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A Study of Slash Burning
and its effect on a
British Columbia Forest Soil

by

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Abstract:

Slash burning has been practiced in British Columbia since 1930 with little regard for the regeneration of forests or the soils which support them. A study of burned soils on Vancouver Island was carried out in order to determine whether or not the inherent site quality of forest soils is altered through burning and whether any such alteration is permanent or exhibits a cyclic trend. For this purpose samples were taken from the surface and subsurface of sites with the same soil type burned in different years and were compared to similar samples from an adjacent virgin site.

It was concluded that slash burning on coniferous forest soils of Vancouver Island causes:

(1) lack of natural regeneration for 10 - 15 years.

(2) a gradual increase in surface soil pH due to the "pumping" action of fast-growing herbs and shrubs which causes bases to be brought to the surface from the subsoil.

(3) increased exchangeable hydrogen in the subsoils of burned sites apparently due to action of herbaceous growth in removing bases to the surface and also to increased biological activity.

(4) an initial increase in exchangeable base content of the burned surface which begins to disappear due to leaching in 3 or 4 years.

(5) increased magnesium and potassium in the subsoils of burned sites as a result of leaching these elements from the accumulated ash.

(6) initial increase in phosphorus content of the surface burned soil with a subsequent removal of this element to the subsoil due to the solvent action of percolating rain water. This phenomenon is especially true in the case of severely burned soils.

(7) increase in ammonia content in both surface and subsurface soils after burning due to stimulated ammonification.

(8) increased nitrification and loss of nitrate by leaching with severe burning.

(9) migration of colloidal organic matter and clay particles to the subsoil.

(10) increased total nitrogen content and a consequent decrease in the carbon-nitrogen ratio of the subsoil.

(11) a reduction in the moisture holding capacity of the surface soil immediately following burning.

As a result of this study the following recommendations were made:

(1) due to the inherent variability of all soils it is advisable to carry out any further studies of slash burning on several sites over a period of 15 to 20 years with annual sampling and analysis of the soil

from each site. Only in this way is it possible to eliminate soil variability so that the effects of burning are elucidated.

(2) in conjunction with soil studies after burning, it is important to analyze the herbaceous growth invading burned sites as a means of correlating changes in soil nutrients with changes in vegetative growth.

(3) careful studies with respect to seedling survival and response on burned soil in this area are necessary to determine whether or not artificial regeneration will be economically feasible.

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INTRODUCTION

Since the early days of settlement, logging has occupied an important place in the economic life of British Columbia and yet the care of our forests and the soils which produce them have until recently been almost entirely ignored. Forested areas have been logged and the slash resulting has been burned without regard for future regeneration of tree growth. In other instances, some areas, after being burned, have been put to entirely different uses such as grazing or cropping regardless of suitability of the soil for such purposes. Thus serious losses of our natural and basic resources have resulted because of this waste and misuse of forests and forest soils.

In some quarters an effort is being made to focus attention on the factors which determine the success of both natural and artificial reforestation. A number of factors are involved but three outstanding ones are the effect of slash burning, the forest sites, and the soils. The first named, in spite of years of discussion is still a controversial topic. The study of forest site indices is now receiving some attention and the conception that soil is the basic resource of forestry is still scarcely acknowledged.

Lutz and Chandler (48), enumerating the differences between forest and agricultural soils simply designate forest soils as those which are relatively unsuitable for agriculture. Such, for instance, include soils extremely low in fertility or moisture holding capacity, i.e. sands and loamy sands, stony and rock outcrop areas, and those of rough topography. Since soils for farming purposes have been selected it may be assumed that they do not vary as much as do forest soils of the same region. Bates (7) observes that forest soils are often in situ, simple in derivation, and quite unbalanced with respect to chemical, physical, and biological properties. This is especially the case when a soil develops from a single geological formation and consequently the parent material is extremely important in studying forest soils.

The problem of firing has been a controversial one in agriculture and in forestry for many years. The burning of slash accumulating as a result of modern logging methods on the British Columbia coast is now compulsory and has been practiced since about 1930. Large areas are broadcast burned every year to reduce the fire hazard resulting from accumulation of large quantities of dry slash. The usual logging operation leaves an average of 9000 cubic feet of logs and large branchwood per acre. In addition, there is a considerable amount of bark, chips, twigs, branchwood, and slabs averaging about 15000 cubic feet per acre. This tremendous accumulation of material becomes a fire hazard of prime importance in this area during the hot, dry summer period. Controlled slash burning has been advocated in the past few years to remove this excessive logging debris and thereby eliminate the possibility of accidental fires spreading to adjacent virgin forests.

The object of the study reported at this time is to determine whether or not the inherent site quality or the potential productivity of forest land is altered through burning and whether any such alteration is permanent or exhibits a cyclic trend.

The main factors which one would logically expect to influence the effects of burning on a soil are: the intensity of burn, local climate, topography, soil type, rapidity of plant succession, and amount and type of slash.

A chemical investigation will be the prime approach to the problem and is, in fact, the only feasible means of study since in situ samples for physical analyses could not be procured due to the extreme stoniness of the area sampled. In the author's opinion, it is doubtful that the physical properties of most of our coast forest soils vary materially under natural conditions or due to burning. However, physical studies such as determinations of non-capillary pore space, infiltration capacity, et cetera, should be made on any heavier textured forest soils. Such research would enable one to determine more fully the effect of burning on the erodability of the soil. The chemical changes caused by burning forest soils have been studied to a certain extent in Oregon (38) but no such research has been carried out on British Columbia soils.

REVIEW OF LITERATURE

A Summary of Logging Practices in British Columbia

Garman and Barr (24) made a study of natural regeneration of logged-over lands on Vancouver Island and the adjacent mainland. They surveyed the problem as it was in the year 1930 and stated that the soils and climate of this area are ideal for the silvical characteristics of the native species (Douglas fir, Western hemlock, Western red cedar, and true firs). Consequently natural regeneration was rapid and prolific so that most of the blocks of cut-over land, typical of logging operations on the west coast prior to 1915, had become well-stocked with thrifty stands of second growth.

The earliest logging operations were definitely selective in nature and only the largest and best trees were felled. As a result of this selection many defective or misshapen mature trees were left standing and since horses or oxen were used to haul logs, little or no damage was done to smaller trees and saplings. Thus, a considerable amount of advance growth remained to partially restock the cut-over area, and there was no lack of seed trees to regenerate the openings. The logging slash consisted of only a few tops and branches of felled trees which were prevented from drying too rapidly during the summer by the remaining trees and undergrowth which shaded them.

Later, horses and oxen were replaced by steam-powered machinery and more intense cutting methods followed with the result that more timber was exploited and many small trees were knocked down in skidding logs. However, these machines were slow enough to leave some unfelled trees standing as a source of seed. The fire hazard became greater because of larger areas and more slash but any fires which occurred were usually restricted to a comparatively small area.

After the first World War the "high lead" and "sky line" systems of logging were developed. The use of high-speed machinery with these methods caused practically every living tree not selected for cutting to be knocked down in skidding the logs. Consequently, an enormous amount of debris accumulated and became exceedingly inflammable during the summer since it was fully exposed to the dehydrating action of sun and wind. Under such conditions disastrous fires were inevitable. These fires destroyed not only seeds on the ground but also the few surviving small or broken trees which were the only means of producing seeds within the boundaries of the cut-over areas. Logging in this region was conducted on such a large scale and at such high speed that a company covered several hundred acres in one year. Fires sweeping through these large areas resulted in complete devastation with no reproduction or seed supply on the burned land.

This was the situation as reported by Garman and Barr in 1930. Today the logging method is the same except that even larger areas are logged every year by each company since faster and more powerful machines are now being used.

To reduce the fire hazard in these tremendous accumulations of slash the practice of slash burning has been inaugurated.

There has been no study made of the effects of slash burning on British Columbia forest soil and only one such study (38) has been carried out on Washington and Oregon soils. There is, however, an abundance of literature on the general effects of burning in all parts of North America, Europe, and Asia. The writings pertinent to this study will be dealt with mainly.

The Effects of Slash Burning on Reduction of Fire Hazard

McCulloch, Assistant State forester in Oregon (52), states that "the purpose of most burning is not only immediate protection but long time hazard reduction so that a new forest can be grown on the area within economic limits and with some assurance of safety from fires." He is also of the opinion that slash should not be burned where 30 percent or less of the stand has been cut, where the residual stand is made up of thin-barked or young trees, where site damage will result, or where "loss of advanced reproduction will outweigh the gain of temporarily decreased fire danger." However, he still advocates burning on clear cut areas; where large areas of slash adjoin or make it difficult to get into an area of high risk; and where slash is so deep as to prevent reproduction.

Munger and Mathews (54) have found that slash burned areas in south-western Washington generally have a lower fire hazard for a 10 year period following burning but after 15 years there is no difference between burned and unburned areas in this respect. Thus, from the point of view of protection, slash burning has a slight advantage. However, this is not the case in the fog belt along the Pacific Coast. One logging company has burned about one-half of its area of slash in the past 20 years and reports that almost 100 percent of this burned area has been reburned accidentally at least once whereas only 50 percent of the unburned area has had accidental fires. These writers also say that unburned slash usually decomposes quickly but the bracken, fireweeds, and vines which soon develop on burned-over areas build up an immediately hazardous source of fuel for conflagrations.

As an example, a total of 60,000 acres of logged-over lands have been accidentally burned during a recent 4-year period. Of this total, 17,000 acres occurred in unburned slash 1 to 3 years old, whereas only 245 acres were in unburned slash over 3 years old. In the same period 15,500 acres of recently burned lands were reburned thereby augmenting any injurious effects of the first fire. The authors conclude that this circumstantial evidence is a good argument for the preservation of residual timber in logging and in burning.

Thus, it seems that although many workers favour the practice of slash burning to reduce fire hazards, it is worth considering the facts presented in the above example where slash burning has proven to be economically unsound as a means of hazard reduction.

The Effects of Burning on the Natural Regeneration of Conifers

Isaac (37) studied the effect of burning on seedling survival in plots near the Wind River Experimental Forest in south-western Washington. The first hot weather in May, 1929, killed 100 percent of the seedlings on the burned and blackened soil as compared to a loss of 16 percent on the yellow unburned soil. The tremendous losses suffered on the darkened surfaces were entirely due to heat injury of the seedlings at the soil surface where a temperature of 135°F. was registered. Higher temperatures a month later did not cause further loss of plants on the yellow soil. Throughout the duration of the experiment there was a heavy loss of seedlings on the yellow soil due to insects, damping-off, and drought which was in addition to the loss already suffered through heat injury. Obviously, seedling losses are serious in the south-western Washington region and as Isaac points out, shading through debris or vegetation is effective in aiding seedling survival. This observation is further supported by Garman and Barr (24) who carried on similar studies in British Columbia. At the same time, they reported that the loss of organic matter due to burning reduces the moisture holding capacity of forest soils, and this is substantiated by Bouyoucos (11). With the high surface temperatures produced by direct exposure of the blackened soil to the sun these burned soils become extremely dry during the prevalent summer drought. Munger and Mathews (54) also support the observation that seedling establishment is retarded by slash burning and add that burning is disadvantageous to most residual seeds. In contrast to the foregoing, Godwin (26) observed that repeated fires cause failures in restocking but he showed that fires occurring before logging seem to aid reproduction on Vancouver Island in that partial removal of litter permits freer contact of the seed with soil. Isaac (37) stresses the importance of burned soils being unable to retain moisture as well as unburned soils in the dry summers of the Pacific Northwest where soil moisture is a critical factor in forest regeneration. He reports that, in general, severe broadcast burns are detrimental to establishment of seedlings, whereas a light burn usually does little harm and sometimes may be slightly beneficial.

