# THE EFFECT OF PRESCRIBED BURNING ON THE PROPERTIES OF THE GRAYLING SOIL SERIES IN UPPER MICHIGAN

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ABSTRACT

THE EFFECT OF PRESCRIBED BURNING ON THE PROPERTIES
OF THE GRAYLING SOIL SERIES IN UPPER MICHIGAN

by David Glenn Scholl

Burning as a widely used forest management practice has been studied for some time with respect to its influence on soil properties. Conclusions as to its influence on a wide variety of soil and environmental conditions are very general. Concerning specific properties some apparent contradictions exist in the literature.

The present study involved the effect of slash and litter burning on a sandy, relatively unproductive soil in northern Michigan. Using units of measure which express the actual amount of a nutrient in a genetic horizon below one square centimeter of surface area, certain important trends following burning were noted as follows: significant reductions were noted for the O plus A1 horizons following slash and litter burning, in total organic carbon, total nitrogen, mineralizable nitrogen, extractable bases, field soil moisture, and water retention capacity. The total quantity of extractable phosphorus in the O plus A1 horizons and the pH and base saturation increased following burning.

These results when expressed on a concentration or percentage basis (as in much of the literature) showed that burning enriched the O and A1 horizons in most of the above nutrients. Many of the published studies failed to utilize changes in mass of those horizons associated with burning in determining the influence of burning.

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By

David Glenn Scholl

A THESIS

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TABLE OF CONTENTS

## LIST OF TABLES

LIST OF TABLES - Continued

## LIST OF PLATES

PLATE | Page

# I. INTRODUCTION

Prescribed burning is used as a forest management practice in the removal of slash, following clear cutting in even-aged stands of Jack pine (*Pinus banksiana*) in Upper Michigan. The effects of prescribed burning on soil properties, in this and other important forested areas, has for some time been a debated question. Many apparent contradictions as to the effects of prescribed burning on soil properties may be found in the literature (Ahlgren and Ahlgren, 1960). It is therefore difficult to make general statements about the effects of burning on soil properties and conclusions need to be restricted to the area which is being studied. Variations of soil texture and topography are among the more important factors which are reported to restrict the use of general statements (Metz et al, 1961).

This study will concern the effects of prescribed burning of Jack pine slash on the chemical and physical properties of the Grayling soil series in Upper Michigan. Three principles to be used, which have not been generally used in the forest soil literature in the United States, are as follows: 1) All samples analyzed represent genetic soil horizons; 2) Quantitative data will be presented in metric units for each genetic horizon; 3) The terms "duff" or "forest floor" will not be used, except in the literature review, instead, the horizon designation used by the Soil Survey Staff (1962) or O horizon will be used. The O horizon will be treated as an integral part of the soil system and so will be analyzed and evaluated as one of the several genetic horizons.

## II. LITERATURE REVIEW

Most studies involving prescribed burning in the United States are concerned with either slash burning or repeated litter burning. Tarrant (1956) and Fuller (1955), working in the Douglas fir region of western United States, have classified slash burning into two intensities, light and severe. Light burning generally refers to those fires which destroy most of the undecomposed litter but generally do not destroy the entire forest floor (O horizon). Severe burning completely destroys the forest floor (O horizon), and if temperatures are high enough, may alter both the chemical and physical properties of the mineral soil. Tarrant (1956) emphasizes the importance of clearly defining these terms and stresses that the proportions of a given area burned to the various degrees should be determined.

The objectives of prescribed burning include reduction of wildfire hazard (Fuller, 1955; Tarrant, 1956), improvement of conifer seed beds, opening of cone scales in species such as Jack pine (Chrosciewiez, 1959), and the destruction of competing vegetation (Metz et al, 1961). In order to organize the information in the literature, the effects of burning on soils will be grouped according to the following topics: chemical properties, physical properties, other morphologic properties, and soil productivity.

## Chemical Properties

(Soil reaction, available Ca, K, Mg, total nitrogen, $NO_3$ nitrogen, and organic matter)

### Reaction

It is reasonable to predict an increase in soil pH from the burning of surface litter when considering that the oxidation of organic compounds liberates basic mineral elements and destroys organic acids and organic colloids (Ahlgren and Ahlgren, 1960). Most of the studies reviewed did indicate that soil pH was increased by burning, including the following: Alway (1928), Austin and Baisinger (1955), Barnette and Hester (1930), Isaac and Hopkins (1937), Lunt (1951), and Metz et al (1961). Tarrent (1956), working in the Douglas fir region, found significant differences in soil pH between unburned, light burned, and severely burned soils. The severe burning resulted in the greatest pH increase, and the rate of reduction of pH following the burn was slower on the severe than on the light burn. Soil reaction declined, after four years, on the severe burn from pH 7.2 to pH 5.0. In the same time period the light burn was reduced from pH 7.1 to pH 4.6.

### Calcium

Available soil calcium, as expected, correlates closely with increases in pH. In the southeastern United States, significant increases of available calcium following burning were reported by Heyward and Barnette (1934), Barnette and

Hester (1930), and Metz et al (1961). Vlamis et al (1955) reported similar increases in the Ponderosa pine region, as did Isaac and Hopkins (1937), Fowells and Stephenson (1933), and Tarrent (1956), for soils of the Douglas fir region. Lunt (1951) reported an increase in exchangeable calcium under red and white pine forests after burning. Lutz (1956) found a seven-fold increase in exchangeable calcium following fires in Alaska. Austin and Baisinger (1955), working with soils in western Washington and Oregon, found an increase in calcium of 830% resulting from the burning of slash. Two years later the calcium level was still 327% higher than in the unburned areas. Finn (1934), however, found that leaching after burning caused a loss of calcium in both sandy and loamy soils. The work of Austin and Baisinger (1955) and Isaac and Hopkins (1937) indicates that calcium tends to show the greatest proportional increase of the major basic elements as a result of burning.

Potassium and Magnesium

Isaac and Hopkins (1937) also found that available potassium and magnesium were increased by burning. Austin and Baisinger (1955) noted that available potassium was initially increased 166% with a drop to 112% two years later, while available magnesium was initially increased 337% with a drop to normal levels in two years. Burns (1952) and Metz et al (1961) found significant increases in potassium and magnesium resulting from repeated litter burning in the

Atlantic Coastal Plain. Finn (1934), however, stated that the leaching which follows most burning decreases soil potassium.

Phosphorus

The reports on the effect of burning on available phosphorus are somewhat conflicting. Austin and Baisinger (1955), Tarrant (1956), Fuller (1955), and Vlamis (1955), working in western United States, and Metz et al (1961), in the Atlantic Coastal Plain found significant increases in available phosphorus following burning. Lutz (1956) observed no significant change in available phosphorus on the New Jersey Coastal Plain, as did Isaac and Hopkins (1937) and Fowells and Stephenson (1933) in the Douglas fir region. Valais et al (1955) discovered that on sandy loam there was a marked increase in available phosphorus following burning, while on loam there was no significant difference. The two results differed because of a higher phosphorus fixation capacity of the loam. Ahlgren and Ahlgren (1960) attributed some of the apparent contradictions in the literature concerning available phosphorus levels, after burns, to the variable fixation capacity of the sites tested.

Total Nitrogen

Total nitrogen contents, as affected by burning, also tend to vary with soil and site. Burns (1952) and Metz et al (1961) found significant increases in total nitrogen due to burning in the mineral soil on the Atlantic Coastal Plain.

Isaac and Hopkins (1937) discovered no important increase in total nitrogen due to burning in the mineral soil. Barnette and Hester (1930), however, noted a loss of 1,125 lb/acre of nitrogen from the duff in 42 years of annual litter burning, while Isaac and Hopkins (1937) found a loss of 594 lb/acre of nitrogen from the duff, following Douglas fir slash burning. Lunt (1951) noted higher total nitrogen after burning under red and white pine stands in the northeastern states. On the other hand, in a slash burning study in the Pacific Northwest, Austin and Baisinger (1955) discovered a 67% loss of nitrogen in the upper 12 inches of the mineral soil with a 75% recovery of the loss two years later. Tarrant (1956) noted that, following severe burning in Douglas fir slash, total nitrogen was seriously reduced in the mineral soil. Klemmedson et al (1962), working in northern California in the Ponderosa pine area, found that severe slash burning reduced the rate of addition of total nitrogen to the mineral soil as compared to slight and no burning.

Nitrification and Mineralization of Nitrogen

Fowells (1934), working in the Douglas fir region, evaluated the effects of prescribed burning on nitrate production. He found that the mineral soil from severely burned plots, following an eight week incubation, contained seven times as much $NO_3$ as did the unburned. Burning, through an increase in soil reaction, strongly favors the bacterial population over the fungi, which results in the increased

$NO_3$ production. Tarrant (1956) also notes that light slash burning increases nitrification. Isaac and Hopkins (1937) indicated that slash burning in the Douglas fir region increases nitrification in the duff and mineral soil. Ahlgren and Ahlgren (1960), summarizing the work of Kivekas (1939) indicate that while ammonification is less as a result of burning, the nitrification process is greatly increased due to the effects of the changed pH on bacterial growth.

Organic Matter

The extent to which soil organic matter is destroyed by fire is very largely a factor of the fire intensity and duration, the extent to which the organic matter is incorporated in the soil, and the type of pre-burn vegetation (Ahlgren and Ahlgren, 1960).

Heiberg (1941) states that fire does not affect organic material incorporated in the mineral soil, probably because soil temperatures below the surface inch are not raised high enough during most fires. Austin and Baisinger (1955) note that the organic matter content of the surface one-half inch of mineral soil following severe slash burning in western Oregon and Washington is reduced as much as 75.5%. Two years later the organic content was still 50% below normal. Isaac and Hopkins (1937) found organic matter was reduced by one-third in the surface three inches of soil following intense Douglas fir slash fires. Barnette and Hester (1930), working in Florida, compared soils which had received annual litter burning for 42 years with those having had no burning. They discovered a loss of 121,289 lb/acre of organic matter from the burning of the duff.

Metz et al (1961), working on the outer Atlantic Coastal Plain, noted significant increases in percent organic matter (Walkley-Black and loss-on-ignition method) in the surface two inches of the mineral soil following annual litter burning for 10 years. The author attributed the increase in organic matter by both methods to the movement of superfically charred organic materials, in a finely divided state, from the litter into the mineral soil. A significant difference, attributed to the inclusion of charcoal in the loss on ignition data, was found between the two methods of analysis. The burned area showed a greater difference between the two methods, suggesting more charcoal on the burned site.

## Physical Properties

The physical properties that will be considered in relation to burning include, field moisture, pore space and bulk density, infiltration, and temperature.

### Soil Moisture

Blaisdell (1953), studying burning of sagebrush and grasslands in the West, noted that any reduction in moisture content, even in the top one-half inch of soil, was only temporary. Greene (1935) and Wahlenburg et al (1939) noted no difference in soil moisture content following burning in the longleaf pine region.

Heyward (1939), on the other hand, working with longleaf pine stands in the southern United States, found that annual litter burning reduced field soil moisture as much as 66%. The reduction of field moisture was thought to be due to the removal of the duff, in closed stands, and a thick grass mulch in open stands, which allowed for increased evaporation.

