THE EFFECT OF LOGGING AND SLASH BURNING ON CERTAIN PHYSICAL PROPERTIES OF FOREST SOILS

by

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INTRODUCTION

At the present time land management on municipal watersheds in the Pacific Northwest varies considerably from place to place. There are examples ranging from full multiple use management (Seattle's Cedar River watershed), to complete isolation and protection (Portland's Bull Run watershed). Forms of use now existing on the Seattle watershed include sustained yield forest management with logging by private operators and limited recreational use to prevent overpopulation of wildlife, as well as power production and railroad use. These activities are regulated to assure the protection of a continuous supply of good quality water. At the other extreme is Portland's watershed which is almost completely undisturbed. The public is excluded and the over-mature timber is allowed to decay on the stump because it is feared that any logging disturbance may indirectly cause pollution of the water supply. This variation in management may be attributed partially to the varied ownership pattern. In some cases the watershed area is owned either partially or entirely by the municipality which is dependent upon it for its water supply. In most cases, however, the watersheds are within National Forests or are a part of the holdings of numerous private companies.

The Corvallis watershed is currently being used as a demonstration area providing an example of a watershed which has been placed under multiple use management. Prior to 1951 the area was protected from disturbances of all types and its only value was as a constant water supply. Since 1951 the watershed has supplied timber as well as water, despite the many individuals who question whether logging should ever be permitted on a municipal watershed such as the Marys Peak area. Many, in fact, have expressed the opinion that the economic loss due to stream siltation may far outweigh any gain which results from harvesting the timber.

It was the purpose of this investigation to determine what effects logging and slash burning have had on the properties of the surface soil which may influence its susceptibility to erosion. The work was carried out on the Corvallis watershed in cooperation with the Pacific Northwest Forest and Range Experiment Station and the Siuslaw National Forest, as one of a series of current studies concerned with determining the effect of broadcast slash burning on soils of the Douglas-fir region.

Although the site for this study was limited to the Corvallis watershed, its results are generally applicable to other soils belonging to the Reddish-Brown Latosol great soil group in the Oregon Coast Range. The degree to which the results of this study can be applied to other soils of the same group will depend, however, on certain variables such as the nature of the slope, the size of the timber to be cut, and the method of logging and slash burning.

LITERATURE REVIEW

The investigations of the effects of logging and slash burning on the soil have, in the past, largely dealt with chemical properties. Until Tarrant's (57, 58) recent work in Washington and Oregon the changes in soil physical conditions brought about by these activities had received little attention except where they pertained to seedling establishment and growth. In addition to reviewing the work done on the effects of fire and logging, papers concerned with watershed erosion research and the physical soil factors controlling erodability will also be covered in this literature review.

Tarrant (59, pp. 2, 5) has classified the soil surface condition following slash fires into three main categories: (1) unburned, (2) light burn, "That condition in which fire had charred the surface of organic litter but had not removed all litter from the soil", and (3) severe burn, "Defined as that condition in which fire had removed all organic litter from the ground surface and in addition had baked the mineral soil to a highly colored crust." He emphasizes that a slash fire does not burn everywhere with equal intensity and that much of the area may not be directly affected. Further work by Tarrant (60, pp. 2-3) showed that the marked changes in soil color characteristic of severe burns are caused by temperatures ranging from 900 to 1200° F. Isaac and Hopkins (29, pp. 266, 268, 278), working on some forest soils in the Douglas-fir region, found that rain falling on severely burned areas had a tendency to puddle the surface and reduce its capacity to absorb water. They concluded that slash fires had no effect on the texture of the soil but that they did greatly alter the structure of the surface layer through elimination of organic matter and breakdown of the colloidal materials. They stated that the harm done by the ordinary slash fire far outweighs any beneficial effects and that this harm seems to be roughly proportional to the completeness with which the fire consumes the organic matter in the surface soil. Isaac (28, p. 50) has calculated that it takes five years of weathering to restore normal soil structure, and much longer for the restoration of the pre-burn level of organic matter. Austin and Baisinger (5, p. 276), working in western Washington and Oregon, noted that the moisture holding capacity of the top one-half inch of the soil was consistently lower following burning. The reduction averaged 33.7 per cent. Lower soil moisture holding capacities following slash burning have also been reported by Isaac and Hopkins (28, p. 50, 29, p. 271).