Isaac (39) studied the vegetative succession following logging in the Douglas fir region with special reference to fires. After destruction by fire the plant association in this region goes through four stages of succession before reaching the climax type unless subjected again to fires or logging. Isaac named these stages the "moss-liverwort", "weed-brush", "intolerant even-aged Douglas fir", and the "tolerant all-aged hemlock-balsam fir", the last of which will persist. The weed-brush stage is very subject to fire and perpetuation of this stage is readily brought about by successive fires. Light cover seems to be beneficial to the survival of coniferous seedlings whereas heavy cover is detrimental. This weed-brush stage is often so dense that forest regeneration is prohibited. A minor part of the weed-brush stage is formed from some virgin forest ground-cover species whose underground parts survive fires. The remaining portion of this stage is made up of such species as bracken, fireweed, blackberry, and snowbrush. Some species soon disappear but others persist until crowded out by the vigorous brush cover and the regenerating forest. Isaac concludes that "successive fires impoverish the soil, favor the herbaceous species, retard the brush species and eliminate from the succession the coniferous seedlings that would go to make up the new forest."

In Washington and Oregon the relationship of slash burning and natural regeneration has been studied for over twenty years (54). It has been shown that although thick-barked trees usually survive severe fires the residual stand seed production declines appreciably after a fire. Reproduction studies showed only 25 percent restocking on burned areas as compared to 50 percent on unburned areas. After 30 years had passed since logging, 80 percent regeneration was observed on burned areas whereas it was 95 percent on unburned areas. Mathews and Munger (54) also report that restocking is retarded by large amounts of slash on a heavy burn. Less slash or a less severe burn are more conducive to stocking but the best reproduction is found on very light burns or on areas covered with a sparse layer of slash. In selectively logged stands, slash burning is disastrous to both young and old stands due to fire injury degrading the timber.

Garman and Barr (24) state that seed is disseminated by wind in effective quantities up to only one-quarter of a mile. McArdle and Isaac (50) report that 1000 feet is the average distance from the nearest timber that adequate restocking will occur. Since the only source of seed on large burns resulting from modern logging methods is marginal timber, much of the burned over land is too far away from the seed source.

These workers state also that single seed trees scattered over logged-off areas are of little or no value since many are permanently injured by logging, burning or being blown down by the wind. Five years after logging, less than half the original number of seed trees were left standing in one area of observation. About 40,000 seeds are produced in a good year by an average seed tree (seed production is actually very erratic from year to year) but at least 400,000 seeds are required to restock an acre. Since Douglas fir seeds are very desirable to birds and rodents there is seldom enough seed left over for regeneration of the forest unless a sufficient amount of seed over and above that required for the animal population is made available. McArdle and Isaac say that 66 - 95 percent of the annual seedling crop at the Pacific Northwest Forest Experiment Station die from the following causes in approximate order of their importance: heat injury to the stem (sun scald), drought, rodents, competition of other vegetation, and frost.

Max Paulik (55) condemns the present logging methods because no natural regeneration occurs unless clear cutting is restricted to areas of about half an acre and ample seed source is present. He claims that 2,000 to 3,000 board-feet should be left on each acre in the form of middle aged viable timber in order to secure proper regeneration.

From this review, it would appear obvious that the practice of burning slash is detrimental to the survival of coniferous seedlings thereby preventing natural regeneration.

The Effects of Burning on the Flora of Forest Soils

Fowells and Stevenson (23) found that nitrification in Oregon forest soils is stimulated by burning and the consequent liberation of basic elements. Wahlenberg et al (66) showed that both burning and grazing are causative factors in increasing bacterial numbers in soil but it is well to observe that their observations are based on only one determination. These results are, however, in agreement with those of Sushkina (64) who reports that fire always has a stimulating effect upon nitrification in the forest soils of Russia. Moderate burning is more favourable and nitrification apparently starts within two days or so after burning. This effect of burning on soils lasts for five years according to Sushkina.

Waksman (69) made a thorough study of the literature in addition to his own experimentations on the effects of partial sterilization of soils which is heating to 140°F. or treatment with volatile antiseptics. This treatment was found to increase the rate of oxidation as well as the numbers of bacteria according to Russell and Hutchinson, Hiltner and Stormer, and Wahlenberg et al. Complete sterilization of a soil can only be accomplished under fifteen pounds steam pressure for two hours or for one hour on seven consecutive days in flowing steam. Thus the degree of sterilization depends upon the temperature and the length of treatment and numerous workers have found that heavier soils require a longer heating period to sterilize partially than do sandy soils. Partial sterilization of soil causes destruction of certain groups of organisms leaving certain groups of fungi and bacteria uninjured with their growth enhanced by the more favourable medium. Thom and Ayers[1] show that temperatures of 140°- 150°F. cause the destruction of large forms of living protozoa, fungus mycelium and spores, as well as vegetative cells of various bacteria. Kruger and Schneindewind suggest that the solubility of soil minerals is increased due to heating. Their results are summarized as follows:

Yield of mustard, in grams per pot

Fertilization:	No Manure:	No NO_3:	Complete Min. Fert.:	No NO_3 plus complete Mineral Fertilizer:
Untreated soil	17.3	17.5	33.7	50.9
Heated soil	33.2	36.5	46.9	62.4

Increased solubility of mineral constituents and soil organic matter due to heating was also observed by Franke. These workers results are in agreement with those quoted previously.

Heating of the soil thus causes a definite change in the microbial population and on subsequent remoistening of the soil non-spore forming bacteria showed the greatest increase in numbers. The fungi make very rapid growth once introduced into sterilized soil (Tokugama and Emoto). Elveden says that the nitrifying bacteria are destroyed by sterilization and ammonia accumulates due to greater rate of organic matter decomposition by micro-organisms. Temperatures

1 Names of authors referred to on this page were selected from a literature survey by Waksman (69).

higher than 212°F. render the soil less fertile due to formation of toxic substances such as guanine, arginine, and dihydroxy-stearic acid which inhibit the growth of higher plants (Pickering). On the other hand, temperatures lower than 212°F. generally improve the soil as a medium for bacterial growth by rendering it more fertile due to the increase of soluble organic matter and bases. The increased number s of bacteria decompose more organic matter thus causing greater liberation of available nitrogen which favours the growth of plants.

Waksman (70) states that if a soil which has been partially sterilized becomes reinfected with a disease producing organism, the infection may become more severe. He suggests that a mixture of saprophytic organisms be introduced into such a soil to counteract any injurious effect of parasites. Anderson (2) reports that damping-off of seedlings is induced when wood ashes accumulate. This is apparently due to the higher pH and is more extreme with softwood ashes than with hardwood ashes. Wakely and Muntz (67) found that light burning controlled the brown spot disease of longleaf pine but did not injure the trees. Daubenmire (17) discusses parasitism resulting from fire injury of trees.

Partial sterilization due to slash burning forest soils is, therefore, a possibility to be considered and its effect would, in all probability, manifest itself in seedling response.

The Effects of Burning on the Chemical Properties of Forest Soils

Wahlenberg et all (66) found that frequently burned-over Mississippi soils had a higher pH, contained more organic matter, total nitrogen and replaceable calcium than adjacent unburned soils. On the other hand, Isaac and Hopkins (38) showed that the usually heavy slash fire almost destroyed the duff layer of western Washington soils and in so doing caused the following:

(1) Loss of 25 tons (89%) organic matter per acre

(2) pH change in duff from 4.95 - 7.6

(3) Loss of about 435 pounds of nitrogen per acre

(4) An increased supply of available plant nutrients in the surface soil

(5) A loss of some duff mineral constituents in smoke

(6) Some dehydration of secondary minerals

Isaac and Hopkins state that the increased supply of available plant nutrients immediately after a slash fire tends to cause luxuriant crowns and shallow root systems on first year seedlings of Douglas fir so that they cannot survive normal summer drought. They corroborate the statement of Garman and Barr (24) that drought conditions of the Pacific Northwest are accentuated by losses of organic matter due to burning. They add that replenishment of this loss cannot be expected during the 10 year period required for reseeding of Douglas fir. The authors are of the opinion that the harmful effects of fires outweigh any beneficial effects.

Barnette and Hester (6) studied the effects of burning litter in Florida and showed by analyses that a total loss of 2,888 pounds of organic matter per acre per year occurred due to burning annually for 42 years. This was accompanied by a loss of 27 pounds of nitrogen per acre per year and an increase in replaceable calcium in the surface 9 inches of soil due to accumulation of ash constituents in this surface soil. They also found an increase in pH and a decrease in hygroscopic moisture due to burning and state that burning indubitably causes the potential supply of plant nutrients to be depleted in addition to destroying the potential organic matter supply of the soil.

Wilde (76) says that potash and phosphates from organic remains are made readily available and acidity is decreased by the "old practice of ground firing." His opinion is one of objection due to loss of nitrogen and loss by leaching of released bases in the absence of organic colloids. Alway and Rost (1) studied burning in Minnesota and report loss of organic material, rise in pH of the surface soil and loss of nitrogen. They maintain that any injury or benefit to productivity due to burning can be attributed to the destruction of the surface layer (forest floor) and that calcium, phosphorus and potassium do not escape in smoke as Isaac and Hopkins (38) have stated.

Eneroth's (20) work in Sweden led him to conclude that higher pH values and higher content of available calcium after fires were associated with better development of tree seedlings to make conditions more favorable for conifer growth. Sims et al (62) say that the essential bases made available by burning are leached deeply into sandy soils especially and are consequently lost as far as plant use is concerned.

The results reported by various workers as outlined here have been substantiated by numerous other experimenters (17,18,23,24,41,48,61,67). Thus, the consensus of opinion seems to be that burning is detrimental to the chemical nature of forest soils due to loss of organic materials, nitrogen, and soluble bases.

The Effects of Burning on the Physical Properties of Forest Soils

The infiltration rate of forest soils was studied (3) in Missouri under hardwood stands on seven soil types which were loamy and sandy loam in texture. It was found that burning annually reduced the infiltration rate of water into the soil an average of 38% as compared to rates in soils protected from fire and grazing for approximately five to six years. The direct effect of the hardwood litter was tested by removal of the forest floor from four soil types and the infiltration rates were found to be reduced an average of 18% because of this removal. Arend states that both these average differences were statistically significant. The indirect effect of the forest floor on infiltration was tested by comparing the infiltration rates of these four soil types with litter removed to the rates of the same types which had been subjected to annual burning. The infiltration rate was 18% lower for the burned forest floor condition and this difference was also significant. Lutz and Chandler (48) report also that repeated burning usually decreases infiltration capacity and that this effect is most pronounced on heavy-textured soils. They recognize that an organic matter covering usually favours infiltration but state that a fibrous mor type of humus layer is less desirable than other mor or mull types of humus as an aid to rapid infiltration.

Heyward (32) found that a dense, relatively impenetrable, single-grained to massive structure (depending on texture) developed in the A_1 horizon of longleaf pine forest soils, which were annually burned. If fires were excluded for a ten year period the forest floor smothered out the ground cover and the A_1 became very penetrable and porous. Sandy loams or heavier soils developed crumb structures and the humus layer became mull-like. Beneath the A_1 horizon the burned and unburned soil profiles were the same. Heyward attributes the characteristically poor structure after burning to the "absence of a vigorous soil fauna and to exposure of the surface soil to the elements when annual fires remove ground cover." An active soil fauna was observed when fires were excluded.

Wahlenberg et al (66), in studying physical properties of soil under longleaf pine in Mississippi, found that porosity, mechanical penetrability, and ability to absorb water were greater on areas protected from grazing and fire. These findings are in agreement with those of Auten (5) who found that if forest cover is adequately maintained the soil under second-growth timber does not lose its porosity unless grazing has been practiced to excess or the litter has been destroyed by fire. In these cases it is difficult to separate the effects of burning from the effects of overgrazing. In a series of tests in the Ozarks (4) Auten found that the rate of water absorption per square foot of soil was six to eight times greater in unburned forests than in burned forests. Alway and Rost (1) determined moisture equivalents of mineral forest soils in Minnesoto and showed that those soils which had been heated sufficiently to destroy the organic matter had consistently lower equivalents. Heyward (34) also found unburned forest soils in Florida were as much as 52% more moist than burned soils down to a ten inch depth. This difference was especially noticeable in the top two inches of surface soil.