Pore Space and Bulk Density

Tarrant (1956) investigated pore space and bulk density in the Douglas fir region of the western United States. He found that severe slash burning reduced the non-capillary pore space and the infiltration rate by one-half. Severe burning increased capillary pore space and bulk density as compared to light and no burning. Metz et al (1961), working on the outer Atlantic Coastal Plain, discovered no significant difference in bulk density and porosity following annual and periodic litter burning. Slight increases in pore volume and decreases in bulk density following repeated litter burning were noted by Burns (1952) working in the New Jersey Pine Barrens. Heyward (1937) noted compaction of surface soil horizon following repeated litter burning in the longleaf pine region.

Infiltration

Arend (1941), working in the Ozark Plateau region, investigated the effects of annual litter burning and litter removal on infiltration rates. He discovered that burning reduced infiltration rates 38%, while removal of the litter reduced them 18%. He explains the difference by considering that the burned area not only has the channels within the duff that conduct water into the mineral soil removed, but the mineral soil has been exposed to raindrop impact many times in the past. Fuller (1955), working in northern Arizona, and Tarrant (1956) working in the Douglas fir region, have found reductions in surface soil permeability following severe slash burning; however, Veihmeyer and Johnson (1944) found infiltration rates of brushlands in California unimpaired by burning. Metz et al (1961) also noted no significant difference in percolation rates following repeated litter burning. Burns (1952) discovered a small increase in infiltration following repeated burning on the New Jersey Pine Barrens.

Temperature During and After Burning

Temperatures recorded during fires cover a wide range at different seasons, under diverse weather conditions, and varying type and quantity of fuel (Ahlgren and Ahlgren, 1960). Isaac and Hopkins (1937) noted temperatures of 1841°F above the forest floor and 608°F one inch below, in piled Douglas fir slash fires. Heyward (1938), reporting soil temperatures during litter fires in the longleaf pine region, has found that in the upper one-quarter inch of soil, temperatures reached 150°F to 175°F for two to four minutes. At the one-half inch depth, the rise in temperature was negligible, but in some cases reached 190°F. Beaufait (1960) has reported maximum temperatures in Jack pine slash in Michigan at 1, 5, 9, 13, and 17 feet above ground. He reports that temperature maxima varied, depending upon slash density, from 1400°F, at one foot above ground, to an average of 600°F at 17 feet above ground. Isaac (1930) noted that surface soil temperature, following Douglas fir slash fires on hot summer days reached as much as 140°F, while unburned surfaces reached only 125°F. It was found that, following three days of the above temperature on the burned area, 100% of the Douglas fir seedlings growing there were killed, while only 16% were killed on the unburned area. Pearse (1943) noted that soil temperatures on previously burned areas were higher during the day and lower at night. These differences could be detected for at least five years after burning.

## Other Morphologic Properties

Heyward (1934), working in the longleaf pine regions of the Atlantic Coastal Plain, found the following morphologic changes resulting from burning. In areas of annual litter burning the 01 and 02 horizons were completely destroyed. The A1 horizon had become compact and massive and all signs of faunal life, except for ants, were missing. The major portion of the organic materials were being added by grass roots rather than forest litter.

After ten years without burning, a forest floor of one and one-half inches under closed stands had developed.

A thick mulch of perennial grasses had accumulated under open stands. The A1 horizon had become loose and permeable and a wide variety of soil fauna had returned. Burns (1952) noted that moderate litter burning in the New Jersey pine barrens reduced the total thickness of the O horizon from 2.5 to 0.8 inches, the L layer from 1.3 to 0.3 inches, the F layer from 0.6 to 0.2 inches, and the H layer from 0.5 to 0.3 inches.

## Soil Productivity

The effects of burning on soil productivity as reported in the literature are quite varied; however, soil and type of plants grown also vary widely. Heikinheimo (Ahlgren and Ahlgren, 1960) carried out tests in which ash was added to neutral sand and peat, and the germination and growth of pine, spruce, birch, and alder was studied. He recorded that the higher concentrations of ash hindered germination and growth of all four species. Tryon (1948) reported decreased germination of white pine seed in soil to which charcoal had been added. Perry (1935) found growth of both white and red pine better on unburned soil. Arnould (Ahlgren and Ahlgren, 1960) discovered that trees grew poorly for 100 years after fire on clay soil. He believed this to be the result of compaction of the soil as a result of burning. Isaac and Hopkins (1937) noted that the survival and growth of Douglas fir seedlings were poorer on burned areas.

From phytometer studies of pitch pine in New Jersey, Lutz (1934) found no consistent differences in fertility of burned and unburned soils. Heyward and Barnette (1934) noted no important differences in soil fertility following burning in the longleaf pine region. On the other hand, Tarrant (1956) working with Douglas fir, found that seed germination was not affected using artificially heated soil, ash-sand mixtures of varying concentration, and soils from slash burned areas. He concluded that relatively high pH (9.8) does not affect the germination of Douglas fir. Tarrent also noted that one and two year old Douglas fir seedling growth under natural conditions was not inhibited; however, there was a reduction of the number of external mycorrhizae in the burned soils. In the longleaf pine region frequent light burning does not appear to harm soil productivity (Burns, 1952). Wahlenberg (1935) noted that forage plants, corn, and slash pine seedlings, grew better on frequently burned areas than elsewhere. Longleaf pine saplings grew faster on unburned plots than on burned plots, although burning did not affect diameter growth of older longleaf pine (Wahlenberg et al, 1939).

## Summary of Literature Reviewed

In spite of the many apparent contradictions to be found concerning the effects of burning on soils, as indicated below, certain broad conclusions may be gathered from the literature. It must, however, be remembered that interaction of many factors such as soil texture, soil structure, type and intensity of burning, climate, relief, and vegetation type all tend to confound the effects of burning.

Conclusions

1) A part or all of the unincorporated organic matter is destroyed, depending on type and severity of burning. Nitrogen and carbon are consequently lost.

2) Only under intense slash fires is organic matter, incorporated in the mineral layers, lost.

3) Soil temperatures are generally higher during the day and cooler at night on burned soil areas.

4) Severe or often repeated burning tends to decrease infiltration and increase bulk density.

5) Burning usually increases pH and available nutrient concentrations in the surface of the mineral soil. Organic matter and nitrogen may also be increased.

6) Burning usually stimulates nitrification.

7) Reports of the effect of burning on soil productivity vary widely, and each situation needs to be considered individually.

## III. GEOLOGY AND ECOLOGY OF THE STUDY AREA

The study area in this investigation is in the northwest part of the Stonington Peninsula of Delta County, Michigan. It is bordered on the west by Little Bay de Noc, on the east and south by Squaw Creek, and on the north by highway U.S. 2.

### Geology

Sinclair (1960) has mapped the area as a sandy glacial-lake deposit. Hough (1958) has indicated from evidence of two Valder's age recessional moraines in Delta County, that as the ice front retreated across the study area, glacial Lake Algonquin (8000 years before present ± 500) had already begun to lower toward the "Upper Group" of lake stages. Interpolating from Leverett and Taylor (1915), figure 8, page 439 and Plate XXIV, this level would be between 750 feet (Lake Algonquin maximum) and 700 feet ("Upper Group" lake levels). From the fact that the elevation of the study area is 625 ± 15 feet, it can be seen that the sandy parent materials were laid down in the shallow waters (approximately 100 feet deep) of glacial Lake Algonquin. With the rather rapid lowering of lake levels from the "Upper Group" to the Lake Chippewa stage 6000 to 8000 years before present, the entire present day Green Bay area became drained (Hough, 1958).

It is apparent therefore that the study area became drained soon after the "Upper Group" of lake stages was reached. During Lake Nipissing time the lake level in the Michigan basin again returned to 610 feet near the study area, but apparently did not inundate the major portion of the area (Leverett and Taylor, 1915). It may then be concluded that the parent materials in the area were exposed and soil development began about 8000 years before present.

## Ecology

The majority of the well-drained sandy soils in the study area are Grayling and Rubicon sand (Soil Survey Staff, U.S. Forest Service, Aug. 19, 1963). The major tree species is Jack pine, *Pinus banksiana*, but an occasional large red pine, *Pinus resinosa*, and some northern red oak, *Quercus borealis*, may be found (Dodge, 1920). Some stands of *Populus tremuloides* and *Populus grandidentata* can also be found (Darlington, 1945). The combination of Grayling sand and Jack pine vegetation is found throughout the Upper Peninsula and the upper Lower Peninsula of Michigan in areas known as the "Jack pine plains" (Darlington, 1945). McCool and Veatch (1924) found that the purest stands of Jack pine occurred on the drier sandy soils, such as Grayling and Rubicon, in the so-called "Jack pine plains."

Darlington (1945) made the following comments concerning the taxonomy of the herbaceous plants of the pine plains:

"the pine plains are particularly well adapted to members of the heath family" (Ericaceae). "Three species of blueberry are found," Vaccinium pennsylvanicum being the most predominant. Other members of the Ericaceae include creeping wintergreen, Gaultheria procumbens, and trailing arbutus, Epigaea repens. "One of the characteristic plants of certain areas is the sweet fern, Myrica asplendifolia, found in the driest sites." The only true fern of any importance is the common bracken fern which forms large patches in some areas. Statistical studies made of the common plants of the "Jack Pine Plains" showed that 95% of them were perennials with deep roots or rootstocks adapted to severe conditions of drought or of surface burning. About one-half of these plants were included in only four families-Compositae, Gramineae, Rosaceae, and Ericaceae.

Veatch (1953) has described the Rubicon-Grayling association as follows: "Most of the soil is dry, yellowish, incoherent sand, acid in reaction to a depth of three feet or more. It has a slight coherence and loaminess a few inches below the surface, but characteristically does not have enough humus in the surface layer, or clay and colloids in the subsurface layers, to make it even moderately retentive and fertile."

## Ecology and Fire

Maissurow (1941), working in northern Wisconsin and Upper Michigan, has stated that at least 95% of the so-called virgin forest, prior to the 1890 lumbering period, was periodically burned by natural forest fires. He considered forest fires as an ecologically normal event that had a very significant effect on the stand composition of the original forests. He states that white pine, Norway pine, and Jack pine types are subclimaxes, dating back to forest fires. Harper (1918) suggested that the normal frequency of fire in the Jack pine and spruce types was about once in the average lifetime of a tree. Such an estimate is difficult to make because of the almost complete destruction of the original stands by logging and fire.

Many foresters and ecologists consider Jack pine to be a "fire species" because of the important roll which fire plays in its seed dissemination and growth. Jack pine cones remain on the tree (unopened) for several years and accumulating until a forest fire, running through the stand, opens the cones and releases the seeds. The seeds fall to the ground and are able to germinate on the freshly burned soil. Jack pine seed germination is generally very poor without burning or scarification of the duff (Eyre and LeBarron, 1944).

The original land survey notes of the 1850's describe the study area as a "burned sand plain with scattered spruce, pine and sand pine" (Soil Survey Staff, U.S. Forest Service, August 19, 1963). The present, even-aged, Jack pine stand is 40 to 50 years old, as determined by increment borings, and most probably originated from the extensive burning, following the pine lumbering era of the 1890's. The lower 02 horizon, on the recently (50 years) unburned sites, has a considerable quantity of charcoal present (as determined from binocular microscopic examination). The upper O2 and O1 horizons appear to have little charcoal present.

# IV. SITE SELECTION, SOIL DESCRIPTION, SOIL SAMPLING

## Site Selection

An area was selected for study that had recently been clear cut (1962) and occupied the major portion of section 25, T 40 N, R 22 W in Delta County, Michigan. The area is two miles east of Squaw Point light house and approximately six miles south of U.S. 2 on County Highway 513. Blocks of the windrowed slash remaining after cutting had been burned in June, 1963. At present approximately one-half of the area has been burned. The topography is flat (0 to 2% slopes) to undulating (2 to 12% slopes). The low undulating swells suggest either off-shore bars or low modified sand dunes.