Tarrant (58) has investigated some of the effects of prescribed burning on soil physical conditions in the ponderosa pine type in eastern Washington. His study is among the first in the Pacific Northwest to deal exclusively with the effects of fire on the physical properties of soil. Using undisturbed core samples, he found a definite increase in percolation rate and macroscopic pore space of burned soils over soils from non-burned areas. The microscopic pore volume of the soil decreased with burning, while the total pore volume remained unchanged. He concluded that the prescribed burning definitely benefited certain physical conditions of the soil. Tarrant (57) obtained similar results in a study of the effects of slash burning on some soils in the Douglas-fir region. Scott (55, p. 68) compared the relative infiltration rates of six burned and unburned upland soils in five different California counties. He found that the relative infiltration rates of the burned soils were higher in every case than those of the unburned soils and that this condition persisted, with one exception, for at least a year.

Most workers agree that one of the most harmful effects of fire is the loss of large amounts of organic matter from the soil. Since organic matter increases aggregation, such losses may be critical from the standpoint of erosion hazard. Austin and Baisinger (5, p. 276) report that 75.5 per cent of the total organic matter in the top one-half inch of soil was removed during a slash fire. Barnette and Hester (7, p. 283) have found that yearly burning of forest and cutover lands in Florida results in an annual loss of almost 3,000 pounds per acre of organic matter. Fowells and Stephenson (22, p. 180) in a study of slash burned areas in western Oregon, found that the humus content of the soil was low in the surface inch and increased with depth. On unburned areas, the reverse was true; the humus content of the soil surface was high and decreased with depth. Youngberg 64, (pp. 202-203) also noted a significant decrease in soil organic matter content of the top three inches of soil following a fire. Only one example of an increase in soil organic matter following burning was noted in the literature. Greene (24, p. 820) working in longleaf pine, analyzed soils taken after eight years of annual grass burning and compared them with soils from areas completely protected from fire. The results of this comparison showed 1.6 times as much organic matter in the burned over soils as in the protected soils.

Since 1942 the trend in the Pacific Northwest has been toward burning slash after a rain, the purpose being to decrease the amount of soil organic matter consumed. The usual practice was to burn at the end of the long dry season prior to rain in an attempt to obtain a complete burn. Aufderheide and Morris (4, p. 80) maintain that slash burning when the duff is still wet results in complete litter and duff removal only in small areas beneath logs or concentrations of slash.

Vegetative succession following burning in the Douglas-fir region has been noted to follow a fairly uniform pattern. In an extensive study of fifteen clear cuts in Oregon and Washington Isaac (27, p. 720) suggested four main successional stages: (1) a moss-liverwort stage persists only into the first growing season following logging and burning, (2) the weed-brush stage then occupies the area until it is over-topped by an even-aged stand of Douglas-fir, (3) an intolerant, even-aged Douglas-fir stage persists until it is replaced, when fully mature, by an all-aged hemlock-balsam fir forest, (4) the tolerant all-aged hemlock-balsam fir forest stage is the final phase of the successional pattern.

Since the multiple use of timbered watersheds is a comparatively new concept in the Pacific Northwest, the soil problems caused by timber harvesting have received very little attention despite the fact that soil conditions are of utmost importance in such critical areas.

One example of a well-managed multiple use watershed in the Pacific Northwest has been described by Thompson (61, p. 204). The city of Seattle's Cedar River watershed has, for some time, been open to timber harvesting operations despite a divergence of opinion as to the advisability of continuing logging within the watershed. Recently an expert commission reported on the results of their study on the effect continued logging would have on the quality, quantity, and purity of Cedar River water. Thompson summarized the findings of this committee as follows, "Logging practices on the watershed in the past have had no important or discernible effect on precipitation, runoff, and quality of water, nor have they produced appreciable erosion of the watershed. The controls required on the water supply for the protection of the consumer against potential or actual sanitary hazards will be required whether logging is or is not practiced in the future."