The temperature of the surface soil is apparently higher after burning because the surface becomes black and therefore absorbs heat more readily than an unburned light colored surface. As mentioned previously, temperatures may rise sufficiently on burned soils to cause heat deaths of Douglas fir seedlings while seedlings on adjacent unburned soil are not affected (39, 50). In heat injury the seedling stem is literally cooked at the soil surface according to McArdle and Isaac of Oregon. At a soil surface temperature of approximately 123°F. this injury begins, especially if seedlings are less than one week old. Seedlings older than this are less susceptible to heat injury. With an air temperature of 90°F. under shelter, a surface yellow soil had an average temperature of 132°F. while the same soil blackened by burning had a surface temperature of 150°F. These results indicate that burning may destroy a crop of seedlings quite readily (50). Heyward (33) recorded temperatures during forty-four experimental fires using several types of fuel in the longleaf pine forests of Florida and found that the temperature of the soil at a depth of 1/8 to ¼ inch averaged 150°- 175°F. and persisted two to four minutes only. He states that heat in this region may favour plant nutrition. However, he did not record temperatures after burning nor did he experiment with seedling survival on these blackened surfaces.

Thus the concensus of opinion of those who have studied the physical properties of forest soils subjected to burning is that this practice is decidedly detrimental to the structure, porosity, penetrability, and the heat and water absorptive capacities of the soil. The effect on the first three properties seems to be most noticeable in the case of heavy soils whereas the latter two properties would probably show more significant changes in a light soil.

<u>The Effects of Burning on the Erodability of Forest Soils</u>

Lowdermilk (45) studied the influence of forest litter on the rate of water run-off and percolation, and on soil erosion in California. The litter in these experiments significantly reduced run-off especially on finer textured soils even after complete saturation. When the mineral soil was exposed due to destruction of this protecting layer of litter the absorptive rate of the soil was reduced and the amount of soil lost by erosion was increased. Some of the soil particles suspended in run-off water sealed the soil pores thus causing noticeable differences in the absorption rates of bare and protected soils. Sims et al (62) also observed that soil channels became clogged by suspended soil particles thereby causing accelerated surface run-off and erosion. Lowdermilk concludes that "the capacity of forest litter to absorb rainfall is insignificant in comparison with its ability to maintain the maximum percolating capacity of soil profiles."

Lütz and Chandler (48) have made a comprehensive study of erosion under forest vegetation and they report that accelerated erosion is negligible from soils under properly managed forest stands. This is due to the favourable soil porosity which develops as a result of the relatively large annual applications of organic matter. The protective covering of unincorporated organic matter breaks raindrop impact thus preventing soil dispersion and thereby keeps percolation water free of suspended particles. Under forest stands snow is delayed in melting so that gradual run-off occurs. Forests also decrease the erodability of soil because of protection against wind action, and the ability of root systems to hold the soil. Lutz and Chandler quote Kotok who reported a case in California where burning of vegetation and litter increased erosion up to 1000 times that on unburned areas. Numerous other such disastrous instances of erosion on burned-over land lead these workers to conclude that removal of native negetation, decreasing stand density, and damaging the soil due to fire are important causes of accelerated erosion in forests. Gustafson (27) is in definite agreement with the findings of Lutz and Chandler. He says that steep slopes now in forests should be maintained as such and all abandoned slopes in cultivation if originally timbered should also be reforested. Sims et al (62) state that erosion is not a factor on light sandy forest soils of low gradient but instead there occurs a dissipation of fertility after burning due to excessive leaching of more soluble bases.

In the Adirondacks, Diebold (18) observed active sheet erosion on slopes of ten to fifteen percent due to baring the bedrock in burning off the humus layer. In that area, severe fires are "a major calamity" because the cover which invades burns is sparse and therefore cannot prevent severe erosion. The destruction of the humus layer under white pine by firing has caused the loss of 1-4 inches of forest floor and 0-2 inches of mineral soil as a result of subsequent erosion. This has occurred over most of the area and constitutes a tremendous loss since the natural depth of soil on these mountains is shallow and irregular.

Garman and Barr (24) report that burned forest soils in the British Columbia coast region are subjected to considerable erosion and sliding of the loose soil expecially during heavy rains. These workers observe that significant losses of recently planted seedlings occur due to the erodability of steeply sloping burned soils. Lutz and Chandler (48) mention that erosion of forest soils is accentuated by logging especially along skid roads. They contend that erosion generally is not serious unless the logged-off areas are burned or lie bare for a few years. However, areas seldom remain bare for longer than one or two years since a protective covering of heliophytes usually develop.

Thus, it can be readily appreciated that increased erodability and consequent degeneration of forest soils should be considered as a possible result of burning.

EXPERIMENTAL

The object of the study, as already intimated, is to determine whether or not the inherent site quality of forest soil is altered through burning and whether any such alteration is permanent or simply exhibits a cyclic trend. For this purpose the Nitinat River Valley situated just west of Cowichan Lake on Vancouver Island was selected. The area has been progressively logged and burned by the British Columbia Forest Products Company over a period of approximately thirty years. The soil throughout the valley is relatively uniform in texture as may be observed from a study of the data on mechanical analyses.

The fire reports and maps published by The British Columbia Forest Service yielded information as to the date of logging and the date, extent and severity of burning. With this information as a guide, seven burned sites and a "control" virgin site were selected. The burns ranged from two months to twenty years old. In order to eliminate as many variables as possible, the sites were chosen with similar elevation, exposure, relief, and soil profiles. Variability due to sampling was offset by taking both surface and subsurface samples from five carefully selected pits dug within 100 feet of one another at each site. The surface samples were obtained just below the Ao horizon, or the burned remains of the duff layer, while the subsurface samples represented a depth of approximately 18 inches depending on the depth of the solum. A study of these samples should disclose any movement through the soil profile of colloids in suspension or salts in solution.

Geology of the Nitinat River Valley

This valley has not been subjected to a detailed geological survey but a reconnaissance party under Clapp covered the area in 1909. Since most of the surrounding districts were subjected to glaciation, it had been assumed by geologists that this valley was no exception. However, Mr. R. H. Spilsbury[1] and the author found that angular rocks increased in size and numbers down through the mantle until bedrock was reached. They therefore concluded that the surface mantle of the valley represents a residual soil.

The parent material of the Nitinat River Valley is composed of rocks belonging to the Vancouver volcanic formation which is one of five formations collectively named the Vancouver Group (14). The Vancouver volcanics are the main rocks of Vancouver Island and make up the greater part of the Vancouver group. The principal rock type of the Vancouver volcanic formation is a meta-andesite which is often associated with augite and is usually phorphyritic with an aphanitic ground mass. The phenocrysts are small but numerous commonly consisting of striated feldspar and altered hornblende (43). The rocks have been sheared and altered and are dark green or dark grey in color. The green color indicates the presence of secondary chlorite. They are also cut by veinlets of quartz, epidote, calcite, and are

[1] Mr. R. H. Spilsbury gave invaluable aid in selection of the sites, arranging for shipment of the samples, and in general giving advice and encouragement throghout the study.

commonly impregnated with pyrite. These rocks were metamorphosed from basic lavas of Mesozoic time and so are alkaline in reaction.[1]

Since no analysis has been carried out on the parent rock of this particular area, the analysis of an augite andesite rock from Rockland Ridge, State of Washington is presented in Table 1. This rock is reported to contain plagioclase, augite, apatite, magnetite, and residual glass and is believed to be similar to that in the Nitinat Valley.

Table 1. Analysis[x] of an Augite Andesite and its Derived Soil.[2]

Compound:	Fresh Rock:	Derived Soil:
SiO_2	50.85	58.16
Al_2O_3	12.54	15.03
Fe_2O_3	10.03	10.59
FeO	7.11	- - -
MgO	5.57	1.99
CaO	9.33	4.57
Na_2O	2.37	2.56
K_2O	1.13	1.68
H_2O	0.34	1.77
Organic	- - -	3.52
P_2O_5	0.76	0.43
SO_3	0.05	0.07
Total	100.08	100.37

[x] All results are percentages by weight.

1 The reaction of ground parent material averaged pH8.33

2 Taken from "The Data of Geochemistry", by F. W. Clarke, 1924, Government Printing Office, Washington, Bul. 770, p.490.

The andesitic parent rock of the Nitinat Valley first cracks into large boulders and then to smaller rocks and shale-like fragments as weathering proceeds. This gradual breakdown is illustrated in Figures 1, 2, and 3. Figure 4 shows how herbaceous growth such as salal seems to flourish on the shaly fragments of weathered rock.

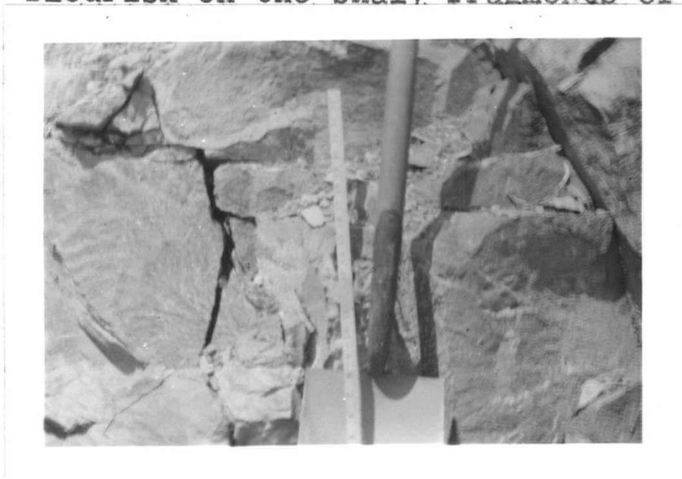

Figure 1.

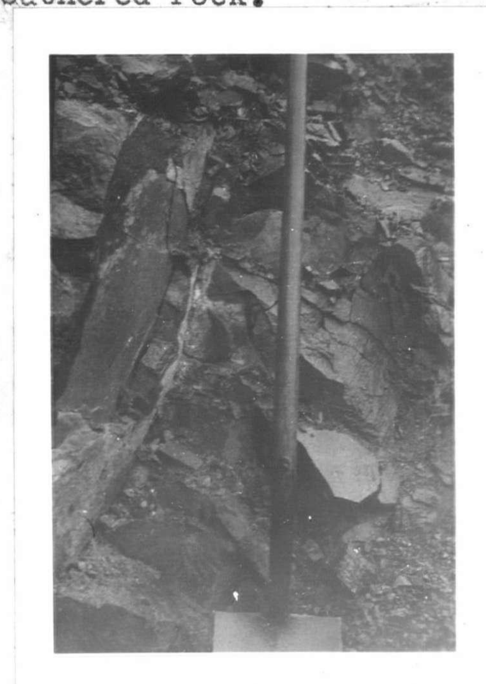

Figure 2.

Figure 3.

Figure 4.

Climate of the Area[1]

No climate report is available for the actual area studied but reports are given from Port Nitinat which is 23 miles west of the sampling area and from Lake Cowichan (the village) which is 21 miles east. The latter reports 70.77 inches of precipitation annually as a 30 year average. Port Nitinat reports 112.49 inches as a 30 year average. From these two figures one would logically expect an annual precipitation in the upper Nitinat Valley of about 90 - 95 inches. Also reported from Lake Cowichan and Port Nitinat are the average annual temperatures which are 50°F. and 48°F. respectively. Thus the Precipitation Effectiveness or PE index of Thorthwaite[2] can be calculated (approximately 304) and places the area in the "wet" humidity province according to Thornwaite's classification. Despite this very wet climate the months of June, July, and August are relatively dry.

Description of Soil profiles, Vegetation, and Burns

The soil samples are designated by the year the site was burned and so the surface samples from the site burned in 1948 are collectively referred to as 1948-A and the corresponding subsurface samples as 1948-B. The samples procured from under virgin timber are named Virgin-A or Virgin-B as the case may be. The 5 pits dug in each site were observed as to their profiles and the average of these 5 was described in de-

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1 "Climate of British Columbia", Report for 1944, Dept. of Agriculture, Province of British Columbia.