After traversing the area and observing the uniformity and development of the soils, as well as the remaining vegetation, an area was selected which is located between 12 and 16 chains south of the north section line along the quarter section line between the northwest and northeast quarters of section 25.

The area is level (0 to 2% slopes) and the soil horizons appear uniform a few centimeters below the surface. The soil type, slope, and vegetation remain constant on approximately 5 acres at this site. The area used as the control (unburned for 40 to 50 years) is a one acre block of undisturbed Jack pine, left during the recent cutting and burning as a check on the development of an outbreak of pine tortoise scale.

No wild fires have been reported in this area since effective fire control was established during the 1930's. From the lack of charcoal in the 01 and upper 02 horizons and the absence of any sign of fire damage to the stand, usually evident following fires in Jack pine (Harper 1918; Chapman, 1952), fire has probably been excluded during the stand's development.

A one acre area adjacent to and west of the undisturbed stand was selected as the burned plot. The area was clear cut, the merchantable pulp removed, and in 1962 the slash was piled in north-south windrows. The windrows were approximately 30 feet wide and 30 feet apart. The slash was piled from 2 to 5 feet high and was completely removed from the areas between the windrows (median areas). It was estimated that the areas of removed and piled slash represent equal portions of the burned area; therefore, results may be averaged to obtain the net effect of burning.

Before cutting, the sampling area was timber typed as Jack pine, 5 to 8.9 inches DBH, of good stand density, by the U.S. Forest Service in 1954. The area yielded 6 to 7 cords per acre of merchantable Jack pine pulp (Soil Survey Staff, U.S. Forest Service, August 19, 1963). The slash was burned in the afternoon of June 27, 1963. The weather was warm and dry and the fire burned "hot and severe" (Rapid River District Ranger, 1963). The slash was completely consumed, except for some of the larger stems, and the median areas were essentially all burned. Soil description and sampling was accomplished 17 months after the burning.

## Soil Description

Two soil pits (3 feet by 4 feet and 5 feet deep) were dug, one in the unburned area and one in the area where slash had been piled and burned. A field description of each soil profile was written according to standard conventions (Soil Survey Staff, 1951, and amended in 1962), except that the ISCC-NBS color names are used (Kelly and Judd, 1955). Depths of horizons were determined by averaging several measurements made from four profiles. Munsell color notations are for moist soil conditions. Laboratory results of pH measurements were incorporated into the descriptions. The species of herbaceous vegetation were identified with the assistance of Dr. Stephenson of the Botany and Plant Pathology department at Michigan State University.

### Grayling sand (unburned)

Vegetation:

Dominant: Jack pine (Pinus banksiana)

Ground cover: Creeping wintergreen (Gaultheria procumbens), trailing arbutus (Epigaea repens), sweet fern (Myrica asplenifolia), common bracken fern (Pteridium aquilinum), bearberry (Arctostaphylos uva-ursi), "dry land sedge"

(*Carex pennsylvanica*), blueberry (*Vacinium pennsylvanicum*), mosses (Bryophyta), "Reindeer moss" (Cladonia sp.), three-toothed cinquefoil (*Potentilla tridentata*)

Relief and Physiography:

The soil described occurs on a level area (0-2 percent slopes) of an Algonquin glacial lake plain.

Drainage: well drained.

Ground water: deeper than 7 feet.

Moisture: moist.

Stoniness: none.

Elevation: 620 feet.

Location:

SW1/4 of NW1/4 of NE1/4 of Sec. 25, T40N, R22W, Bay de Noc Township, Delta County, Michigan.

Profile description:

| Horizon | Depth in cm. | Description |
|---|---|---|
| 01 | 4.5-4.0 | Forest litter of pine needles, herbaceous leaves and stems, lichens and mosses. 0-1 cm. thick. |
| 02 | 4.0-0 | Forest litter in various stages of decomposition; dense root mat. 3.5-4.5 cm. thick. |
| A2 | 0-2.5 | Dark grayish brown (10YR 4/2) to grayish yellowish brown (10YR 5/2); sand; single grain loose; very strongly acid (pH 4.7); abrupt smooth boundary. 2.0-3.0 cm. thick. |

| Horizon | Depth in cm. | Description |
|---|---|---|
| Bir | 2.5-25 | Light brown (7.5YR 5/4) to moderate brown (7.5YR 4/4); sand; single grain; loose; strongly to medium acid (pH 5.5); clear smooth boundary. 22-25 cm. thick. |
| B3 | 25-55 | Light brown (7.5YR 6/6); sand; single grain; loose; medium acid (pH 5.8); gradual smooth boundary. 28-32 cm. thick. |
| C | 55* | Light yellowish brown (10YR 7/4); sand; single grain; loose; medium to slightly acid (pH 6.0). |

Additional Notes:

(1) A thin, 0.1 cm., discontinuous A1 horizon was noted in the lower 02 but was not described. Pieces of charcoal were noted in the lower 02 horizon.

(2) Little charcoal was noted in the 01 and upper 02 horizons.

(3) The official Grayling series description, written in Cheboygan County, Michigan, is predominated by Hue-10YR colors and shows a less well developed Bir horizon (National Cooperative Soil Survey, 11-7-1958).

*(4) The C horizon was observed to a depth of two meters.

Grayling sand (burned)

Vegetation:

Ground cover: "dry land sedge" (*Carex pennsylvanica*), blueberry (*Vaccinium pennsylvanicum*), bearberry (*Arctostaphylos uva-ursi*), three tooth cinquefoil (*Potentilla tridentata*), mullein (*Verbascum thospus*).

Relief and Physiography:

The soil described occurs on a level area (0-2% slopes) of an Algonquin glacial lake plain.

Drainage: well drained.

Ground water: deeper than 7 feet.

Moisture: moist.

Stoniness: none.

Elevation: 620 feet.

Location:

SE1/4 of NE1/4 of NW1/4 of Sec. 25, T40N, R22W Bay de Noc Township, Delta County, Michigan.

Profile description:

| Horizon | Depth in cm. | Description |
|---|---|---|
| O2 | .9-0 | Burned forest litter in various stages of oxidation; pieces of wood charcoal present. .5-1.5 cm. thick. |
| A1 | 0-2.5 | Brownish gray (10YR 3/1); sand; very weak, fine, granular structure, aggregates held together mainly by fine roots; very friable; very strongly to strongly acid (pH 5.0); abrupt smooth boundary. 1-3 cm. thick. |
| A2 | 2.5-4.0 | Grayish yellowish brown (10YR 4/2); sand; single grained; loose; very strongly acid (pH 4.8); abrupt smooth boundary. .5-2.5 cm thick. |
| Bir | 4.0-28 | Light brown (7.5YR 5/4) to moderate brown (7.5YR 4/4); sand; single grain; loose; strongly to medium acid (pH 5.5); clear smooth boundary. 23-25 cm. thick. |

| Horizon | Depth in cm. | Description |
|---|---|---|
| B3 | 28-58 | Light brown (7.5YR 6/6); sand; single grain; loose; (pH 5.8); medium acid; gradual smooth boundary. 28-32 cm. thick. |
| C | 58* | Light yellowish brown (10YR 7/4); sand; single grain; loose; slight to medium acid (pH 6.0). |

Additional Notes:

(1) The official Grayling series description, written in Cheboygan County, Michigan, is predominated by Hue-10YR colors and shows a less well developed Bir horizon (National Cooperative Soil Survey, 11-7-1958).

*(2) The C horizon was observed to a depth of two meters.

## Soil Sampling

Soil samples, collected from three treatments, are as follows: unburned, burned where slash had been piled, and burned where slash had been removed. Four profiles, 30 feet apart north and south in a row, were sampled by genetic horizons in each of the three areas. The row of unburned plots sampled is 100 feet east of those in the slash removed area and 130 feet east of those in the slash piled area. The slash piled and slash removed plots were consequently 30 feet apart. The row of unburned plots is 20-25 feet inside the Jack pine stand. The burned profiles were kept at some distance from the edge of the fire area to avoid effects of fire control operations. The horizons sampled were those as described, except that the 01 horizon (unburned) was included with the 02 horizon.

Sampling for Chemical Analyses

Samples for chemical analyses were taken of the O and A horizons by removing a six inch square of soil to the depth of the surface of the B horizon, as in Plates 1 and 2. Each horizon was then separated with the blade of a flat shovel. This method allows one to inspect all four sides of the material to be sampled. The balance of the horizons were sampled from the remaining hole with a bucket auger, the depth being determined from the profile descriptions. Several trial attempts at sampling the lower horizons with the bucket auger suggested that the sampling area was quite uniform with respect to depth of horizons. Each sample was inspected for compliance with the profiles as described. Approximately one quart of sample was taken in each case.

Sampling for Physical Analyses

1) Bulk Density

Four undisturbed core samples were taken of each horizon of each of the 12 profiles using the Uhland sampler. The Bir and B3 were sampled using the (3 by 3 inch) cores. The A2 (unburned) and A1 (burned) were sampled using the (1 by 3 inch) core. The 01 plus 02 (unburned), A2 (burned), and 02 (burned) presented a special problem due to their limiting thickness. In the case of the 01 plus 02 (unburned) a

(3 by 3 in.) core was taken which included both the 01 plus 02 and all of the A2. In the case of the A2 (burned) a (1 by 3 in.) core was taken which included the A2 and the A1. The 02 (burned) was so thin and unconsolidated that it was impossible to take an "undisturbed sample."

2) Field Soil Moisture

Five soil moisture samples of the 01 plus 02, A2 and Bir (unburned), and the 02, Al plus A2, and Bir horizons (burned) were taken in (300 ml) metal sample cans for the 12 profiles. Considerable difference was noted in soil moisture of the burned 02 horizons on bare soil areas and in clumps of the dry land sedge; therefore, an attempt was made to equally distribute the sampling between these two conditions.

3) Depth of Horizon

The depth of the horizon for each profile was determined by taking at least 5 measurements, more were taken in the thin variable horizons.

Plate 1. Unburned upper soil profile (1/2 actual size). The fifty year accumulation of decomposing litter (O horizon) is shown on the surface of the mineral soil.

Plate 2. Burned upper soil profile (1/2 actual size). The O horizon shown is thin, blackened, and almost indistinguishable from the A1. Some of the O and A1 horizons in this area show a more blackened appearance than does this plate.

Plate 3. Ground vegetation on unburned area (1/5 actual size.

Plate 4. Ground vegetation on the burned area (1/8 actual size). This plate emphasizes the predominance of the dry land sedges in the burned areas. The sedges are growing mainly in clumps, and so a portion of the ground surface is actually bare. It was noted that the O and A1 horizons were thickest under these clumps. In patches where the O and A1 horizons had been greatly reduced in thickness, the ground was generally bare. Soil moisture was notably reduced in these bare areas.

# V. LABORATORY PROCEDURES

## Chemical Analyses

Each soil sample was air dried and passed through a 2 mm sieve. All litter materials not passing the sieve (leaves, stems, etc.) were ground, resieved, and included with their respective sample. Less than one percent (approximately) of the mineral grains remained on the 2 mm sieve. The results of the following analyses are reported as percentages of the oven dried less than 2 mm materials.