The question asked most often concerning logging on timbered watersheds is whether or not the resulting soil disturbance will result in a serious increase in stream turbidity. Lieberman and Hoover (33, pp. 1-3) have reported on some important work at the Coweeta Hydrologic Laboratory in North Carolina which has supplied information relative to this problem. These studies showed that when the trees were removed from a watershed area with little or no soil disturbance there was an increase of 65 per cent in water yield with no appreciable increase in stream turbidity. Timber removal by conventional logging methods, however, resulted in a decided increase in stream turbidity and sedimentation which was attributed to the soil disturbance. In another study reported by Lieberman (32, pp. 450-451) a drainage area at the Coweeta Laboratory was severely burned in an attempt to ascertain the effects of fire on the rainfall-runoff relationships. It was found that there were no significant increases in surface runoff or soil erosion, however, there were indications that repeated burnings would lead to a breakdown of the soil structure and a consequent increase in erosion.

In certain areas of the west soil erosion on watersheds has been an important and difficult problem. This has been especially true of drainages supporting rangeland or chaparral vegetation. Consequently, most research work has been carried out in these areas. In 1941 Fletcher and Beutner (20, pp. 7-9) conducted an extensive investigation on the soils of the upper Gila watershed of Arizona and New Mexico in an attempt to pinpoint some of the factors which had contributed to the serious erosion in that area. Their work on soils of the Gray Desert and Brown great soil groups revealed that granitic soils eroded much more readily than did soils developed on basalt, and that coarse-textured soils were more erodable than soils having fine texture. They also asserted that compactness was an important factor, as loose topsoil was noted to erode much more readily than firm topsoil. Renner (52, pp. 12-17) also noted the higher erodability of granitic soils during an erosion survey on the Boise River watershed in Idaho. He attributed it to the scarcity of colloidal material in the soil. When erosion was correlated with slope and aspect it was found that there was a marked variation in erosion depending on the directions the slopes faced, and that erosion increased with slope up to 35 per cent and then decreased. Renner discovered that four-fifths of the south-facing slopes were eroded, while erosion on the north slopes was only one-half as prevalent as on the south slopes.

Many workers have emphasized the importance of vegetative cover in controlling erosion on mountainous slopes. Craddock and Pearse (16, pp. 8-10) found that the type of range cover present had a pronounced influence on surface runoff from a mountain soil in Idaho. Their work showed rainfall intensity, steepness of slope, and soil disturbance to be of secondary importance in influencing runoff. In a U. S. Department of Agriculture research progress report (62, pp. 35-42) reporting on the chaparral watersheds of southern California, it is stated that if summer fires remove the vegetation semi-torrential rains during the subsequent fall and winter seasons cause serious erosion. Lowdermilk (34, p. 3968) maintains that accelerated erosion is caused by an increase of erosion potential as a result of the removal of controls exercised by a mantle of vegetation. As evidence for this conclusion he cites the results of several field plot studies conducted in California. These tests revealed that removal of vegetation by burning significantly increased the surficial runoff and hence caused erosion.

The protective influence of surface litter produced by the vegetative cover is also important in controlling runoff and erosion. Lowdermilk (35, pp. 482-483) was among the first to recognize the importance of litter, establishing its role in erosion control by means of several field experiments initiated in 1927. Litter removal by burning resulted in consistently greater surface runoff than came from the litter-covered surfaces. He found that the differences in amounts of eroded material were of greater magnitude than the differences in runoff. Lunt (36, p. 34) compared the structure of soils with and without litter cover and found that litter removal had resulted in significant soil compaction. The compaction was greater in the first inch, but was also evident in the second two inches. Johnson (30, p. 520) performed various tests on sandy soils in Colorado and reports that litter removal reduced the infiltration capacity by more than one-third. Arend (3, p. 727) found a corresponding decrease in infiltration rate due to litter removal. Dunford (18, p. 927) found that removal of pine litter from an area previously not subject to erosion caused serious erosion to occur on three occasions during the first summer.