2 Jenny, Hans, "Factors of Soil Formation", New York, McGraw - Hill, 1941, pp. 110 - 111.

tail as being representative of the site. A profile description for each site is presented in Tables 2 to 9 inclusive.

Table 2. Profile description of soil under mature forest

Depth	Texture	Color	Structure	Consistence	Stones	Roots
2"	humus	black	aggregated	sticky	nil	many - interwoven
0-4"	gravelly sandy loam	red to dk. br.	"	friable	50%	many
4-22"	"	red-brown	some aggregation	"	60%	some
22-30	stony, sandy loam	yellow	single-grained		80%	few
30 +	bedrock					

Profile development: poor

Topography: 500 feet elevation, southerly slope, spots sampled were on a shoulder.

Micro-relief of pit: uniform gentle slope

Soil drainage: subsoil drainage excessive.

Vegetation: Forest cover: Douglas fir - dominant
Red cedar - codominant

Herbs: sword fern - dominant
lichen - codominant

Other species: huckleberry, deer fern, lady fern, maiden-hair fern, may leaf, tiarella, bracken, blackberry, nettles.

Site quality: excellent.

Figure 5.

Virgin Site

Table 3 - Profile description of soil burned 1948

Depth	Texture	Color	Structure	Consistence	Stones	Roots
0-3"	gravelley sandy loam	red - brown	single-grain	friable	45%	many
3-6"	"	yellow	"	"	50%	"
6-8"	"	red - brown	cloddy	"	50%	quite a few
8-30"	stony	yellow	"	"	80%	nil
30" +	bedrock					

Note: Ao burned off

Profile development: some tendency for leached A_2 but is probably mostly due to color change of minerals.

Topography: 700 feet elevation, shoulder on mountain

Micro-relief of pits: uniform gentle slope

Soil drainage: some surface runoff, subdrainage excessive

Vegetation: Forest cover: nil

Herbs: sword fern - dominant
bracken - codominant (very few of either)

Site quality: no reproduction as yet but stumps indicate a good site index before logging.

Figure 6:- 1948 burn

This burn was carried out during the first week of May and since the samples were collected in July of 1948 the burn was only two months old when sampled. The photograph shows the typical blackened appearance of a recent burn with the large quantity of partially burned slash strewn over the surface.

<u>Table 4. Profile description of soil burned 1947</u>

Depth	Texture	Color	Structure	Consistence	Stones	Roots
--	burned humus					
0-4"	gravelly sandy loam	reddish brown	single - grain	friable	many 50%	numerous
4-18"	"	red-brown	some aggregation	"	larger 60%	few large
18-30	gravel	drab	single-grained	"	90%	nil
30 +	bedrock					

Profile development: little development, slight accumulation of iron oxide at about 16".

Topography: 600 feet elevation, south-east exposure, shoulder on mountain side.

Micro-relief of pit: gently sloping

Soil drainage: subdrainage excessive

Vegetation: Forest cover: nil

Herbs: senecio - dominant
bracken - codominant

Also blackberry, thistle, sword fern and elderberry.

Surface is 50% covered

Site quality: no reproduction as yet but size of stumps indicate that it was an excellent site.

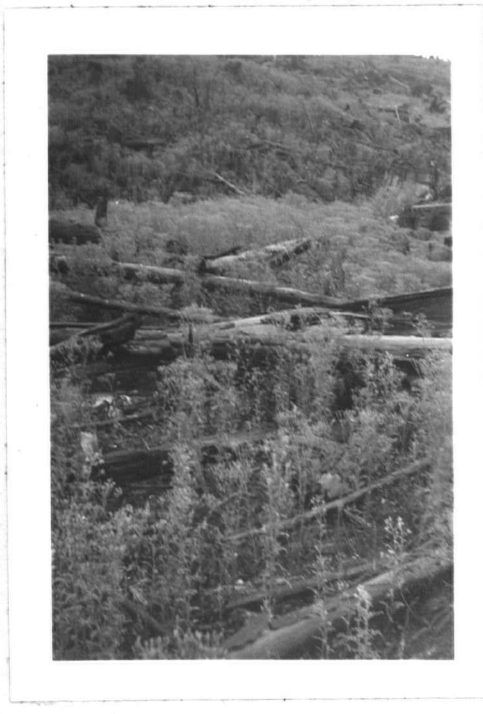


Figure 7:- 1947 burn

This area was burned accidentally according to the Provincial Fire Reports (22) and was a surface fire which burned through felled and bucked timber in June, 1947 with periodic outbreaks until August of that year. Its appearance is similar to the 1948 burn except that herbaceous growth has commenced.

Table 5. Profile description of soil burned 1945

Depth	Texture	Color	Structure	Consistence	Stones	Roots
½"	burned humus					
0-2"	gravelly sandy loam	dk. red-brown	crumb	friable	55% many small	numerous
2-12"	"	reddish-brown	nut-like	"	60%	some
12-24"	"	drab to red br.	single-grained	"	80 - 90%	few
24" - 1 bedrock						

Profile development: may be a slight concretionary layer at 24" depth otherwise little development.

Topography: 400 feet elevation, slight northerly slope situated on a benchland on two knolls.

Micro-relief of pit: gently sloping.

Drainage: subsoil drainage excessive.

Vegetation: Forest cover: nil

Herbs: senecio is dominant
fireweed is codominant
also salal, hawkspur, salmonberries, bracken, huckleberries and an unknown white clustered flowering plant.

Surface 75% covered

Site quality: this site was apparently an excellent one as can be seen in the accompanying photograph. Large stumps were observed but no reproduction has occurred as yet.

Figure 8:- 1945 burns

This area was slash burned in the fall of 1945 and according to the fire report was a "good burn."

Table 6. Profile description of soil burned 1942

Depth	Texture	Color	Structure	Consistence	Stones	Roots
½-1"	humus (mostly moss)					
0-2"	gravelly sandy loam	red-br. to black	granular	friable	50%	many
2-16"	stony sandy loam	red-brown	quite granular	"	75%	"
16"-30"	gravel	light red-br.	single-grained -- some aggregate	"	all stones	few
30" +	bedrock					

Profile development: practically none.

Topography: 500 feet elevation, northerly slope, shoulder of a small hill.

Soil drainage: subsoil drainage excessive

Vegetation: Forest cover: nil

Herbs: Fireweed - dominant
Bracken - codominant
Other species - huckleberry, thimbleberry, salal, lichens, hawkspur, white clustered flower.

100 % cover

Site quality: stumps indicate a very good site, as yet no reproduction.

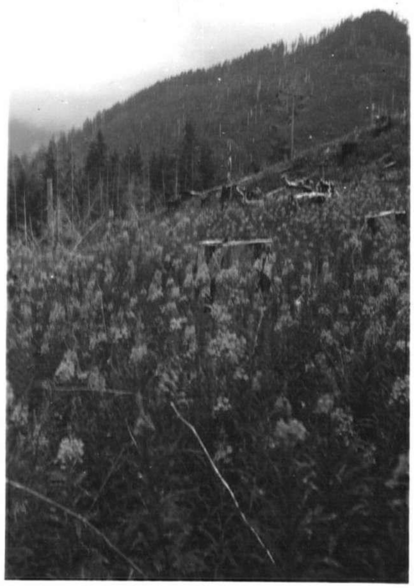


Figure 9:- 1942 burn

This burn was a "good burn" according to the fire report. The photograph illustrates the density which fireweed can reach on a site after burning.

Table 7. Profile description of soil burned 1937

Depth	Texture	Color	Structure	Consistence	Stones	Roots
2"	humus	black	many roots holding together this layer			
0-3"	gravelly sandy loam	dark red-brown	granular	friable	50%	many
3-12"	stony sandy loam	red-br.	"	"	70% more and larger	some
12-24"	"	drab	single - grained	"	many	few
24" +	bedrock					

Profile development: very little, the fine soil is more loamy in texture here but rocks are very numerous.

Topography: 900 feet elevation, north-west exposure in draw of Vernon Creek.

Micro-relief of pits: gentle slope

Soil drainage: subsoil drainage excessive

Vegetation: Forest cover: Hemlock - dominant
Cedar - codominant
Also Douglas fir, alder.

Herbaceous cover: Salal - dominant
fireweed - codominant
other species - huckleberry, blueberry, bracken, lichens, hawkspur, white cluster, may leaf, blackberry, blackcap, Oregon grape, swamp grasses, sword fern.

Site quality: this site was excellent judging by the stump size and number. Reproduction is about 10% in the spot sampled and this is low when one considers the proximity of seed trees which can be seen in the background of the photograph.

Figure 10:- 1937 burn

This burn was a slash burn started in fall of 1937. The fire report indicates that a generally good burn resulted.

Table 8. Profile description of soil burned 1932

Depth:	Texture:	Color:	Structure:	Consistence:	Stones:	Roots:
2"-3"	humus	black	granular	friable	few	many roots which bind
0-4"	gravelly sandy loam	dark red-brown	"	"	60% many	many
4-14"	"	red-brown	"	"	70% many	fibrous many
14-24"	gravel	drab yellow	single-grained	"	85%	fewer
24" +	bedrock					

Profile development: A and B horizons quite distinct as compared to other areas. Humus layer thicker than any other burned or virgin area.

Topography: 600 feet elevation, southerly exposure, gentle slope from adjacent mountain.

Micro-relief of pits: gentle slope

Soil drainage: subsoil drainage excessive

Vegetation: Forest cover: Douglas fir - dominant
Hemlock - codominant

Also cedar and some alder

Herbaceous cover: Oregon grape - dominant
huckleberry - codominant
other species - sword fern, lichens, white cluster, thimbleberry, blackberry, hawkspur, fireweed, salal.

Site quality: this site has streams close by and judging by stump size it has been a very good site. The accompanying photograph indicates the good reproduction taking place.

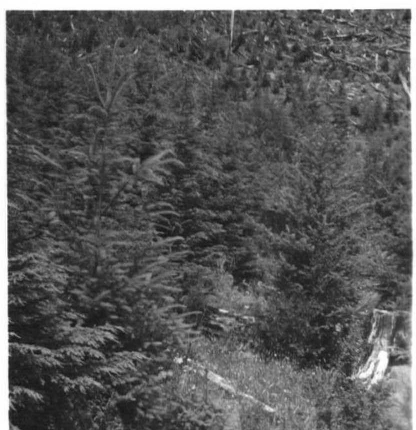


Figure 11:- 1931-32 burn

This area was slashed burned in 1931 and burned again accidentally in 1932. Both burns occurred in the fall.

Table 9. Profile description of soil burned 1929

Depth	Texture	Color	Structure	Consistence	Stones	Roots
1"	humus	black	granular	friable	- -	moss, roots
0-4"	gravelly sandy-loam	red-brown	slightly granular	"	many small	many fibrous
4-13"	"	light red-brown	single grained	"	many large	fibrous roots
13-24"	gravel	drab	"	"	80-90%	--
24-36"	bedrock					

Profile development: not well developed.

Topography: 600 feet elevation, southerly exposure, isolated knoll in center of wide valley.

Micro-relief of pits: uniform gentle slope

Soil drainage: subsoil drainage excessive

Vegetation: Forest cover:

western red cedar - dominant

hemlock - codominant

also - alder, willow, fir

Herbaceous cover:

Salal - dominant
huckleberries - codominant
other species - sword fern, salmonberry, fireweed, thimbleberry, bracken, lichens, blueberry.

100% ground surface covered.

Site quality: about 50% regeneration has occurred on this 19 year old burn. It was a good site previous to logging.

Figure 12:- 1929 burn.

No record of this old burn is available but a fairly severe slash burn must have occurred from indications in the area.

Methods of Analysis

Mechanical analysis:- All samples were passed through a 2 mm. seive preparatory to analysis and the relative proportion of rocks and fine soil was determined by averaging the weights of the five replicates at each site. Mechanical analyses were carried out on the fine soil fraction by the Bouyoucos method (10) and interpreted using the textural triangle (53).