### Total Carbon

Total carbon content was determined by the dry combustion method, in a stream of oxygen, using the sequence of gas purifying devices and collection tubes suggested by Piper (1944). Twenty-five gram subsamples were ground to pass a .25 mm sieve, then were thoroughly mixed. From .200 to 2.000 g (depending on carbon content) portions were weighed and placed in an alundum boat which contained .25 g of $MnO_2$ spread over the bottom. Exactly two grams of clean quartz sand were spread over the sample to prevent premature combustion of the sample while loading into the tube of the combustion furnace. The combustion temperature was maintained at 940°C for 15 minutes and care was taken to always place the boat at exactly the same position in the furnace. The $CO_2$ absorption bulb was cooled to a constant temperature and weighed to the nearest .1 mg. Determinations were made in duplicate and accepted if the $CO_2$ weights were within ± 3% of each other. Carbonate-carbon was not determined since all samples were in the acid range and believed to contain very little carbonates. The averages of the duplicate determinations are reported unless otherwise noted.

Walkley-Black Carbon

Organic carbon was determined using the Walkley-Black (wet oxidation) method as described by Jackson (1958). Aliquots of the subsamples used for total carbon were used for the Walkley-Black method. Determinations were made in duplicate and accepted if the amounts were within 3% of each other. The averages of the duplicate determinations are reported unless otherwise noted.

Total Nitrogen

Total nitrogen was determined by the Kjeldahl method as described by Jackson (1958, pp. 183-190), except that the "Kel-pak,"(containing 9.9 g $K_2SO_4$, .41 g HgO, .08 g $CuSO_4$), plus 8.0 g of $K_2SO_4$, was used as the catalyst. The $NH_3$ was distilled into 4% boric acid and titrated with $\underline{N}/14$ $H_2SO_4$. Duplicate determinations were made and accepted if the amounts were within 5% of each other. The averages of the duplicate determinations are reported unless otherwise noted.

Reaction*

Soil pH was measured using a glass electrode pH meter. Duplicate determinations were made and accepted if no more than two-tenths of a pH unit different.

Extractable Calcium, Potassium, and Magnesium*

The above bases were extracted by adding 20 ml of neutral 1N $NH_4AC$ to 2.50 g of sample, shaking the suspension for one minute, and filtering. The determinations were made and accepted if the amounts in the O and A1 horizons differed by no more than 5%. Duplicate determinations for the A2, Bir, and B3 were accepted if the amounts differed by no more than 8%, because difficulty was encountered in duplicating the low values observed.

Available Phosphorus*

Available phosphorus was extracted from 2.50 g of sample with 20 ml of a solution .03 N in $NH_4F$ and .025 N in HCl (Bray and Kurtz, 1945, No. 1 solution). The suspension was shaken for one minute and then filtered. Phosphorus in solution was determined colorimetrically, using the ammonium molybdate-hydrochloric acid solution of Dickman and Bray (1940) and the 1-amino, 2-naphthol, 4-sulphonic acid reducing agent developed by Fiske and Subbarrow (1925).

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*Analyses by Soil Testing Laboratory, Michigan State University. Subsampling and weighing of samples was done by the author.

Exchangeable Hydrogen*

Exchangeable hydrogen was estimated by the Shoemaker, McLean, and Pratt (1961) buffer method.

Cation Exchange Capacity

Cation exchange capacity was estimated by summing the four exchangeable cations; hydrogen, calcium, magnesium, and potassium.

Mineralization of Nitrogen

Total mineral nitrogen (exchangeable $NH_4^+$ plus $NO_2^-$ plus $NO_3^-$) was determined before and after a 14 day incubation period, using the method of Bremner (1965, pp. 1191-1206). Ten grams of soil (passing a 2 mm sieve) were weighed into a 250 ml flask. Thirty grams of nitrogen free quartz sand plus 6 ml of water were added and mixed. The top of the flask was covered with polyethylene and incubated for 14 days at 30°C. The mineral forms of N were extracted by shaking the sample with 100 ml of 2 N KCl for one hour. Twenty ml of the extract from this treatment was analyzed by steam distillation with MgO and Devarda alloy. The resulting $NH_3$ was distilled into boric acid and titrated with .0545 N $H_2SO_4$. Duplicate determinations were made both before and after the incubation. The averages of the duplicate determinations are reported unless otherwise noted.

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*Analyses by Soil Testing Laboratory, Michigan State University. Subsampling and weighing of samples was done by the author.

## Physical Analyses

### Water Retention and Bulk Density

Water retentions by undisturbed soil cores were measured at saturation, 10, 20, 30, 40, and 60 cm of water tension by the blotter paper-tension table method of Leamer and Shaw (1941). These were done in quadruplicate. The percentages reported are averages for the oven dried whole soil. The moisture contents at 1/3, 1, and 5 atm tension were measured by the ceramic plate-pressure method. Richards and Fireman (1943) and Richards (1948) have described the use of the ceramic plate method for 1/3 and 1 atm tensions. The 5-atmosphere determinations were made by using the 15-atmosphere ceramic plate. The determinations of moisture retention at 1/3, 1, and 5 atm were made on disturbed samples and done in triplicate. The results reported are averages for triplicate samples of the oven dry, less than 2 mm materials. Bulk densities were calculated by dividing the oven-dry weight of the core samples used for water retention determinations by the volume of the core.

In cases where two horizons were included in one core (O and A2, unburned; A1 and A2, burned), moisture retention measurements had also been made on separate cores containing only one of the component horizons (A2, unburned; A1, burned). Moisture retention values for the undetermined component horizon in each case were calculated by difference.

For this calculation, the two-horizon cores were rewetted (after determining their oven dry weights) to near original field moisture. The component horizons were then carefully cut apart, oven dried and reweighed. The assumption was made that the moisture characteristics and bulk density of the separately determined horizons were the same in two-horizon cores as in one-horizon cores. Moist weights, corresponding to saturation and 10, 20, 30, 40, and 60 cm tension, were calculated for the undetermined horizons by use of the following formula:

$$MWt_x = MWt_{a'+x} - [\, MWt_a \, (\frac{DWt_{a'}}{DWt_a}) \,]$$

where: MWt = moist weight

DWt = oven-dry weight

x = calculated horizon

a = separately determined one-horizon core

a' = counterpart of (a) in two-horizon core

a'+x = two-horizon core

The bulk density of the undetermined horizon was calculated similarly by dividing its determined oven dry weight by its volume calculated by difference from known volume and weight relationships in one-horizon and two-horizon cores.

The bulk density and moisture retention of the O2 (burned) was found by filling a (1 by 3 inch core) with unground soil, then gently tapping the core several times on the table and refilling. The materials observed in this horizon in the field did not seem to be any more dense or consolidated than after treatment in this manner. The samples were duplicated and determinations were made as if they were undisturbed.

## Total and Capillary Porosity

Total porosity, by volume, was determined by multiplying the weight percent of moisture at saturation by the bulk density. Capillary porosity by volume was determined by multiplying the weight percent of moisture at 60 cm tension by the bulk density.

## Field Soil Moisture

The percent field moisture by weight, on an oven-dry basis was determined by weighing the samples as taken in the field and after oven drying at 105°C.

## VI. RESULTS AND DISCUSSION

Bulk density, thickness, and percentage values (Appendix, tables 8 through 13) were used to calculate the data presented in this section (tables 1A through 7). Bulk density (grams per cubic centimeter) multiplied by horizon thickness (centimeters) equals the grams of soil in a column under a surface area of one square centimeter extending the thickness of the horizon. Multiplying the percentage or ppm data, by the above parameter and adjusting the decimal point gives the grams of an element, or the centimeters of water, found in one square centimeter of each layer. Grams per square centimeter in each horizon is analogous in dimensions to pounds per acre furrow slice but does not assume a constant bulk density and thickness.

The standard deviations (tables 1 through 13) were calculated for properties of the four profiles in each treatment area. A standard "t" test (Patterson, 1939 pp. 14 and 248) was applied to all comparisons among means in tables 1A through 6. The probability for chance occurrence of equal or greater differences between means is shown for each comparison in tables 1B, 2B, 3B and 7. The actual probabilities lie between that shown and the next lower value in the "t" test tables. Because treated areas were not replicated, treatment effects are confounded with location effects. However, observed variations in subsurface horizons, which were not directly affected by burning, were low, suggesting that the three treatment areas were similar before burning. The Jack pine stand density, height, diameter and age were also similar in all three areas before cutting and burning.

## Chemical Properties

### Total Carbon

Tables 1A and 1B show that the unburned O horizon is significantly higher in total organic carbon than in the two burned areas (1 or 5% level of probability). Total carbon of the O horizons on the two burned sites did not differ significantly. The difference obtained between the unburned and burned O horizons represents a 4-fold reduction in total carbon on the burned areas. A trend toward higher total carbon is evident in the O and A1 horizons on the burned, slash piled site as compared to the burned, slash removed area. The differences between the unburned and burned areas appear to persist in the underlying A2 horizons, although the differences are not significant at the 5% level of probability.

Metz et al (1961) found that annual litter burning increased organic carbon in the O horizon on a percent basis, while on a pounds per acre basis it was considerably reduced.

Table 1A. Chemical properties of horizons on unburned and burned sites.

| Site and Chemical Property | Horizon O Mean | O S.D. | A1 Mean | A1 S.D. | A2 Mean | A2 S.D. | Bir Mean | Bir S.D. |
|---|---|---|---|---|---|---|---|---|
| (U) Unburned | | | | | | | | |
| Total carbon mg/cm$^2$ | 301 | 85.8 | ---- | ---- | 27.7 | 6.82 | 165 | 1.05 |
| *W.-B. resistant C " | 19.8 | 13.7 | ---- | ---- | 1.30 | .49 | 12.2 | 4.50 |
| Total nitrogen " | 11.8 | 3.44 | ---- | ---- | 1.48 | .38 | 8.48 | 1.14 |
| Mineralizable N µg/cm$^2$ | 364 | 172 | ---- | ---- | 18.1 | 7.74 | 131 | 25.6 |
| (P) Burned, slash piled | | | | | | | | |
| Total carbon mg/cm$^2$ | 73.8 | 10.9 | 71.5 | 19.1 | 19.5 | 12.6 | 157 | 22.1 |
| *W.-B. resistant C " | 14.8 | 7.36 | 6.70 | 1.45 | 3.00 | 2.18 | 28.1 | 9.66 |
| Total nitrogen " | 3.11 | 1.03 | 2.66 | .92 | .73 | .47 | 9.04 | 1.53 |
| Mineralizable N µg/cm$^2$ | 41.1 | 15.1 | 48.0 | 29.2 | 18.9 | 12.6 | 111 | 84.0 |
| (R) Burned, slash removed | | | | | | | | |
| Total carbon mg/cm$^2$ | 65.3 | 24.7 | 46.6 | 13.6 | 19.2 | 6.77 | 132 | 29.4 |
| *W.-B. resistant C " | 10.4 | 6.77 | 1.30 | .86 | 1.83 | 1.72 | 12.8 | 6.70 |
| Total nitrogen " | 3.08 | 1.33 | 1.91 | .57 | .73 | .19 | 7.50 | 1.53 |
| Mineralizable N µg/cm$^2$ | 40.6 | 1.98 | 30.4 | 14.8 | 16.6 | 3.84 | 102 | 27.9 |

*W.-B. resistant carbon was found by subtracting Walkley-Black carbon data from total carbon data.