The physical properties of soils affecting erosion may be conveniently divided into two main categories: (1) those factors which influence the amount of runoff, and (2) soil properties which determine its susceptibility to removal by runoff. Baver (9, pp. 51-52) suggests that the soil's absorptive capacity for water and the permeability of the soil profile are the two most important factors affecting runoff. He also states that the factors affecting the movement of the soil are ease of dispersion, size of the particles, and the degree of aggregation. Besides these inherent soil properties there are several so-called environmental factors which have a controlling influence on erosion. Some of the most important are: amount and intensity of rainfall, amount and nature of vegetation, degree of slope, and area.

Since the literature dealing with factors influencing runoff is unusually abundant, the review which follows is by no means exhaustive. Hendrickson (25, pp. 504-505) added both clear water and water plus a clay suspension to plots and noted the resulting infiltration. When clear water was added to a plot runoff remained at a minimum, but when water plus clay was added infiltration decreased and excessive runoff was induced. He concluded that soil not protected by a vegetative cover is exposed to the beating effects of rain which tends to disperse soil material into suspension, thus clogging the natural porosity of the soil. Auten (6, pp. 1004-1005) compared the rates of water absorption on undisturbed forest soils and adjacent open field soils. He reports that the forest soil absorbed fifty times more water per minute at a depth of one inch than did the field soil. Diseker and Yoder, Conner et al., and Neal (17, pp. 10-14, 15, pp. 22-25, 45, p. 27) all agree that a high initial soil moisture content results in an increased amount of runoff if the rainfall is of sufficient duration. These workers also place considerable importance on the rainfall intensity in determining the amount of runoff. Neal (45, pp. 33-37) calculated that rainfall intensity had three times more effect on erosion than did the slope of the land. He concluded that it was, by far, the most important factor affecting runoff and erosion in his experiments.

In the past there has been considerable work done to identify the soil properties controlling the amount of soil erosion for a given amount of runoff. The degree to which silt and clay form water-stable aggregates appears to be one of the most important factors causing variations in the erodability of different soils. Lutz (38, pp. 443, 455) compared the physical and chemical properties of an erodable soil with those of a soil which was non-erodable in an attempt to isolate those factors causing the difference in the amount of erosion. He concluded that the difference in erodability was due primarily to the degree of aggregation of the finer particle fractions. He also found that the aggregates larger than 0.25 millimeters in diameter were resistant to erosion, while aggregates smaller than this size were frequently carried off. Baver and Rhoades (10, p. 929) stressed the importance of having the soil in the natural moist condition to obtain the best results in aggregate analyses. They maintained that when a soil is air-dried the whole system is dehydrated resulting in the formation of temporary aggregates. Yoder (63, pp. 340-346) recommended the opposite procedure in suggesting that the samples be allowed to approach air-dryness prior to the analysis. He also stated that, in the case of a structural soil, it is the aggregates rather than the textural separates which are primarily involved in the erosion process. Middleton (42, pp. 3-6) noted that non-erodable soils were low in sand and high in colloidal material and iron and aluminum sesquioxides. The erodable soils that he worked with were low in clay and high in sand. Middleton et al. (44, p. 19) found no general relationship between the erodability of the soils tested and the chemical character of their colloids. They concluded that erosion is probably affected more by the quantity than the kind of colloid. Several workers (38, p. 444; 40, p. 18; 42, p. 13) have suggested that the erodability of soils may be either directly or indirectly affected by the relative amount of iron and aluminum present. It has been stated as a general rule that soils possessing a low silica-sesquioxide ratio are non-erodable.