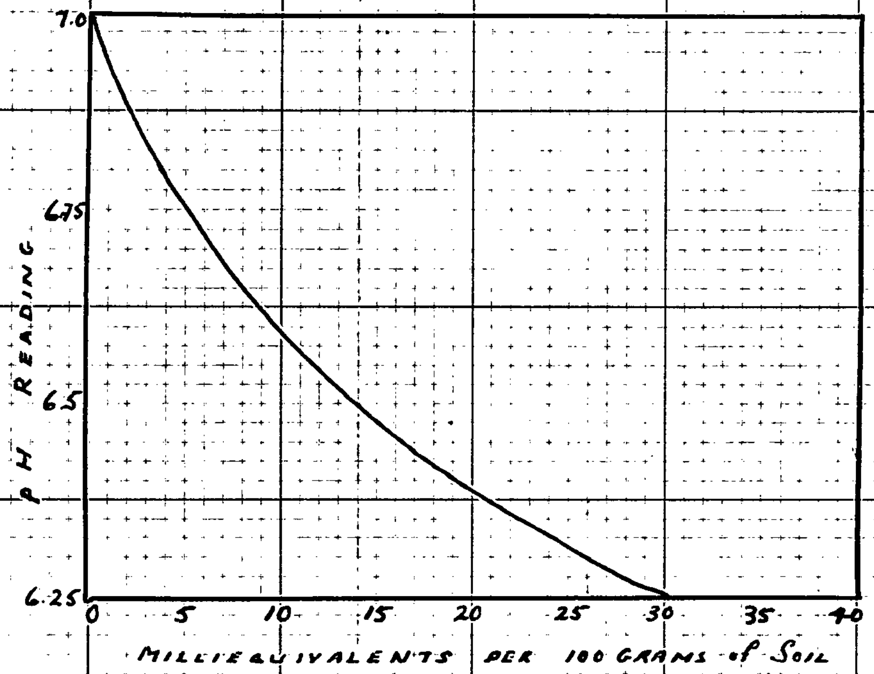
Determination of pH:- Five grams of the sieved soil were weighed into a 50-ml. beaker and 10 ml. of fresh tap water at a temperature of 25°C. were added. The soil and water were mixed thoroughly with a stirring rod and allowed to slake for 30 minutes. The mixture was stirred well and the pH read using a Beckman meter. The method outlined was adopted because of variability noted when distilled water was used which, on standing, absorbed carbon dioxide and became quite acid. Even though the carbonic acid formed is very weak, it seemed to affect the pH of these soils materially. Since it was inconvenient to keep sufficient quantities of freshly boiled distilled water on hand, fresh tap water was used instead as it had a neutral reaction. Reed and Cummings (59) discuss dilution as it affects pH readings and on the strength of their arguments the dilution of 1:2 (soil to water) was employed.

The Determination of Exchangeable Hydrogen and Total Exchangeable Bases:- The method as outlined by Brown (12) was used for determinations of exchangeable hydrogen and total exchangeable bases with certain modifications, i.e. - 10 grams of soil were used with 100 ml. of extracting solution and the sample slaked with a shaking apparatus for 15 minutes. After this thorough shaking, the mixtures had reached their ultimate pH values and no changes were noticed with further slaking. The two graphs shown in Figure 13 are the standard graphs made up by titrating the leaching solutions as described by Brown. From the results of the exchangeable hydrogen and total exchangeable bases the percent base saturation was calculated.

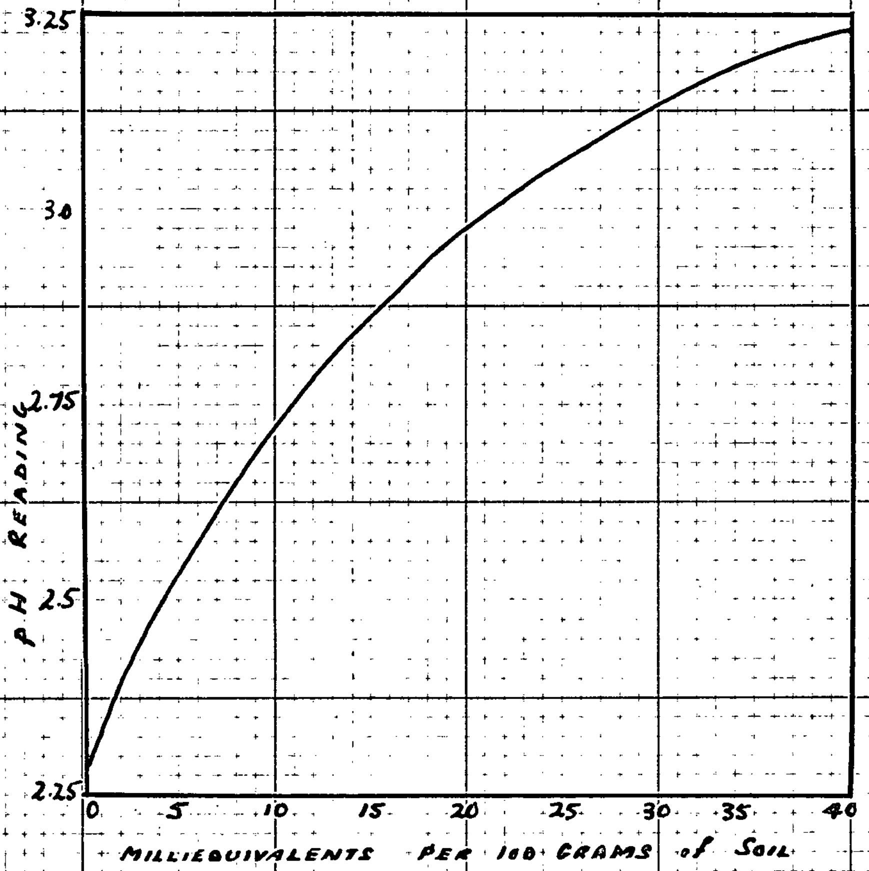
The Determination of Readily Soluble Plant Nutrients:- The principles underlying the method of Peech and English (56) were used to determine the amounts of readily available chemical constituents. This rapid microchemical test provides a ready means for determining the chemical components in soil

FIGURE 13

STANDARD GRAPH for EXCHANGEABLE HYDROGEN



STANDARD GRAPH for EXCHANGEABLE BASES



which are affected by burning. Deviations from the method involved minor changes in technique in order to adopt it for use with the rotary shaker, and the Fisher electrophotometer. The standard graphs for the various nutrients determined are shown in Figures 14, 15, and 16. These were calculated using known standards.

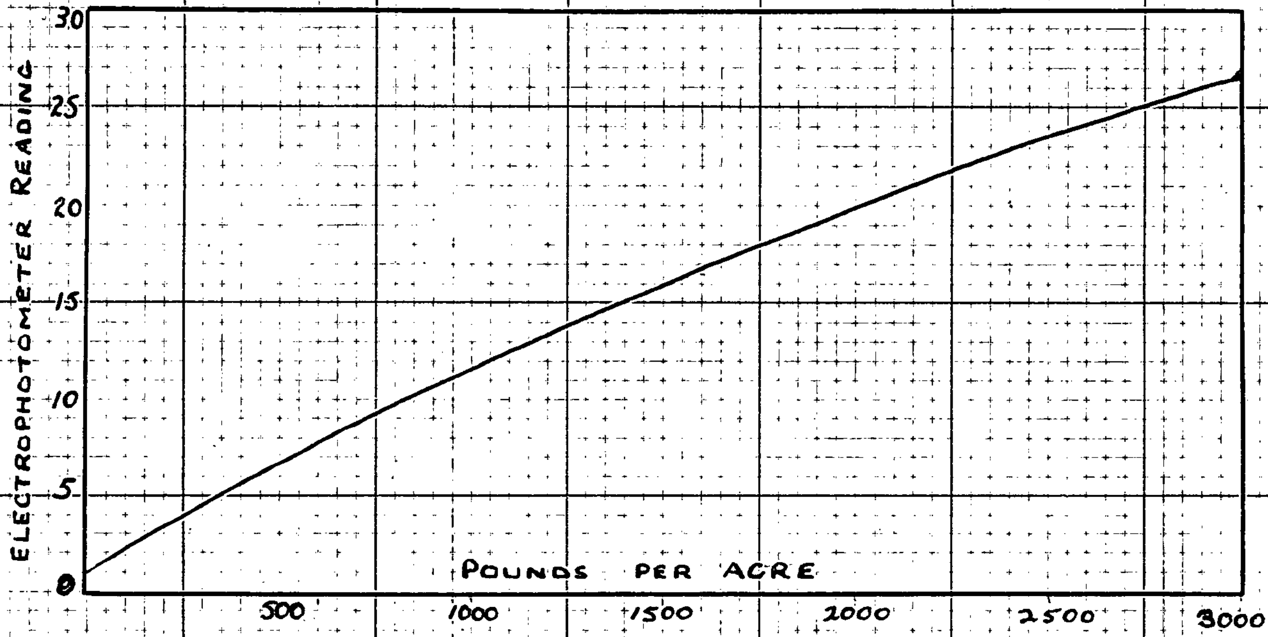
The Determination of Organic Matter:- The method used for organic matter determination was essentially that of Wilde and Patzer (75) with a few minor changes such as using a more dilute potassium dichromate solution, (0.4 Normal) and using a different indicator (barium diphenylaminesulfonate).

The Determination of Total Nitrogen:- Total nitrogen was determined by means of the Kjeldahl - Gunning method which requires the use of potassium sulphate, salicylic acid, sodium thiosulphate and selenized granules in addition to concentrated sulphuric acid. The mixture was digested until white in color and was then diluted with fresh distilled water, sodium hydroxide added to basicity, and the distillation carried out in the usual manner. From the percent organic matter the percent organic carbon was calculated by dividing the value by 2 (75). From the foregoing data carbon-nitrogen ratios were calculated.

The Determination of Moisture Equivalent:- The Briggs - McLane method was followed in determining the moisture equivalents for the fine soil fraction.