Table 1B. Probabilities that the observed difference in carbon and nitrogen are due to chance.

| Property and Site Comparison* | Horizons | | | |
|---|---|---|---|---|
| | O | A1 | A2 | Bir |
| **Total carbon** | | | | |
| U vs P | .01 | -- | .3 | .5 |
| U vs R | .01 | -- | .2 | .1 |
| P vs R | .6 | .1 | .7 | .3 |
| **W.-B. resistant C** | | | | |
| U vs P | .6 | -- | .2 | .05 |
| U vs R | .3 | -- | .6 | .9 |
| P vs R | .5 | .1 | .5 | .05 |
| **Total nitrogen** | | | | |
| U vs P | .01 | -- | .1 | .6 |
| U vs R | .01 | -- | .02 | .4 |
| P vs R | .9 | .6 | .9 | .3 |
| **Mineralizable N** | | | | |
| U vs P | .01 | -- | .9 | .7 |
| U vs R | .02 | -- | .8 | .3 |
| P vs R | .9 | .4 | .8 | .9 |

*U = Unburned; P = Burned, slash piled; R = Burned, slash removed

Where the O horizon data (pounds per acre) were added to the surface of the mineral soil data (pounds per acre) there was no significant change with burning reported in their study.

The literature reveals that while severe slash fires may reduce organic carbon (percentage basis) in the mineral soil, litter or light slash burning may increase organic carbon. The present study indicates (comparing the A1 burned and the A2 unburned) that the mineral soil has been enriched with organic carbon on a percent basis. However, where the absolute amounts of total carbon above the A2 are considered (tables 4 and 7), burning caused a significant reduction, particularly where slash was removed before burning.

It is apparent that a problem of the use of appropriate units of measure exists. The present study shows that on a percent or ppm basis (concentration basis) the level of an element may not change or even increase, but on an absolute basis very important amounts of the element can be lost. For example, in this study there was no change in the concentration of organic carbon in the O horizon while its concentration in the mineral soil was increased. Using an absolute unit, so that changes in mass were also considered, there was not only an important reduction of organic carbon in the O horizon, but also a net decrease when the surface of the mineral soil was included. Many articles reporting on burning show results on a concentration basis and judge the influence of burning solely on the concentration of an element in an arbitrarily chosen zone. These analyses may be quite misleading and result in unwise management practices.

## Walkley-Black (wet oxidation) Resistant Carbon

Subtracting Walkley-Black (wet oxidation) carbon from total carbon approximates the amount of charcoal or other highly resistant forms of carbon present in the soil (Metz et al, 1961). Significance among means was not noted for any of the comparisons in tables 1A and 1B at the 1% level of probability. However, the Bir horizon in the slash piled and burned area was significantly higher, at the 5% level, than the other treatments. It is noted that the percentage data for the resistant carbon values is very low, so experimental error is likely high. There is, on the other hand, a general trend toward higher resistant carbon throughout the profile for the slash piled and burned area, particularly when the percentage data are considered (table 8).

## Total Nitrogen

The total nitrogen content in the unburned areas was significantly higher ($p = 2\%$) in the O horizon and approached significance ($p=2$ and $10\%$) in the A2 horizons compared to the burned areas (tables 1A and 1B). The difference in the O horizon represents a 3.5-fold reduction in total nitrogen in the burned sites. No other horizons or treatment combinations in the profile showed significant differences.

Several authors found that severe slash fires in the Douglas fir region reduced the concentration of total nitrogen in the mineral soil, while others noted an increase with less severe burning. In the present study, comparing total nitrogen for the burned A1 with the unburned A2 shows that the concentration of total nitrogen in the surface of the mineral soil has been increased with burning. However, the total amounts of nitrogen in the profiles above or including the A2 horizons decreased in the burned plots compared to the unburned plot. The total amounts of nitrogen seem a much more pertinent measure of actual changes due to fire.

Mineralizable Nitrogen

Subtracting mineral nitrogen content before a two week incubation period from that after the incubation gives the amount of nitrogen mineralizable in the two week period. The O horizon of the unburned area was significantly higher ($p = 1$ and 2%) in mineralizable nitrogen than in the two burned areas (tables 1A and 1B). No other significant differences in mineralizable nitrogen were found in the profiles of the three areas. The difference in the O horizon represents a 9-fold reduction of mineralizable nitrogen in the two burned areas. The net effect of burning on mineralization was a marked decrease, tables 4 and 7, in the soil above or including the A2 horizon. Considering results on a concentration basis (table 10) mineralizable nitrogen is shown to decrease in the O horizon following burning and increase in the surface of the mineral soil.

Although nitrification was not evaluated in the present study there is no reason to believe that results different from the literature would be obtained. The literature shows almost unanimously that burning results in an increased concentration of nitrate in the mineral soil.

Ahlgren and Ahlgren (1960) indicate that ammonification may be reduced while nitrification is increased with burning. Wilde (1958) reports that in acid litter, fungi build up a nitrogenous residue of mycelia which when broken down releases $NH_3$. He further indicates that the majority of the conifers, especially spruce, fir, and hemlock, are capable of utilizing $NH_3$ and some amino acids as a nitrogen source since $NO_3$ production is normally low in acid conditions.

Extractable Calcium, Potassium and Magnesium

All three extractable bases (tables 2A and 2B) were significantly higher, at the 1% level, in the O horizon of the unburned area as compared to the two burned areas. Significance was not noted between the two burned areas for the O horizon but a trend toward higher bases in the plot where slash was piled is evident. The three bases showed significant increases at the 2 and 5% level in the slash piled site as compared to the slash removed site for the A1 horizon. Calcium and magnesium were significantly higher (p = 1 and 10%) in the A2 of the unburned compared to the two burned areas. Magnesium was significantly higher at the 2% level in the Bir for the unburned compared to the burned sites.

Table 2A. Chemical properties of horizons on unburned and burned sites.

| Site and Chemical Property | Horizon O Mean | O S.D. | A1 Mean | A1 S.D. | A2 Mean | A2 S.D. | Bir Mean | Bir S.D. |
|---|---|---|---|---|---|---|---|---|
| (U) Unburned | | | | | | | | |
| Calcium $\mu g/cm^2$ | 2246 | 339 | ---- | ---- | 295 | 50 | 1302 | 200 |
| Potassium " | 518 | 127 | ---- | ---- | 63 | 19 | 450 | 159 |
| Magnesium " | 269 | 41 | ---- | ---- | 45 | 12 | 273 | 100 |
| Phosphorus " | 28 | 2 | ---- | ---- | 12 | 3 | 539 | 173 |
| (P) Burned, slash piled | | | | | | | | |
| Calcium $\mu g/cm^2$ | 927 | 214 | 575 | 91 | 137 | 122 | 1868 | 740 |
| Potassium " | 132 | 54 | 127 | 37 | 50 | 38 | 477 | 11 |
| Magnesium " | 101 | 39 | 68 | 19 | 19 | 13 | 67 | 34 |
| Phosphorus " | 56 | 17 | 75 | 54 | 27 | 26 | 698 | 17 |
| (R) Burned, slash removed | | | | | | | | |
| Calcium $\mu g/cm^2$ | 657 | 176 | 351 | 69 | 137 | 39 | 1471 | 918 |
| Potassium " | 124 | 47 | 63 | 11 | 40 | 24 | 292 | 126 |
| Magnesium " | 50 | 17 | 32 | 15 | 12 | 2 | 81 | 16 |
| Phosphorus " | 35 | 18 | 22 | 1 | 8 | 3 | 568 | 129 |

Table 2B. Probabilities that the observed differences in extractable calcium, potassium, magnesium and phosphorus are due to chance.

| Property and Site Comparison* | Horizon | | | |
|---|---|---|---|---|
| | O | A1 | A2 | Bir |
| Calcium | | | | |
| U vs P | .01 | -- | .1 | (-) .2 |
| U vs R | .01 | -- | .01 | .8 |
| P vs R | .2 | .02 | .9 | .6 |
| Potassium | | | | |
| U vs P | .01 | -- | .6 | .8 |
| U vs R | .01 | -- | .2 | .2 |
| P vs R | .9 | .05 | .7 | .05 |
| Magnesium | | | | |
| U vs P | .01 | -- | .05 | .02 |
| U vs R | .01 | -- | .01 | .02 |
| P vs R | .1 | .05 | .4 | (-) .5 |
| Phosphorus | | | | |
| U vs P | (-) .02 | -- | (-) .3 | (-) .1 |
| U vs R | (-) .6 | -- | .3 | .8 |
| P vs R | .2 | .2 | .2 | .1 |

*U = Unburned; **P** = Burned, slash piled; **R** = Burned, slash removed

(-) In these cases there was an increase in the constituent instead of a decrease compared to the first treatment listed in each comparison.

All other comparisons for the Bir, except the higher potassium in the slash piled and burned area compared to the slash removed area, show no significance. Table 9 shows that the concentrations of magnesium in the Bir were rather low; therefore, experimental error is probably high. The significant difference in calcium found in the O horizon represents a 2.4-fold reduction in extractable calcium when slash was piled and burned, and a 3.4-fold reduction when slash was removed and the site burned. Potassium and magnesium both showed approximately a 4-fold reduction in the O horizons of the burned areas.

Much of the literature indicates that the concentration of available or extractable calcium, potassium and magnesium in the O horizon and the surface of the mineral soil tend to increase following burning under a variety of soil and burning conditions. The concentration of calcium (table 9) in the present study was significantly greater at the 2% level in the area where slash was piled and burned as compared to the unburned site. Magnesium showed the same trend but potassium showed little differences in the O horizon. Burning has also enriched the surface of the mineral soil in the three bases when the unburned A2 and burned A1 were compared. However, the actual amounts of calcium, magnesium, and potassium in the layers above the A2 were lower in the burned sites than in the unburned and lowest in the slash removed and burned area.

Extractable Phosphorus

The absolute amount of extractable phosphorus in the O horizon of the slash piled and burned area (table 2A and 2B) was significantly higher at the 2% level than in the unburned plot. The above significant differences represent a 2-fold increase in extractable phosphorus on the slash piled and burned site. Statistically significant differences were not noted for any other comparisons; however, a trend toward greater extractable phosphorus is noted throughout the slash piled and burned profile. The concentration of available phosphorus, as reported in the literature, following burning, shows either no change or an increase in the mineral soil. It may be noted again that Vlamis et al (1955) found no change in a loam soil but marked increases, with burning, in a sand soil. Marked increases in phosphorus (ppm) were noted in both the O horizon and the surface of mineral soil in the present study. These increases following burning persisted even when expressed as the total amounts of phosphorus in the O plus A1 layer, particularly where slash was piled and burned (tables 5 and 7).

pH, Base Saturation and Exchange Capacity

The following discussion involves data in the appendix (table 11). The pH in the unburned O horizon was significantly lower at the 2 and 5% levels than in the two burned areas. A trend toward higher pH was noted on the slash piled site as compared to the slash removed area. All other combinations in the profile showed no significant differences in the means.

A significant increase in base saturation (p = 2%), of the slash piled and burned O horizon as compared to the unburned, was noted. Although the other comparisons showed no significant differences, a trend toward higher base saturation was noted, except for the A2, in the burned areas and particularly where the slash was piled and burned.

The cation exchange capacities in the O and Bir horizons are significantly lower (p = 1%) in the burned area, where slash was removed, than in the unburned areas. The exchange capacity in the slash piled and burned O horizons was also lower (p = 5%) than in the unburned area. At exchange capacities as low as those in the Bir, better experimental methods and more replication are needed for positive conclusions.

## Physical Properties

### Soil Moisture

Soil moisture (retention and field moisture) will be presented in this section (tables 3A and 3B) in units of centimeters of water in a given horizon.