Several formulas for determining the relative erodability of a soil using laboratory data have been proposed. In 1930 Middleton (42, pp. 2-3) introduced the dispersion and erosion ratios as indexes for determining the approximate erodability of the soil. The dispersion ratio is defined as the ratio of silt and clay in suspension after a given settling time to the total weight of silt and clay in the sample. The erosion ratio is calculated by dividing the dispersion ratio by the ratio of per cent clay in the soil to the moisture equivalent. Middleton classifies soils possessing an erosion ratio of over ten as erodable. Middleton et al. (44, p. 18) have asserted that the erosion ratio is the best single index of erosion, and that where field information is lacking the erosion ratio is a fair guide to the behavior that might be expected. Lutz (38, p. 444; and 40, p. 8) criticized the erosion ratio as being too empirical. He questions the validity of the assumed relationship between the colloid-moisture equivalent ratio and soil erodability. He receives the dispersion ratio more favorably, however, and maintains it should give a better index since it measures the stability of aggregates under the influence of moving water. Bouyoucos (11, pp. 738-740) has introduced the clay ratio as a simpler method for determining the relative erodability of soils. He compared this ratio of sand and silt to clay to Middleton's erosion ratio and found that the results were quite similar. Middleton et al. (43, pp. 14-15) also suggested a percolation ratio which was based on their observation that in easily dispersed soils the muddy percolation water closed the water passageways with deposits of silt and clay. This ratio is calculated by dividing the suspension percentage by the ratio of per cent colloid to the moisture equivalent.

In view of the important role of soil aggregation in determining erodability, the various factors influencing aggregation have received widespread attention of soil scientists. Browning (13, p. 88) added organic matter to several different soils and found that this treatment increased the percentage of larger-sized aggregates and, at the same time, decreased the percentage of small aggregates. Peele (48, p. 82) substantiated these findings when he noted that additions of organic matter resulted in decreased soil erodability. Meyers (41, p. 355) found that organic colloids, when saturated with either calcium or hydrogen ions, were several times more effective in cementing sand particles into water-stable aggregates than were equal amounts of mineral colloids. Several other workers have also noted this close relationship of total organic matter content to the amount, stability, and size of soil aggregates (2, p. 102; 1, p. 211; 19, p. 274; 46, pp. 44-45). Hubbell (26, p. 37) reports a close relationship between aggregation and the amount of two micron clay present in the soil. This relation was linear and had a correlation coefficient of .960. Rost and Rowles (54, p. 425) also found a significant correlation between aggregation and per cent clay.

They calculated odds of 99 to 1 that the content of clay was positively correlated with soil aggregation. Lutz (40, p. 43) found a high positive correlation between the free iron content of the soil and the degree of aggregation of the silt and clay. He attributes this to the flocculation and cementing effects exerted on the soil by the free iron. Peele (49, pp. 50-51) added calcium carbonate to several soils and noted a decrease in aggregate stability and a marked reduction in permeability. He concluded that the only favorable effect lime could have on granulation would be indirectly through its affect on organic matter. Peele and Beale (50, pp. 33-34) inoculated Cecil clay loam with several cultures on fungi and bacteria. The results showed an increase in aggregation with all inoculations, whereas no increase was noted in the uninoculated soils. Gilmour et al. (23, pp. 292-294) added oat straw, ground alfalfa, and eight different mold species to a sandy, a silt-loam, and a clay soil. Very little increase in aggregation was noted in the sand, however, the silt-loam and clay showed an appreciable increase in the amount of soil aggregated. The greatest increase was found in the clay soil.

DESCRIPTIONS OF THE STUDY AREAS

The field portion of this study was conducted on the eastern slopes of Marys Peak. This is the highest peak in the Oregon Coast Mountain Range, and is situated in the Siuslaw National Forest, Benton County, Oregon. The eastern, or watershed, side of Marys Peak is drained by Rock and Griffith Creeks which together serve as a source of water for the communities of Corvallis and Philomath. Until just recently most of this watershed area remained virtually untouched although it supported virgin stands of Douglas-fir. Recently, however, a Douglas-fir bark beetle epidemic resulted in a number of concentrations of beetle-killed trees and subsequently salvage logging of these areas was initiated on a restricted scale. The cuttings were made as small clear cut units ranging from 1 or 2 acres to approximately 20 acres in size. Three of these cutting units were selected for study during the summer of 1955. Since every clear cut has its own distinct characteristics and history, each unit will be discussed separately.

Cutting Unit No. 3

This area was logged in the winter and spring of 1953 and is approximately 11 acres in extent. The following fall an attempt at broadcast slash burning gave very poor results and consequently much of the surface area of the unit is still covered by several feet of slash. The logs were yarded to the landing by a high-lead