FIGURE 14

STANDARD GRAPH for AVAILABLE CALCIUM



STANDARD GRAPH for AVAILABLE MAGNESIUM

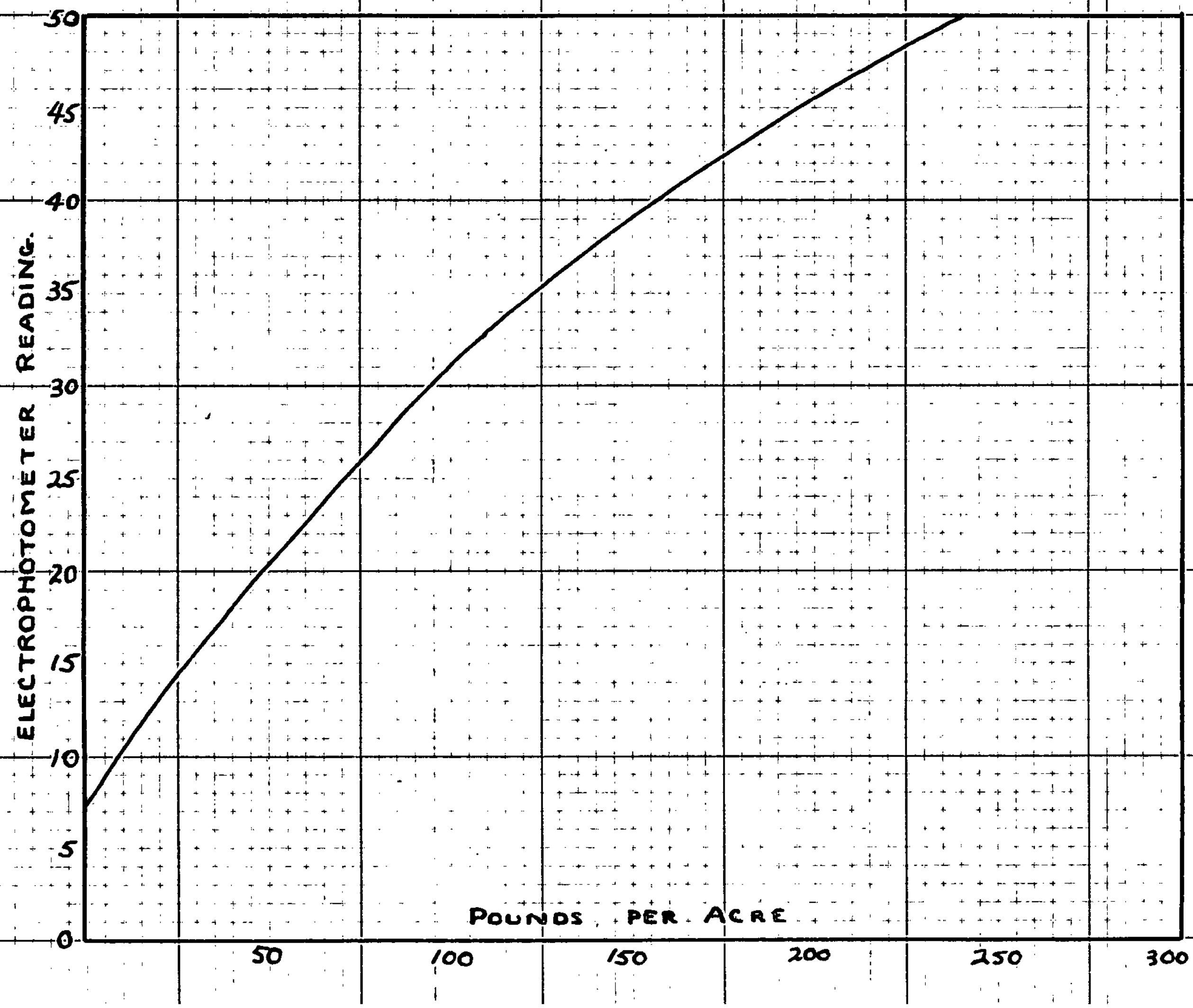
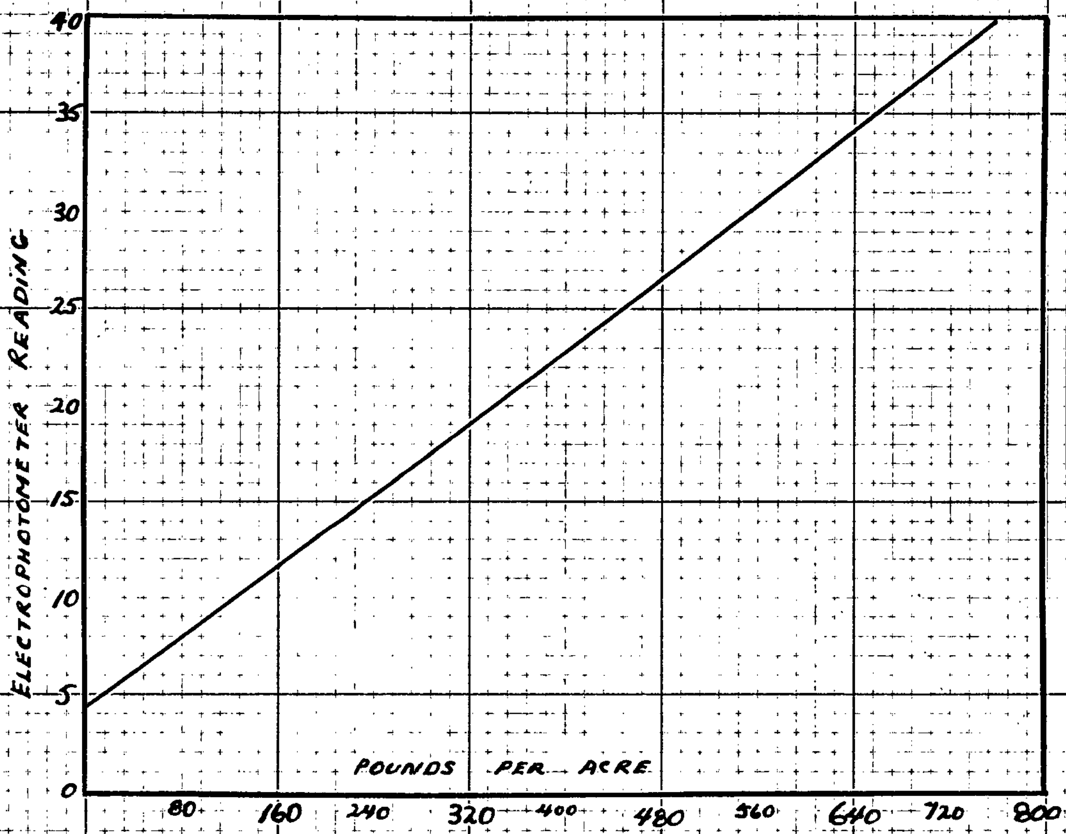


FIGURE 15

STANDARD GRAPH for AVAILABLE POTASSIUM



STANDARD GRAPH for AVAILABLE PHOSPHORUS

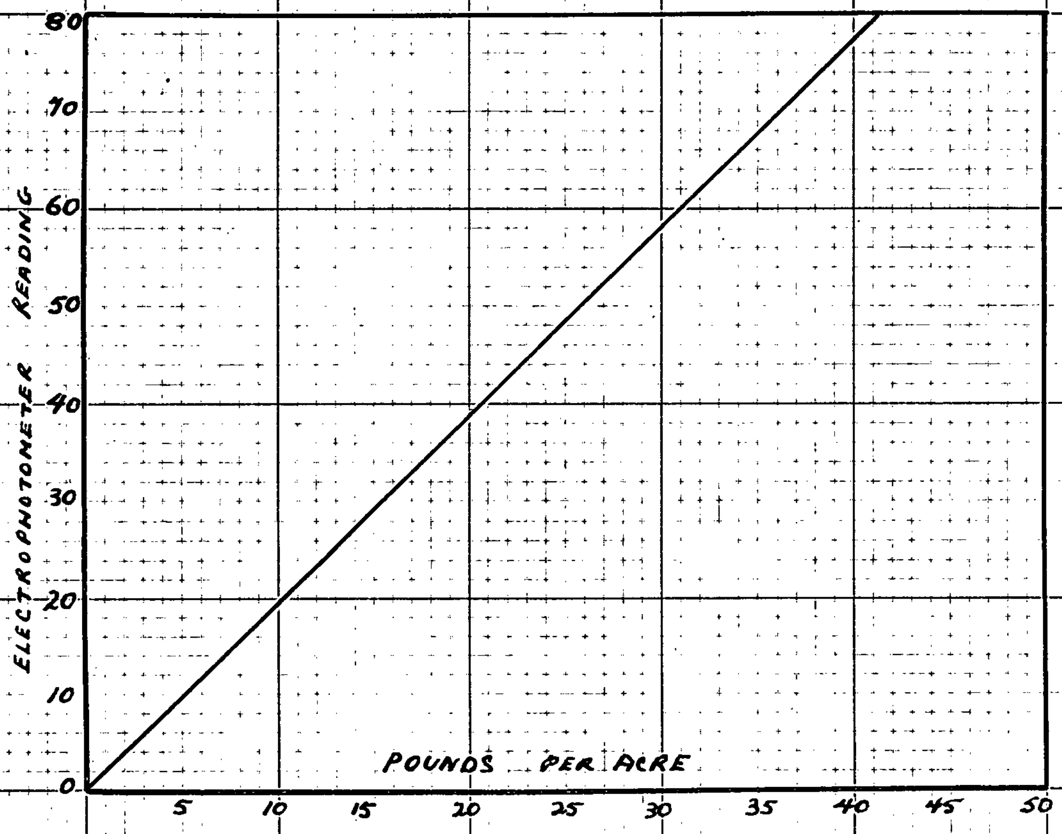
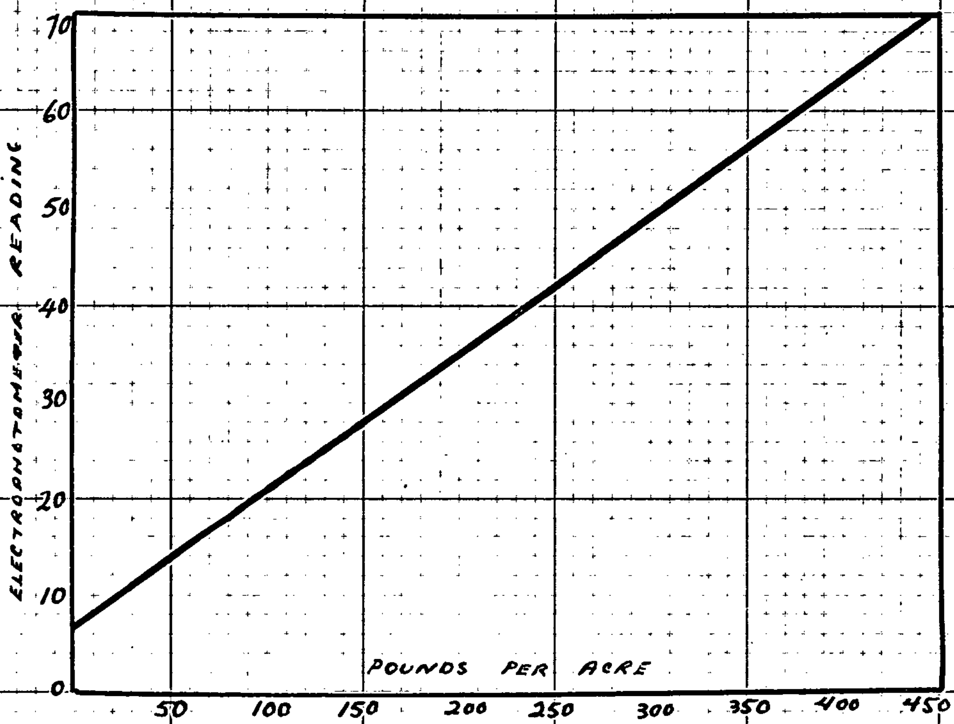
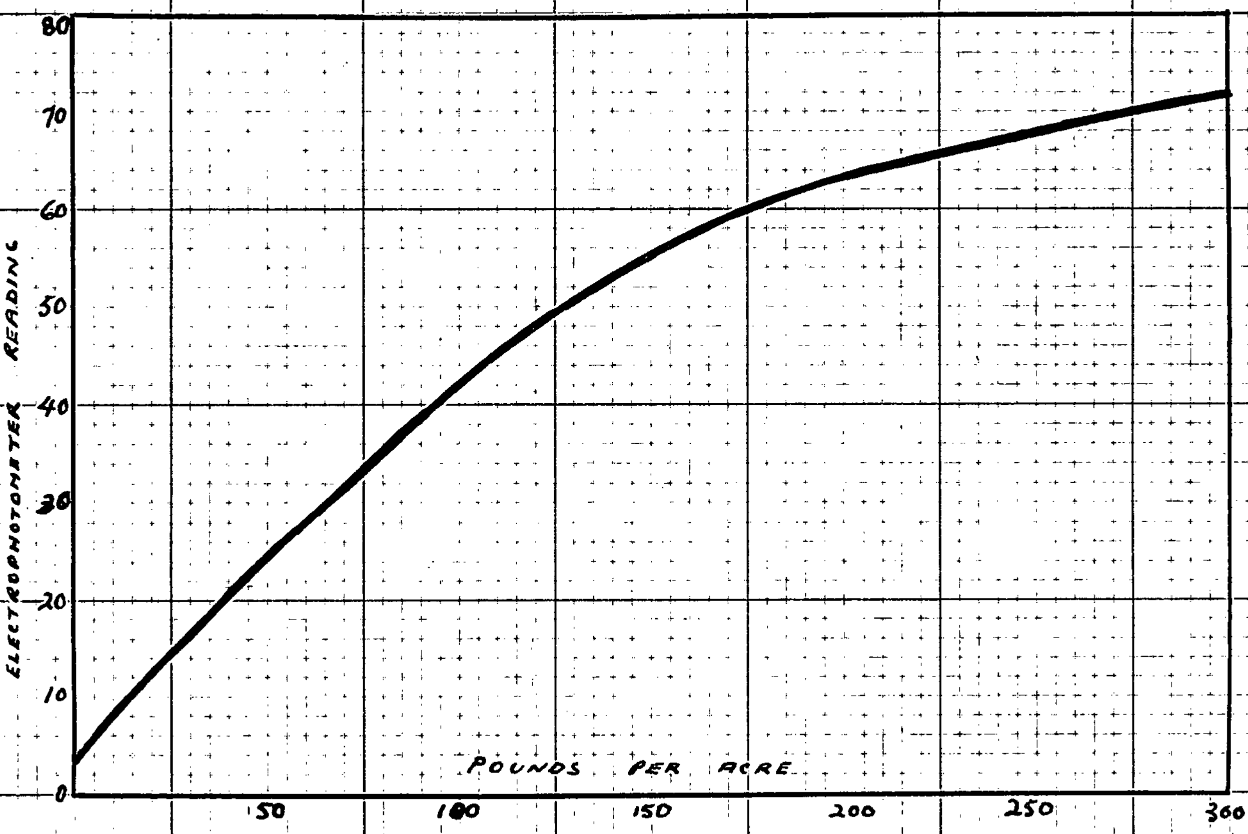