### Moisture Retention (.06 atmospheres, .06 to 5 atmospheres)

Moisture retention in the O horizon (.06 atm tension) was significantly reduced (p = 1 and 5%) in the two burned areas as compared to the unburned area. No other combinations

Table 3A. Moisture retention and field moisture of horizons on unburned and burned sites.

| | Horizon | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | O | | A1 | | A2 | | Bir | |
| Site and Property | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| (U) Unburned | | | | | | | | |
| *.06 atm tension cm $H_2O$ | 1.19 | .21 | ---- | ---- | .29 | .04 | 2.52 | .10 |
| *.06-5 atm tension " | .63 | --- | ---- | ---- | .20 | --- | 1.66 | --- |
| Field moisture " | 1.02 | .34 | ---- | ---- | .26 | .10 | 2.17 | .33 |
| (P) Burned, slash piled | | | | | | | | |
| *.06 atm tension cm $H_2O$ | .24 | .00 | .47 | .10 | .17 | .09 | 2.48 | .26 |
| *.06-5 atm tension " | .09 | --- | .33 | --- | .12 | --- | 1.53 | --- |
| Field moisture " | .08 | .00 | --- | --- | --- | --- | 1.91 | .20 |
| (R) Burned, slash removed | | | | | | | | |
| *.06 atm tension cm $H_2O$ | .20 | .05 | .34 | .11 | --- | --- | 2.50 | .14 |
| *.06-5 atm tension " | .09 | --- | .25 | --- | --- | --- | 1.75 | --- |
| Field moisture " | .08 | .05 | --- | --- | --- | --- | 2.05 | .33 |

*Moisture retention capacity.

Table 3B. Probabilities that the observed differences in moisture retention and field moisture are due to chance.

| Property and Site Comparison* | Horizon | | | |
|---|---|---|---|---|
| | O | A1 | A2 | Bir |
| .06 atm tension | | | | |
| U vs P | .05 | -- | .1 | .8 |
| U vs R | .02 | -- | -- | .9 |
| P vs R | .2 | .4 | -- | .9 |
| Field moisture | | | | |
| U vs P | .01 | -- | -- | .3 |
| U vs R | .01 | -- | -- | .2 |
| P vs R | .9 | -- | -- | .5 |

*U = Unburned; P = Burned, slash piled; R = Burned, slash removed.

in the profile showed significant differences, but a trend toward lower moisture retention (.06 atm tension) in the A2 of the burned areas was noted. The significant difference in the O horizon represents a 5-fold reduction in moisture retention (.06 atm) on the two burned sites.

The disturbed samples used for the 1/3, 1, and 5 atm moisture data were composites of the four profiles in each area; therefore, significance levels cannot be determined. The soil moisture retained between .06 atm tension (undisturbed) and 5 atm (disturbed) has been termed readily available water capacity by Franzmeier (1962). If one assigns the same relative standard error for the .06 atm (O horizon) data to the 5 atm data it is clear that there is a very large reduction in readily available water capacity on the two burned areas.

## Field Moisture

Soil moisture content under field conditions in the O horizon was significantly reduced (p = 1%) in the two burned areas as compared to the unburned sites (table 3A and 3B). Significance between means was not reported for the remaining comparisons in the O and Bir horizons. The same trend toward reduced field moisture in the burned O horizon is also clearly evident where the percentage data are considered (table 12). The significant differences in the O horizon represent a 13-fold reduction in soil moisture in the two burned sites.

It must be realized, however, that the level of soil moisture in the unburned area includes the effects of shading by the Jack pine stand. The moisture samples were taken four days after one inch of rainfall and so represent relatively moist conditions. It may be noted from tables 12 and 13 that the field moisture percent for the unburned plot (O horizon) is only slightly less than that at .06 atm tension. The percent field moisture, however, in the burned areas is already less than the 5 atm tension percent.

Grams Soil Per Square Centimeter of the Horizon

As explained earlier, this value is obtained by multiplying bulk density (grams per cubic centimeter) by the horizon thickness in centimeters and represents the total dry matter in the horizon (table 12). There was a significant reduction in total dry matter in the burned O horizons as compared to the unburned areas. No other combinations in the profile gave significance at the 1 or 5% level. The significant differences between the unburned and the two burned sites represents a 3-fold reduction in the total dry matter in the O horizon. The above result was primarily due to a 5-fold reduction in thickness of the O horizon (table 12).

## Profile Summation

In tables 4, 5, and 6, experimental values determined for the O and A1 horizon in the two burned areas have been summed for comparison with the values for the O horizon of

Table 4. Distribution of carbon and nitrogen in the profiles on unburned and burned sites.

| | Property | | | | | |
|---|---|---|---|---|---|---|
| Portion of Profile and Site | Total carbon | | Total nitrogen | | Mineralizable N | |
| | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| | $mg/cm^2$ | | $mg/cm^2$ | | $\mu g/cm^2$ | |
| Above A2* | | | | | | |
| (U) Unburned | 301 | 85.8 | 11.8 | 3.44 | 364 | 172 |
| (P) Burned, slash piled | 145 | 18.6 | 5.64 | .66 | 96.2 | 35.2 |
| (R) Burned, slash removed | 112 | 16.2 | 4.99 | .89 | 70.9 | 13.3 |
| | $mg/cm^2$ | | $mg/cm^2$ | | $\mu g/cm^2$ | |
| O+A1 + A2 + Bir (root zone) | | | | | | |
| Unburned | 494 | ---- | 21.8 | ---- | 513 | ---- |
| Burned** | 293 | ---- | 14.4 | ---- | 204 | ---- |
| Burned as % of unburned | 59.3% | ---- | 66.0% | ---- | 39.8% | ---- |
| | % | | % | | % | |
| % of rooting*** zone above A2 | | | | | | |
| Unburned | 61 | ---- | 54 | ---- | 71 | ---- |
| Burned** | 44 | ---- | 37 | ---- | 41 | ---- |

*O + A1 in burned areas, O only in unburned areas.

**average of burned, slash piled and burned, slash removed.

***percent of the total amount of the element in the root zone that is above the A2 horizon.

Table 5. Distribution of extractable calcium, potassium and phosphorus in the profile in unburned and burned sites.

| Portion of Profile and Site | Calcium Mean | Calcium S.D. | Potassium Mean | Potassium S.D. | Phosphorus Mean | Phosphorus S.D. |
|---|---|---|---|---|---|---|
| | $\mu g/cm^2$ | | $\mu g/cm^2$ | | $\mu g/cm^2$ | |
| Above A2* | | | | | | |
| (U) Unburned | 2246 | 339 | 518 | 127 | 28 | 22 |
| (P) Burned, slash piled | 1502 | 263 | 262 | 72 | 131 | 70 |
| (R) Burned, slash removed | 1079 | 71 | 208 | 4 | 63 | 21 |
| | $\mu g/cm^2$ | | $\mu g/cm^2$ | | $\mu g/cm^2$ | |
| O + A1 + A2 + Bir (root zone) | | | | | | |
| Unburned | 3843 | --- | 1031 | --- | 579 | --- |
| Burned** | 3062 | --- | 653 | --- | 744 | --- |
| Burned as % unburned | 79.7% | --- | 63.3% | --- | 129% | --- |
| | % | | % | | % | |
| % of rooting*** zone above A2 | | | | | | |
| Unburned | 58 | --- | 50 | --- | 5 | --- |
| Burned** | 40 | --- | 36 | --- | 13 | --- |

*O + A1 in burned areas, O only in unburned areas.
**average of burned, slash piled and burned, slash removed.
***percent of the total amount of the element in the root zone that is above the A2 horizon.

Table 6. Distribution of moisture retention and field moisture in the profile on unburned and burned sites.

| Portion of Profile and Site | †.06 atm Mean | †.06 atm S.D. | †.06-5 atm Mean | †.06-5 atm S.D. | Field moisture Mean | Field moisture S.D. |
|---|---|---|---|---|---|---|
| | cm $H_2O$ | | cm $H_2O$ | | cm $H_2O$ | |
| Above A2 or Bir* | | | | | | |
| (U) Unburned | 1.19 | .21 | .63 | ---- | 1.28 | .30 |
| (P) Burned, slash piled | .66 | .10 | .42 | ---- | .43 | .13 |
| (R) Burned, slash removed | .52 | .09 | .34 | ---- | .40 | .15 |
| | cm $H_2O$ | | cm $H_2O$ | | cm $H_2O$ | |
| O + A1 + A2 + Bir (root zone) | | | | | | |
| Unburned | 4.00 | ---- | 2.49 | ---- | 3.45 | ---- |
| Burned** | 3.29 | ---- | 2.14 | ---- | 2.40 | ---- |
| Burned as % unburned | 82.2% | ---- | 86.0% | ---- | 69.6% | ---- |
| | % | | % | | % | |
| % of rooting*** zone above A2 | | | | | | |
| Unburned | 30 | ---- | 25 | ---- | 37 | ---- |
| Burned** | 18 | ---- | 18 | ---- | 18 | ---- |

† moisture retention capacity in atmospheres
* above A2 horizon (moisture retention capacities)
above Bir horizon (field moisture)
** average of burned, slash piled and burned, slash removed
*** percent of total centimeters of water in the root zone that is above the A2 horizon (moisture retention capacity) and above the Bir horizon (field moisture).

Table 7. Probabilities that the observed differences in chemical and physical properties, in the profile above the A2 or Bir horizons, are due to chance.

| Property and Profile Portion | | Site Comparisons** | | |
|---|---|---|---|---|
| | | U vs P | U vs R | P vs R |
| Total carbon | (above A2) | .02 | .01 | .05 |
| Total nitrogen | " | .02 | .01 | .3 |
| Mineralized N | " | .05 | .02 | .4 |
| Calcium | " | .05 | .02 | .05 |
| Potassium | " | .05 | .02 | .2 |
| Phosphorus | " | .4 | .2 | .6 |
| *.06 atm tension | " | .05 | .02 | .3 |
| Field moisture | (above Bir) | .01 | .01 | .8 |

*Moisture retention capacity.
**U = Unburned; P = Burned, slash piled; R = Burned, slash removed.

the unburned site. This procedure yields data which represent the portion of the profile above the A2 horizon for the three treatments. When this was done, decreases significant at 5% or less were associated with both burning treatments compared to the unburned areas for all properties except available phosphorus (table 4, 5, 6 and 7). Available phosphorus had increased in both burned plots but the differences were not significant by the usual tests.

The sum of total carbon in the O and A1 horizons was significantly greater in the area where slash was piled before burning than where it was removed (tables 4 and 7). The same was true for extractable calcium (tables 5 and 7). These differences between the two burned areas in carbon and calcium above the A2 horizon were due primarily to differences in the A1 horizon (tables 1A and 2A) but were augmented by similar trends in the O horizons.

The summation values probably better represent differences in soil productivity since all of the surface organic materials and nutrients are being considered in the burned sites. The zone also represents a major region of root concentration.

## Horizon Relationships

In order to evaluate the extent to which burning may influence the major rooting zone of a soil, such as the one studied, it may be helpful to compare (on an absolute basis) the amount of nutrients and moisture retained in the unburned O horizon (zone primarily affected by burning) with the A2 plus Bir horizons. The data in tables 4, and 5, reveal that the unburned O horizon contains one-half or more of the total carbon (61%), total nitrogen (54%), mineralizable N (71%), extractable calcium (58%), and extractable potassium (50%), of the major rooting zone. On the other hand, the O horizon contains only 5% of the extractable phosphorus, and 25% of the readily available moisture retention capacity (table 6).

