processes as well as loss of nutrients can result in serious impacts offsite. The impacts may include deposition of soil and debris downslope, stream eutrophication, increased turbidity, channel alterations, reservoir sedimentation, and reduction in water quality and stream habitat. There is a need for papers addressing these issues, for proper land management should include an assessment of the off-site as well as the on-site effects of prescribed fire before it is used as a major land-management tool.

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