FIGURE 16



STANDARD GRAPH *for* AVAILABLE AMMONIA

STANDARD GRAPH *for* AVAILABLE NITRATE



Discussion of Natural Regeneration

It may be observed from the vegetation reports and accompanying Figures that natural regeneration is now under way on the two oldest burned sites. Even this regeneration is not as good as it should be. Apparently, restocking does not begin on a burned site for 10 to 15 years depending on the proximity of seed trees and the number of good seed years. These results are in agreement with numerous workers such as Isaac (39), Reid et al (60), Mathews and Munger (54) and Paulik (55).

Data and discussion

The results of the mechanical analyses as listed in Table 10 were determined from composite samples and it can be seen that all the soils belong to one textural class -- sandy loam. It is important to note that these results do not represent the true field soil since all the particles larger than 2 mm. in diameter, about 60 percent by weight, had been removed. If this large proportion of rocks is taken into consideration the true textural class of all these soils would be stony sandy loam.

As one would expect, with a residual soil, the percentages of sand and silt particles seem to be higher in the subsoil than at the surface of an undisturbed Virgin soil while percentages of clay and colloidal particles are higher at the surface. Close observation of Table 10 reveals that the burned soils exhibit a marked increase of fine particles in the subsoil as compared to that of

Table 10. Mechanical Analysis[x]

	% Sand	% Silt	% Clay	% Colloidal	Texture
1948-A	60.0	28.3	11.7	9.65	Sandy Loam
1947-A	58.6	29.6	11.8	10.1	" "
1945-A	61.0	26.0	13.0	10.5	" "
1942-A	54.4	32.1	13.5	10.6	" "
1937-A	54.7	25.4	19.9	17.0	" "
1932-A	59.8	28.9	11.3	8.5	" "
1929-A	57.2	31.0	11.8	9.2	" "
VIRGIN-A	56.6	31.6	11.8	8.8	" "
1948-B	56.9	31.5	11.6	10.2	Sandy Loam
1947-B	54.9	31.9	13.2	9.7	" "
1945-B	63.8	23.9	12.3	9.4	" "
1942-B	54.6	35.4	10.0	7.6	" "
1937-B	54.6	26.1	19.3	16.3	" "
1932-B	67.9	23.0	9.1	7.3	" "
1929-B	54.2	29.5	16.3	13.5	" "
VIRGIN-B	58.3	35.9	5.8	5.0	" "

x Based on oven-dry weight.

the unburned soil. This phenomenon is quite noticeable in the three oldest burns (1929, 1931 - 32, and 1937) and to a certain degree in the others. The increase of fine particles in the subsoil after burning is undoubtedly the result of heat destroying the soil aggregates so that the colloidal particles become dispersed and consequently moved down into the profile by percolating water. In support of this, Puri and Ashgar (58) report that colloidal properties of soils are destroyed by heating. However, it seems probable that a migration such as this could only take place where the electrolytes were first removed by leaching to prevent flocculation (8).

The results of all analyses other than mechanical are presented in Table 11. The determination of pH and available nutrients were carried out on each replicate and the results averaged whereas all other determinations were performed on composite samples in duplicate and averaged.

A review of the data as presented in Table 11 suggests considerable natural variation in respect to soil properties and hence it is not proposed to discuss absolute values but rather to indicate trends which appear as a result of burning.

The pH data for the Virgin soil show a wide range between subsurface and surface, the latter being more acidic as it should be. The surface soils of all the burned sites are also more acidic than the corresponding subsoils. The 1948 and 1947 burns do not show an increased pH as one might expect and even the "B" appears to be lower. This may be explained as being due to excessive leaching following removal of surface cover.

Vegetation high in minerals (fireweed and groundsel) has become well established on the 1945 burn and appears to be "pumping" minerals into the surface soil from depth thereby

TABLE 11. SUMMARY OF ANALYTICAL RESULTS.

SITE	VIRGIN			1948			1947			1945			1942			1937			1931-32			1929		
HORIZON	A	B	Difference	A	B	Difference	A	B	Difference	A	B	Difference	A	B	Difference	A	B	Difference	A	B	Difference	A	B	Difference
pH	4.92	5.68	0.76	4.98	5.47	0.49	4.72	5.26	0.54	5.13	5.65	0.52	5.59	5.94	0.35	5.58	5.79	0.21	5.29	5.64	0.35	5.31	5.45	0.14
EXCHANGEABLE HYDROGEN (m.e./100gms)	15.5	4.7	10.8	12.3	5.3	7.0	17.0	8.5	8.5	17.1	7.8	9.3	10.8	5.9	4.9	13.0	9.0	4.0	12.4	6.8	5.6	15.4	9.4	6.0
TOTAL EXCHANGEABLE BASES (m.e./100gms.)	13.5	13.5	0	13.1	10.0	3.1	14.0	10.5	3.5	12.0	10.3	1.7	13.5	12.3	1.2	14.0	16.0	-2.0	10.7	10.5	0.2	13.7	14.3	-0.6
PERCENT BASE SATURATION	46.7	74.1	27.4	51.6	65.3	13.7	45.2	55.3	10.1	41.2	56.9	15.7	55.6	67.6	12.0	51.9	64.0	12.1	46.4	60.7	14.3	47.1	60.4	13.3
AVAILABLE CALCIUM. (lbs./Acre)	400	130	270	285	65	220	190	70	120	455	100	355	285	80	205	720	290	430	350	160	190	500	90	410
AVAILABLE MAGNESIUM (lbs./Acre)	60	16	44	38	10	28	37	20	17	50	18	32	42	12	30	70	29	41	69	26	43	85	17	68
AVAILABLE POTASSIUM (lbs./Acre)	70	0	70	68	4	64	32	0	32	38	8	30	56	6	50	76	38	38	42	8	36	134	9	125
AVAILABLE PHOSPHOROUS (lbs./Acre)	3.0	1.2	1.8	8.5	2.5	6.0	8.4	6.9	1.5	8.0	4.4	3.6	3.6	2.5	1.1	6.0	2.9	3.1	7.3	6.4	0.9	5.1	2.6	2.5
AVAILABLE AMMONIA (lbs./Acre)	56	46	10	90	42	48	80	55	25	59	54	5	54	49	5	60	56	4	68	60.5	7.5	57	56.5	0.5
AVAILABLE NITRATE (lbs./Acre)	305	188	117	242	55	187	450	107	343	245	125	120	330	109	221	295	223	72	320	330	-10	274	183	91
PERCENT ORGANIC MATTER*	9.94	4.07	5.87	8.86	3.33	5.53	10.92	7.56	3.36	10.85	3.18	7.67	8.03	3.66	4.37	7.85	4.24	3.61	8.11	6.08	2.03	11.4	3.95	7.45
PERCENT TOTAL NITROGEN*	.230	.023	.207	.258	.113	.145	.256	.100	.156	.228	.091	.137	.206	.103	.103	.171	.037	.134	.181	.133	.048	.267	.058	.209
CARBON-NITROGEN RATIO	21.6	88.6	67.0	17.2	12.5	-4.7	21.3	38.0	16.7	23.8	18.6	-5.2	19.5	17.8	-1.7	23.0	57.6	34.6	22.4	22.8	0.4	21.3	34.1	12.8
MOISTURE EQUIVALENT*	44.9	35.4	9.5	33.3	33.7	-0.4	38.7	34.1	4.6	34.7	29.4	5.3	38.9	35.5	3.4	44.3	39.1	5.2	37.2	30.4	6.8	49.1	37.0	12.1

* Based on oven-dry weight.

raising the pH level. With the older burns this process has proceeded further and hence differences between A and B samples are greatly reduced as is apparent in the table. Once the burn has become sufficiently old, the shrubbery with high mineral content may give way to coniferous growth of lower mineral content and so ultimately the condition, as pertaining in the virgin soil, will develop.

It is generally recognized that coniferous trees use smaller amounts of soil nutrients than do most agricultrual plants. In addition, support for the postulation that herbaceous ground cover is high in basic nutrients is given by Lutz and Chandler (48) who describe Tamm's work in Sweden. The latter found that basic igneous rocks and calcareous sedimentary rocks have the highest calcium content and produce soils which support Norway spruce forests with prolific herbaceous undergrowth. Tamm observed, in contrast, that more acidic rocks supported a different and less prolific type of growth.

In all sites, the amount of exchangeable hydrogen is greater in the surface than in the subsurface soil. This difference is less for all burned sites than for the virgin due no doubt to the added ash. Other differences are indicated but the lack of definite trends suggest that they are due to natural variation.

The total exchangeable bases are negatively corelated with the exchangeable hydrogen as one would expect. The values for the virgin site show that the content of bases is the same in the surface and subsurface soil. The 1948, 1947, and 1945 burns exhibit higher base contents due to the residual ash but in the 1942 burn and older burns the surface and subsurface values approach one another as in the virgin site. This would appear to suggest that under the conditions of the experiment the effect of added ash begins to disappear 3 or 4 years following burning.

The percent base saturation data show some apparent differences but none appear to be significant except the fact that the virgin subsoil has a higher saturation percentage than any of burned site subsoils. This lower percentage after burning may possibly be due to increased biological activity, to the "pumping" action of herbaceous growth as mentioned with respect to pH increases, or to a combination of the two. One may also observe that a significantly greater difference occurs between surface and subsurface samples of the virgin site as compared to all burned soils. This too can be accounted for by the decrease in percent base saturation of subsoils.

Amounts of available calcium,magnesium,and potassium are invariably higher in the surface soils of both burned and unburned sites. Calcium shows wide variation and therefore does not indicate any particular trend. With magnesium and potassium, however, it is noted that the subsoils of burns are distinctly higher than the unburned virgin subsoil. This effect is undoubtedly the result of salts from the surface ash moving to the subsoil through leaching which supports the explanations given for changes in exchangeable bases and pH. This is in agreement with Sims et al (63), Wilde (76), Wilde and Kopitke (74) and numerous other workers.

Available phosphorus is significantly increased in the surface soil after burning and then, over a period of years, gradually declines to the normal amount found in the virgin surface soil. After 19 years (1929 burn) the content of phosphorus is still high and so considerable time is required to return to the normal. This initial increase in phosphate must result from burning the litter thereby leaving excesses of the element on the surface in a soluble form. Alway and Rost (1) and Wilde (76) report increases in phosphorus for this reason.