Considering the influence of burning (average of the two treatments) in this study it is seen that burning has altered the distribution of nutrients in the profile (tables 4 and 5). In all cases, except extractable phosphorus, the proportion of nutrients above the A2 horizon was reduced in the burned plots. This surficial zone now contains less than one-half the total carbon (44%), total nitrogen (37%), mineralizable N (41%), extractable calcium (40%), and extractable potassium (36%). The proportion of extractable phosphorus above the A2 horizon, however, increased following burning from 5 to 13% of the entire rooting zone. The zone above the A2 horizon following burning contains only 18% of the readily available moisture retention capacity as compared to 25% in the unburned plot, table 6.

## Soil Comparisons and Classification

A comparison of the results obtained for Grayling with those obtained by Franzmeier (1962) for Rubicon and Kalkaska sands (percent and ppm basis), shows a basic similarity of the three sand soils. The Bir horizon of the Grayling shows more development than that of the Rubicon (Bir) and less than that of the Kalkaska (Bh and Bhir). Concentrations of total carbon, total nitrogen, and extractable phosphorus fall between those of Rubicon and Kalkaska, but are generally closer to those of Kalkaska. Exchangeable base values were similar to those of the Rubicon.

The A2 horizon of the Grayling is only one-eighth the thickness of the Rubicon and the Kalkaska and as a whole would be influenced more greatly by the surface. The A2 of the Grayling shows much less eluviation than the Rubicon and the Kalkaska A2, as indicated by three times the percent of total carbon, 4 times the percent of total nitrogen, and 2 times the extractable phosphorus (ppm). Data on these properties for the A1 horizon of Grayling generally fell between those for Rubicon and Kalkaska; however, extractable phosphorus (ppm) for the slash piled and burned area was higher than either Rubicon or Kalkaska.

Assuming that the O horizons are similar in the three soils mentioned, burning would affect a smaller proportion of the major rooting zone in the Kalkaska. This is true because the above mentioned percentage data are generally higher in the Kalkaska Bhir and especially since the Grayling Bir is only 65% as thick as the Kalkaska. Although the percentage data in the Rubicon Bir are lower than the Grayling, some of this effect would be compensated for since the Grayling Bir is only 80% as thick as the Rubicon. The greater concentration of nutrients in the Grayling A2 would be compensated for by the much greater thickness in the Kalkaska and Rubicon A2 horizons. Bulk density in all three soils was similar. It may be concluded that although a smaller proportion of the Kalkaska rooting zone, and probably a smaller proportion of the Rubicon, may be influenced by burning, all three soils may be affected to an important degree.

Classification by Seventh Approximation

(Soil Survey Staff, 1960, Revised 1964)

The Bir horizon for Grayling does not meet the requirements for the spodic horizon in that it contains less than .58% total carbon and probably less than 1% $Fe_2O_3$. The $Fe_2O_3$ content was inferred by comparison with Rubicon and Kalkaska data obtained by Franzmeier (1962). The lack of diagnostic horizons and the coarse texture place Grayling in the Entisol order and Psamment suborder. The following is a complete classification of the Grayling described in this study. This classification agrees with the official classification (National Cooperative Soil Survey) for Grayling.

| | |
|---|---|
| Order . . . . . . . . . . . | Entisols |
| Suborder. . . . . . . . . . | Psamments |
| Great Group . . . . . . . . | Normipsamments |
| Family. . . . . . . . . . . | Sandy, Siliceous, Frigid, Acid |
| Series. . . . . . . . . . . | Grayling |

## Loss Mechanisms

Some mechanisms involved in the loss of nutrients from soils associated with burning include the following: gaseous loss, solid particle loss in smoke, and leaching or eluviation. Very little comprehensive work concerning these mechanisms has been done. Finn (1934) found losses of basic nutrient elements in both sandy and loamy soils that were due to leaching. Isaac and Hopkin (1937) proposed that loss of soil particles in smoke is of sufficient importance to warrant further study. The gaseous loss of carbon as $CO_2$ is an obvious effect; however, direct quantitative measures are not available. Isaac and Hopkin (1937) found that important quantities of nitrogen were lost to the atmosphere under the high temperatures of slash fires.

All three loss mechanisms may have been involved in the present study. The deep sandy profile would allow for a rapid leaching rate of the abundance of soluble bases released from the burning or even for eluviation of silt or clay size particles. Judging from the great size of the smoke cloud produced (1000 feet or more high), resulting from the burning of 44 acres of slash in three hours time, it would seem that significant amounts of soil particles and other gases could be lost in this manner. Ash was also noted drifting to the ground a short distance from the fire.

# VII. SUMMARY

## Influence of Burning on Soil Properties

1) Burning resulted in a reduction of the absolute amount of the following chemical elements in the O horizon: total organic carbon, total nitrogen, mineralizable nitrogen, and extractable calcium, potassium, and magnesium.

2) Burning resulted in an increase in the absolute amount of extractable phosphorus in the O horizon but this was not statistically significant except where slash had been piled before burning.

3) The pH in the O horizon was increased with burning while the cation exchange capacity was decreased.

4) Both field soil moisture and moisture retention capacity (centimeters of water in the O horizon) showed a reduction with burning.

5) The total dry matter of the O horizon was reduced with burning and is a major factor in the above changes.

6) Where the above properties, except pH and CEC, were summed to give total quantities in the soil above the A2 horizon all but extractable phosphorus were considerably reduced with burning. The proportions (of the entire root zone) of the total amount of the nutrient elements above the A2 horizon, except extractable phosphorus, were reduced in the burned areas.

7) Some significant differences were noted beneath the thin surficial mineral horizon, but most properties showed little changes deeper in the profile.

8) The percentage of total available nutrients remaining in the root zone of the burned areas compared to the unburned were as follows: 39.8% of the mineralizable nitrogen, 79.7% of the extractable calcium, 63.3% of the extractable potassium, and 129% of the extractable phosphorus. The readily available moisture capacity in the burned plots was 86.0% of that in the unburned plots. These changes are thought to significantly reduce the productivity of this already relatively unproductive soil.

## Additional Investigations Needed

The preceding study was a preliminary investigation of the influence of burning on a number of soil properties, and has shown certain important trends resulting from burning. In order, however, to show with more statistical certainty the influence of burning on sandy soil in Upper Michigan, further research is needed. Variables such as intensity and percent of the area burned, as well as other soil series, need to be considered. The mechanisms involving the loss of nutrient elements associated with burning need special attention. The influence of burning on the establishment and growth of the species to be regenerated on such sites also needs to be evaluated.

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APPENDIX

Table 8. Carbon and nitrogen in the horizons on unburned and burned sites.

| | Horizon | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | O | | A1 | | A2 | | Bir | | B3 |
| Site and Property | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean |
| Unburned | | | | | | | | | |
| Total carbon (%) | 10.3 | 2.99 | ---- | ---- | .85 | .21 | .50 | .05 | .11 |
| W.-B. carbon " | 9.66 | 3.15 | ---- | ---- | .81 | .23 | .47 | .05 | --- |
| *W.-B. resistant C (%) | .67 | .48 | ---- | ---- | .04 | .001 | .03 | .001 | --- |
| Total nitrogen " | .400 | .120 | ---- | ---- | .046 | .015 | .026 | .007 | --- |
| C/N ratio | 26 | 3.4 | ---- | ---- | 19. | 3.4 | 20 | 1.3 | --- |
| Burned, slash piled | | | | | | | | | |
| Total carbon (%) | 9.30 | 2.27 | 2.62 | .84 | 1.01 | .29 | .46 | .07 | .06 |
| W.-B. carbon " | 7.42 | 1.57 | 2.38 | .77 | .86 | .30 | .38 | .08 | --- |
| *W.-B. resistant C (%) | 1.88 | .99 | .25 | .07 | .15 | .001 | .08 | .002 | --- |
| Total nitrogen " | .377 | .071 | .097 | .034 | .037 | .008 | .027 | .004 | --- |
| C/N ratio | 26 | 8.0 | 28 | 2.9 | 27 | 2.4 | 18 | 1.0 | --- |
| Burned, slash removed | | | | | | | | | |
| Total carbon (%) | 7.37 | 2.01 | 1.81 | .41 | .90 | .14 | .38 | .06 | .07 |
| W.-B. carbon " | 6.21 | 1.61 | 1.75 | .42 | .82 | .13 | .34 | .07 | --- |
| *W.-B. resistant C (%) | 1.16 | .63 | .06 | .002 | .08 | .06 | .04 | .002 | --- |
| Total nitrogen " | .346 | .109 | .074 | .019 | .036 | .010 | .022 | .002 | --- |
| C/N ratio | 22 | 1.7 | 25 | 3.4 | 26 | 5.0 | 18 | .57 | --- |

*W.-B. resistant carbon was found by subtracting Walkley-Black carbon data from total carbon data.

Table 9. Extractable calcium, potassium, magnesium and phosphorus of horizons on unburned and burned sites.

| | Horizon | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | | A1 | | A2 | | Bir | | B3 | | C |
| Site and Property | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean |
| | (ppm) | | (ppm) | | (ppm) | | (ppm) | | (ppm) | | (ppm) |
| Unburned | | | | | | | | | | | |
| Calcium | 749 | 20 | ---- | ---- | 92 | 17 | 40 | 6 | 68 | 24 | |
| Potassium | 177 | 57 | ---- | ---- | 19 | 3 | 14 | 9 | 10 | 3 | |
| Magnesium | 91 | 22 | ---- | ---- | 14 | 3 | 8 | 3 | 1 | 0 | |
| Phosphorus | 10 | 2 | ---- | ---- | 4 | 1 | 16 | 5 | 15 | 5 | |
| Burned, slash piled | | | | | | | | | | | |
| Calcium | 1156 | 278 | 207 | 35 | 86 | 12 | 54 | 20 | 53 | 22 | 58 |
| Potassium | 156 | 32 | 44 | 9 | 24 | 4 | 14 | 0 | 8 | 1 | 8 |
| Magnesium | 126 | 44 | 24 | 4 | 9 | 4 | 2 | 1 | 1 | 0 | 1 |
| Phosphorus | 70 | 20 | 24 | 12 | 11 | 6 | 20 | 5 | 18 | 6 | 12 |
| Burned, slash removed | | | | | | | | | | | |
| Calcium | 711 | 49 | 124 | 28 | 66 | 15 | 43 | 14 | 51 | 16 | 64 |
| Potassium | 133 | 46 | 25 | 3 | 17 | 5 | 8 | 4 | 8 | 1 | 7 |
| Magnesium | 53 | 15 | 13 | 6 | 7 | 1 | 3 | 0 | 1 | 0 | 1 |
| Phosphorus | 20 | 38 | 9 | 0 | 4 | 3 | 16 | 3 | 18 | 3 | 19 |

Table 10. Mineral nitrogen in horizons on unburned and burned sites before and after incubation.