Since the subsequent decline of phosphorus in the surface soil is accompanied by an increase in the subsoil, there must be some movement of this element through the profile. The soil is high in iron and aluminum (see Table 1) and so it is very probable that much of the phosphorus released by burning is leached to the subsoil where it is fixed as ferric phosphate or perhaps as aluminum phosphate. In support of this, much concretionary material is present in these soils as a rock coating and as weakly cemented aggregates. Somewhat similar material has been described by Drosdoff and Nikiforoff (19) and by Wheeting (71). The latter described soil in western Washington which contained shot particles high in sesquioxides and phosphorus. He attributed their formation to the dehydration of iron and aluminum during the dry summer season to form permanently insoluble shot which is, in reality, a diffused B horizon.

Available ammonia content is noticeably higher in both the surface and subsurface soil of burned sites as compared to the virgin condition. At the same time, it appears that the surface soil of the 1948 and 1947 burns contains even more ammonia than the old burns. This initial accumulation after burning is in agreement with Waksman and Starkey (68). They state that ammonia-forming organisms are uninjured by heat treatments whereas the nitrifiers will be eliminated. Sushkina (64) and others (23, 48) report stimulation of the nitrifiers after burning. The data presented in Table 11 indicates that there is stimulated ammonification immediately following burning after which increased nitrification is noticeable. Both processes are speeded up as a result of better aeration when timber is removed and lack of competition by fungi which are eliminated by burning. The increased surface soil temperatures as a result of blackening is also a factor contributing to increased biological activity.

The figures for available nitrate show, with two exceptions, a decrease in both surface and subsurface soil after burning which is indicative of leaching losses. This effect is supported by the fact thatthe surface soil of the relatively severe 1947 burn shows a significant increase in nitrates as do both the surface and subsoil of the doubly burned 1931-32 site. The latter exhibits a higher content of nitrate in the subsoil than in the surface soil which is definite evidence that leaching of nitrate has occurred to a considerable extent following increased nitrification at the surface.

It is worth noting that the type of humus layer found under virgin stands in the study area is apparently a fibrous mor (9, 29, 48). Lutz and Chandler state that the fungi comprise the most important organisms in mor humus. They observe that this humus type does not exhibit nitrification readily as a result of exposure alone and that fires may be used to advantage for this purpose.

The results of organic matter determinations show that no significant loss results because of burning. The reader must keep in mind, however, that the surface (A) samples tested were taken from the mineral soil, not from the duff remainder. Over much of the burned sites the duff layer had been completely removed. It is worthy of note that the subsoils of burned sites except 1947 and 1931-32 contain approximately the same percentage of organic matter as the virgin subsoil. The two exceptions have subsoils distinctly higher in organic matter and as already intimated represent severely burned sites. It is possible that severe burning causes dispersion of organic aggregates and consequent movement of suspended organic particles to the subsoil where a higher degree base saturation causes flocculation. These results therefore support the theory for the movement of colloidal clay particles. Such migrations as these are accepted as normal processes resulting in the characteristic profile development of heavier soils than the one under study.

There is no reason, therefore, why such a phenomenon is not acceptable for porous soils such as these.

Observation of the data for total nitrogen determinations reveals that no apparent loss results from the burning to which these soils were subjected. This seems to be more in agreement with (66) than most other workers. It is evident, however, that burning has caused an increased subsurface nitrogen content due to greater bacterial activity and the consequent removal of soluble nitrogenous salts to the subsoil. This movement could be as nitrate in solution or as the ammonium radicle adsorbed to colloidal particles in suspension. The very noticeable decrease in the carbon-nitrogen ratio in the subsoils of all burned sites is naturally due to increased nitrogen, since the organic matter content is only definitely altered in two cases. The 1948 surface soil is the only case where the carbon-nitrogen ratio is lower at the surface. This fact supports the theory of increased ammonification and nitrification which has been presented since Lutz and Chandler (48) state that "very little nitrogen is liberated as nitrate until the carbon-nitrogen ratio of the organic matter has narrowed."

The moisture equivalent of the surface soil is materially reduced by burning and 18 to 19 years are required for this surface soil to regain its normal water holding capacity. This trend is quite apparent in the results of the 1948 to 1931-32 burns and the oldest burn (1929) shows a slightly increased capacity to hold water as compared to the virgin site. These findings are in agreement with Alway and Rost (1), Auten (4), Wahlenberg et al (66), Heyward (34) and Garren (25).

Conclusions

Slash burning on coniferous forest soils of Vancouver Island causes:

(1) lack of natural regeneration for 10 - 15 years.

(2) a gradual increase in surface soil pH due to the "pumping" action of fast-growing herbs and shrubs which causes bases to be brought to the surface from the subsoil.

(3) increased exchangeable hydrogen in the subsoils of burned sites apparently due to action of herbaceous growth in removing bases to the surface and also to increased biological activity.

(4) an initial increase in exchangeable base content of the burned surface which begins to disappear due to leaching in 3 or 4 years.

(5) increased magnesium and potassium in the subsoils of burned sites as a result of leaching these elements from the accumulated ash.

(6) initial increase in phosphorus content of the surface burned soil with a subsequent removal of this element to the subsoil due to the solvent action of percolating rain water. This phenomenon is especially true in the case of severely burned soils.

(7) increase in ammonia content in both surface and subsurface soils after burning due to stimulated ammonification.

(8) increased nitrification and loss of nitrate by leaching with severe burning.

(9) migration of colloidal organic matter and clay particles to the subsoil.

(10) increased total nitrogen content and a consequent decrease in the carbon-nitrogen ratio of the subsoil.

(11) a reduction in the moisture holding capacity of the surface soil immediately following burning.

Recommendations

(1) Due to the inherent variability of all soils it is advisable to carry out any further studies of slash burning on several sites over a period of 15 to 20 years with annual sampling and analysis of the soil from each site. Only in this way is it possible to eliminate soil variability so that the effects of burning are elucidated.

(2) In conjunction with soil studies after burning, it is important to analyze the herbaceous growth invading burned sites as a means of correlating changes in soil nutrients with changes in vegetative growth.

(3) Careful studies with respect to seedling survival and response on burned soil in this area are necessary to determine whether or not artificial regeneration will be economically feasible.

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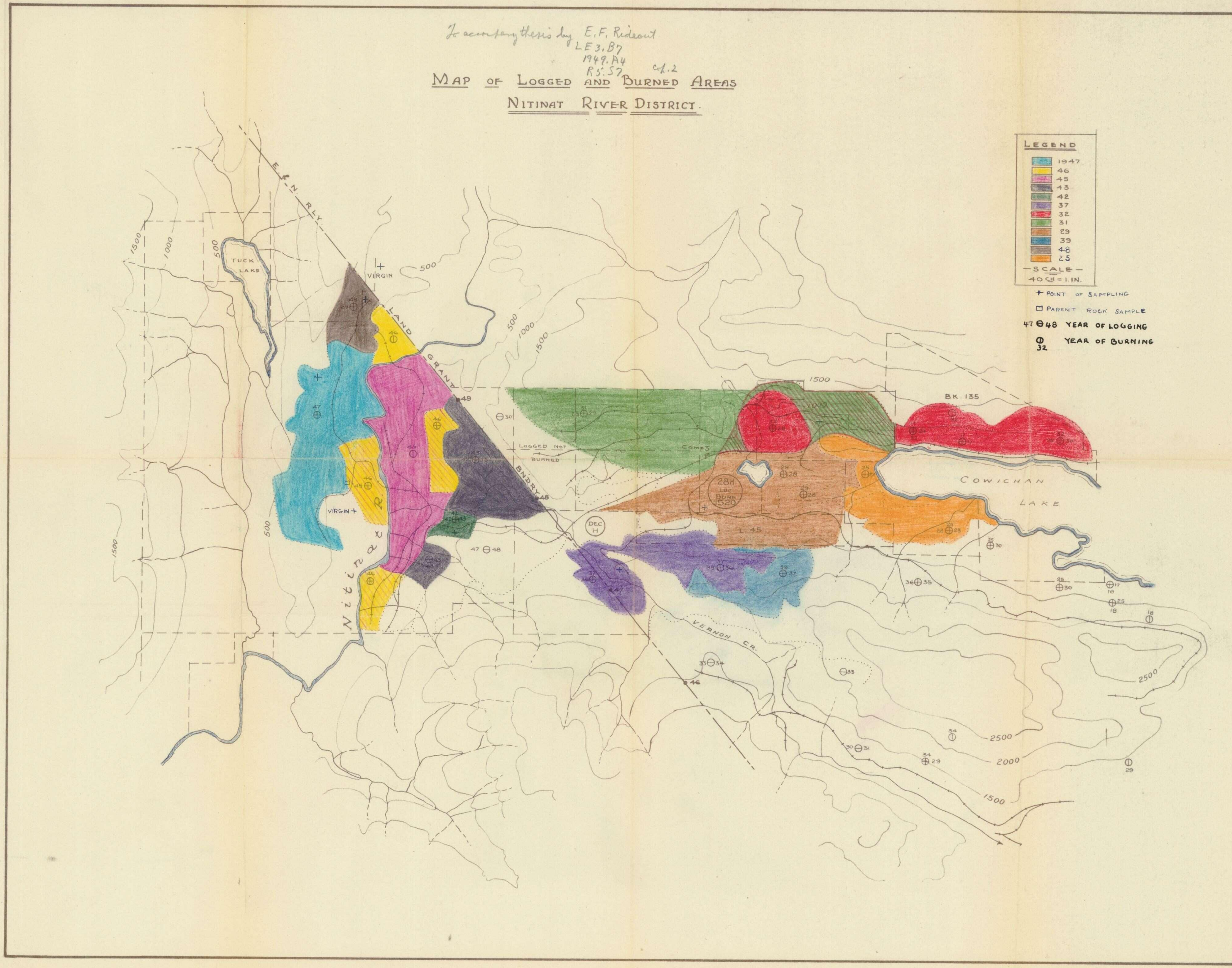
APPENDIX

Common and Scientific Names of Trees and Herbs.

Common Name:	Scientific Name:
Douglas fir	Pseudotsuga taxifolia
Western red cedar	Thuja plicata
Red alder	Alnus rubra (oregana)
Engelmann spruce	Picea engelmanii
Longleaf pine	Pinus palustris
Western hemlock	Tsuga heterophylla
True firs	Abies spp.
Sitka spruce	Picea sitchensis
Groundsel	Senecio vulgaris
Fireweed	Chaemaeraerion angustifolium
Oregon grape	Berberis nervosa
Tiarella	Tiarella triofoliatia
Deer fern	Struthiopteris spicant
Lady fern	Asplenium cyclosorum
Sword fern	Polystichum munitum
Maidenhair fern	Adiantum pedatum
Wild lily of the valley	Maianthemum bifolium
Salmonberry	Rubus spectabilis
Trailing blackberry	Rubus macropetalus
Mountain blueberry	Vaccinium membranaceum
Evergreen huckleberry	Vaccinium ovatum
Red huckleberry	Vaccinium parvifolium
Hawkweed (hawkspur)	Hieracium albiflorum
Thimbleberry	Rubus parviflorus
Elderberry	Sambucus glauca
Salal	Gaultheria shallon
Hichen	Peltigera aphthosa
Stinging nettle	Urtica lyallii
Bracken	Pteris aquilina
Grass	Bromus sp.
May leaves	Achlys triphylla


To accompany thesis by E.F. Rideout
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MAP OF LOGGED AND BURNED AREAS
NITINAT RIVER DISTRICT.
LEGEND
1947
46
45
43
42
37
32
31
29
39
48
25
SCALE
40 CH = 1 IN.
+ POINT OF SAMPLING
PARENT ROCK SAMPLE
47 ⊖ 48 YEAR OF LOGGING
32 YEAR OF BURNING
TUCK LAKE
E & N RLY
LAND GRANT BNDRY
VIRGIN
LOGGED NOT BURNED
COWICHAN LAKE
VERNON CR.
Nitinat R.
BK. 135
DEC H
L. 45
1500
1000
500
2000
2500