| Site and Property | Horizon | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | O | | A1 | | A2 | | Bir | |
| | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. |
| Unburned | | | | | | | | |
| N after incubation (ppm) | 136 | 71.4 | ---- | ---- | 6.77 | .79 | 4.71 | .58 |
| N before incubation " | 9.82 | 4.99 | ---- | ---- | 1.33 | 1.19 | .63 | .22 |
| Mineralizable N " | 126 | 66.9 | ---- | ---- | 5.44 | 1.40 | 4.08 | .79 |
| Burned, slash piled | | | | | | | | |
| N after incubation (ppm) | 77.7 | 24.9 | 21.9 | 4.67 | 11.1 | 3.00 | 5.44 | 2.32 |
| N before incubation " | 27.9 | 7.66 | 4.58 | 3.63 | 1.53 | .00 | 2.20 | .19 |
| Mineralizable N " | 49.9 | 18.3 | 17.3 | 11.1 | 9.53 | 3.00 | 3.24 | 2.5 |
| Burned, slash removed | | | | | | | | |
| N after incubation (ppm) | 57.9 | 6.52 | 13.0 | 5.41 | 9.15 | 3.74 | 3.94 | .80 |
| N before incubation " | 10.7 | 5.34 | .76 | .38 | .57 | .22 | .90 | .25 |
| Minearlizable N " | 47.2 | 6.3 | 12.2 | 5.40 | 8.58 | 4.00 | 3.04 | .75 |

Table 11. Base exchange properties and pH of horizons on unburned and burned sites.

| | Horizon | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | O | | A1 | | A2 | | Bir | | B3 | | C |
| Site and Property | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean |
| Unburned | | | | | | | | | | | |
| Ca(% saturation) | 16.4 | 1.9 | ---- | ---- | 8.1 | 2.3 | 3.6 | 1.9 | 39.2 | 7.9 | |
| K " | 2.0 | .4 | ---- | ---- | .8 | .2 | .7 | .4 | 2.0 | .4 | |
| Mg " | 3.0 | .6 | ---- | ---- | 1.4 | 1.0 | .5 | .0 | .0 | .0 | |
| Base saturation (%) | 21.4 | 1.0 | ---- | ---- | 10.3 | 2.4 | 4.8 | 1.6 | 41.2 | 7.9 | |
| *Exchange capacity | 22.7 | 2.6 | ---- | ---- | 5.0 | .6 | 4.4 | 1.0 | .8 | .4 | |
| pH | 4.8 | .2 | ---- | ---- | 4.8 | .2 | 5.5 | .2 | 5.8 | .3 | |
| Burned, slash piled | | | | | | | | | | | |
| Ca(% saturation) | 33.9 | 10.2 | 8.7 | 2.5 | 6.7 | 2.7 | 6.2 | 2.0 | 37.1 | 10.6 | 55.0 |
| K " | 2.3 | .3 | .9 | .4 | .9 | .3 | .9 | .4 | 2.2 | .9 | 3.5 |
| Mg " | 5.9 | 1.8 | 1.2 | .2 | .0 | .0 | .0 | .0 | .0 | .0 | .0 |
| Base saturation(%) | 42.1 | 11.6 | 10.8 | 2.8 | 7.6 | .8 | 7.1 | 2.0 | 39.3 | 10.6 | 58.5 |
| *Exchange capacity | 17.1 | 3.0 | 12.4 | 4.4 | 6.4 | 1.5 | 3.5 | 1.7 | .6 | .2 | .4 |
| pH | 5.5 | .3 | 5.0 | .3 | 4.8 | .3 | 5.5 | .1 | 5.8 | .1 | 6.0 |
| Burned, slash removed | | | | | | | | | | | |
| Ca(% saturation) | 24.0 | 4.7 | 7.7 | 2.6 | 6.0 | 2.2 | 6.8 | 2.5 | 43.7 | 18.4 | |
| K " | 2.2 | .8 | .8 | .2 | .7 | .2 | .8 | .5 | 3.5 | 2.2 | |
| Mg " | 2.7 | .6 | .7 | .0 | .0 | .0 | .0 | .0 | .0 | .0 | |
| Base saturation(%) | 28.9 | 5.8 | 9.2 | 2.7 | 6.7 | 2.2 | 7.6 | 2.5 | 47.2 | 18.4 | |
| *Exchange capacity | 14.5 | .4 | 7.8 | 2.6 | 5.3 | 1.7 | 2.2 | .1 | .4 | .0 | |
| pH | 5.3 | .2 | 5.2 | .2 | 5.0 | .1 | 5.5 | .2 | 6.0 | .3 | |

*m.e./100 grams of soil

Table 12. **Physical properties of horizons on unburned and burned sites.**

| Site and Property | Horizon O Mean | O S.D. | A1 Mean | A1 S.D. | A2 Mean | A2 S.D. | Bir Mean | Bir S.D. | B3 Mean |
|---|---|---|---|---|---|---|---|---|---|
| Unburned | | | | | | | | | |
| Bulk density (g/cc) | .68 | .06 | ---- | ---- | 1.22 | .05 | 1.40 | .02 | 1.53 |
| Thickness (cm) | 4.3 | .21 | ---- | ---- | 2.60 | .45 | 24 | .57 | 30 |
| g soil/cm$^2$ | 2.96 | .32 | ---- | ---- | 3.24 | .60 | 32.8 | 1.38 | 45.9 |
| Total porosity (% vol.) | 68.6 | 3.48 | ---- | ---- | 51.1 | 4.30 | 45.2 | 1.11 | 38.6 |
| Cap. porosity " | 27.3 | 5.42 | ---- | ---- | 10.9 | 1.20 | 10.6 | .30 | 5.6 |
| Non. cap. porosity " | 41.3 | 7.90 | ---- | ---- | 40.2 | 4.06 | 34.6 | 1.00 | 33.0 |
| Field moisture (% wt.) | 35.2 | 13.1 | ---- | ---- | 7.85 | 2.14 | 6.26 | 1.13 | ---- |
| Burned, slash piled | | | | | | | | | |
| Bulk density (g/cc) | .96 | .16 | 1.08 | .09 | 1.26 | .07 | 1.41 | .04 | 1.58 |
| Thickness (cm) | .85 | .10 | 2.60 | .56 | 1.60 | .98 | 24 | .51 | 30 |
| g soil/cm$^2$ | .83 | .2 | 2.84 | .64 | 2.00 | 1.32 | 34.1 | .78 | 47.4 |
| Total porosity (% vol.) | 62.2 | 7.20 | 52.6 | 5.21 | 48.9 | 11.1 | 44.9 | 1.00 | 37.7 |
| Cap. porosity " | 26.9 | 2.93 | 17.5 | .61 | 10.7 | .56 | 10.5 | .65 | 6.00 |
| Non. cap. porosity " | 35.4 | 4.42 | 35.1 | 4.60 | 38.2 | 11.2 | 32.9 | .93 | 31.8 |
| Field moisture (% wt.) | 11.4 | 4.63 | ---- | ---- | ---- | ---- | 5.61 | .69 | ---- |
| Burned, slash removed | | | | | | | | | |
| Bulk density (g/cc) | 1.02 | .13 | 1.15 | .07 | 1.22 | .10 | 1.44 | .04 | 1.56 |
| Thickness (cm) | .85 | .13 | 2.20 | .24 | 1.80 | .37 | 24 | .81 | 30 |
| g soil/cm$^2$ | .86 | .14 | 2.55 | .17 | 2.13 | .69 | 34.4 | 1.92 | 47.1 |
| Total porosity (% vol.) | 56.8 | 3.74 | 47.4 | 8.20 | ---- | ---- | 42.7 | .90 | 37.7 |
| Cap. porosity " | 23.6 | 2.54 | 15.2 | 2.40 | ---- | ---- | 10.4 | .78 | 6.2 |
| Non. cap. porosity " | 33.2 | 1.35 | 32.2 | 5.73 | ---- | ---- | 32.3 | .57 | 31.5 |
| Field moisture (% wt.) | 9.10 | 5.81 | ---- | ---- | ---- | ---- | 5.44 | .31 | ---- |

Table 13. Moisture retention of horizons on unburned and burned sites.

| | Horizon | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | O | | A1 | | A2 | | Bir | | B3 |
| Site and Property | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean | S.D. | Mean |
| Unburned | | | | | | | | | |
| Saturation (% wt.) | 101 | 12.8 | ---- | ---- | 42.0 | 3.59 | 32.6 | 1.33 | 25.2 |
| .01 atm " | 72.5 | 11.4 | ---- | ---- | 37.0 | 3.90 | 31.9 | 1.27 | 24.9 |
| .02 " | 65.5 | 11.4 | ---- | ---- | 32.2 | 3.51 | 29.2 | 1.44 | 23.9 |
| .03 " | 55.6 | 8.98 | ---- | ---- | 19.4 | 3.33 | 17.9 | .36 | 17.8 |
| .04 " | 46.6 | 12.6 | ---- | ---- | 12.4 | 1.78 | 12.3 | 1.76 | 6.8 |
| .06 " | 40.2 | 9.32 | ---- | ---- | 8.99 | 1.23 | 7.68 | .26 | 3.64 |
| .33 " | 25.3 | ---- | ---- | ---- | 4.08 | ---- | 3.68 | ---- | ---- |
| 1.0 " | 20.1 | ---- | ---- | ---- | 3.11 | ---- | 3.09 | ---- | ---- |
| 5.0 " | 19.0 | ---- | ---- | ---- | 2.65 | ---- | 2.63 | ---- | ---- |
| Burned, slash piled | | | | | | | | | |
| Saturation (% wt.) | 67.1 | 19.0 | 50.3 | 9.22 | 39.5 | 8.01 | 32.1 | 1.29 | 24.0 |
| .01 atm " | 61.6 | 16.5 | 46.8 | 7.88 | 37.5 | 9.58 | ---- | ---- | ---- |
| .02 " | 56.4 | 13.6 | 41.8 | 6.57 | 33.5 | 9.48 | 29.3 | 1.46 | 22.6 |
| .03 " | 49.6 | 11.2 | 31.6 | 3.48 | 19.6 | 4.16 | 19.9 | .14 | 16.9 |
| .04 " | 39.4 | 8.27 | 22.3 | 2.43 | 11.9 | 1.51 | 11.9 | 2.28 | 7.58 |
| .06 " | 28.9 | 8.07 | 16.7 | 1.99 | 8.65 | .70 | 7.26 | .83 | 3.80 |
| .33 " | 21.7 | ---- | 6.89 | ---- | 4.22 | ---- | 3.63 | ---- | ---- |
| 1.0 " | 19.6 | ---- | 5.55 | ---- | 3.32 | ---- | 3.10 | ---- | ---- |
| 5.0 " | 18.0 | ---- | 4.90 | ---- | 2.50 | ---- | 2.78 | ---- | ---- |
| Burned, slash removed | | | | | | | | | |
| Saturation (% wt.) | 56.6 | 12.0 | 41.7 | 11.2 | ---- | ---- | 29.8 | 1.29 | 24.0 |
| .01 atm " | 52.6 | 11.8 | 37.6 | 9.68 | ---- | ---- | ---- | .37 | ---- |
| .02 " | 48.4 | 10.0 | 34.1 | 9.56 | ---- | ---- | 27.5 | ---- | 21.8 |
| .03 " | 43.0 | 9.48 | 26.6 | 7.88 | ---- | ---- | 19.4 | 1.81 | 14.4 |
| .04 " | 34.0 | 8.40 | 18.3 | 5.10 | ---- | ---- | 13.5 | 2.80 | 6.00 |
| .06 " | 23.6 | 5.91 | 13.4 | 3.41 | ---- | ---- | 7.26 | .74 | 3.96 |
| .33 " | 15.1 | ---- | 5.79 | ---- | 3.92 | ---- | 3.10 | ---- | ---- |
| 1.0 " | 13.6 | ---- | 4.55 | ---- | 3.12 | ---- | 2.69 | ---- | ---- |
| 5.0 " | 12.6 | ---- | 3.64 | ---- | 2.48 | ---- | 2.18 | ---- | ---- |