The effect of spring burning of big sagebrush -grassland (Artemisia tridentata Nutt - grassland) on the soil and vegetation
by Mutasim Bashir Nimir

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN Range Management
Montana State University

Abstract:
The study was planned to find the effect of spring burning of big sagebrush - grassland (Artemisia tridentata Nutt - grassland) on the soils and vegetation of a part of Taylor Fork cattle and horse allotment, Gallatin National Forest, Montana.

The study area was burned on May 30, 1973. The burn was not thorough due to unfavorable weather conditions and considerable green growth.

Procedures used to obtain information on the effect of burning on the soil physical properties were: measuring the soil temperature during the burn, weekly measurements of the soil temperature following the burn, biweekly measurements of the soil penetration indices, measurements of the infiltration rates and measurements of the soil moisture contents.

Samples of soil were collected before and after burning for chemical analyses.

Procedures used to obtain information on the effect of burning on vegetation were: weekly measurements of the basal cover, weekly measurements of the vegetational development, measurement of the production and estimation of the big sagebrush killed by the burn.

This study produced the following results: The soil physical properties did not show major changes induced by the burn. The slight changes of the soil physical properties reported are not expected to trigger immediate changes in the vegetation. The soil chemical analyses reflected that the changes due to biological reasons were greater than the changes due to burning effect and that the change in soil nutrients was not very important. Burning resulted in a considerable temporary reduction of the basal cover of most of the vegetation as a result of direct damage caused by the fire. The damage did not last for more than three or four weeks for most of the species. Differences in, vegetation and soil characteristics were more related to the time of measurement than to burning.

Festuca idahoensis was more susceptible to damage by the burn while Agropyron trachvcaulum was favored by the burn.

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ABSTRACT

The study was planned to find the effect of spring burning of big sagebrush - grassland (Artemisia tridentata Nutt - grassland) on the soils and vegetation of a part of Taylor Fork cattle and horse allotment, Gallatin National Forest, Montana.

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Festuca idahoensis was more susceptible to damage by the burn while Agropyron trachycaulum was favored by the burn.

INTRODUCTION

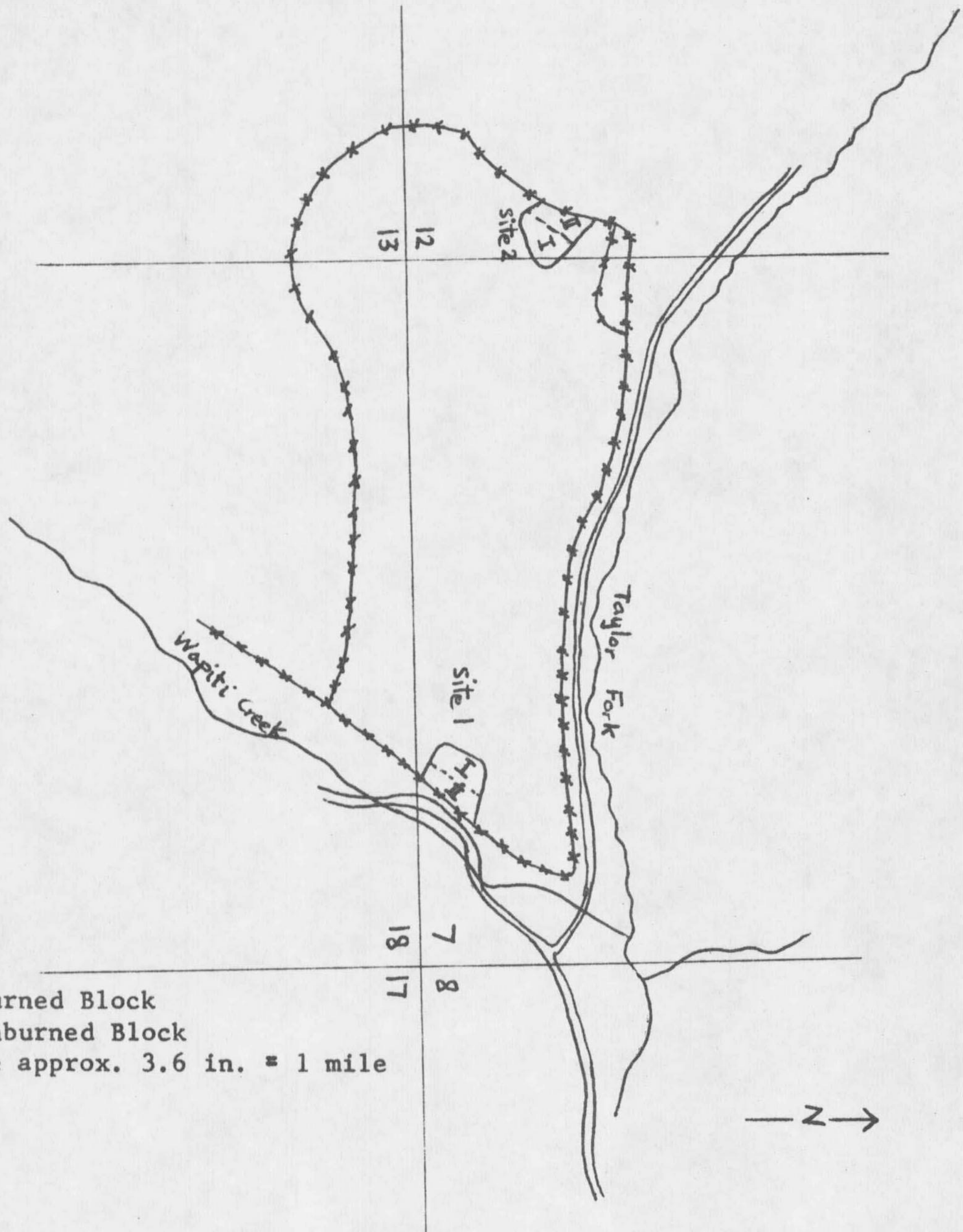
The area under study is a part of Taylor Fork cattle and horses allotment, Gallatin National Forest. It is located on Taylor Fork of the Gallatin River, immediately southwest of the Taylor Fork and Wapiti Creek junction (Figure 1).

The range is classified as good condition. It is mainly managed as a horse pasture. This pasture is part of a grazing system. The pasture was rested one year before the study and throughout the study period.

Spring burning was planned as a method for controlling big sagebrush (*Artemisia tridentata*) and for increasing forage production. About 140 acres were burned on May 30, 1973. The burn was not thorough due to unfavorable weather conditions and considerable green growth.

The study was planned to find out changes in the vegetational composition and cover which might be caused by the burn. The study was planned to provide explanation to such vegetational changes through an understanding of the burning effect on the physical and chemical properties of the soil.

The field work was started at the end of the spring and terminated by the end of summer, 1973.



I Burned Block
II Unburned Block
Scale approx. 3.6 in. = 1 mile

Figure 1. Taylor Fork, Wrangling pasture cattle and horses allotment - Gallatin National Forest, Montana.

REVIEW OF LITERATURE

The effect of fire on plant communities was recognized very early. Daubenmire (1968) stated that whenever plants grow close enough together to carry a conflagration, fire can be a significant component of the biotic environment. Vallentine (1971) pointed out that fire is a natural factor on wildland and probably no range site with its associated vegetation has developed without being influenced by fire. The effect of fire on vegetation, soil and microclimate is a highly controversial subject. In order to understand how burning affects vegetation it is necessary to consider not only the direct effect on vegetation, but also the direct and indirect effects on the soil and microclimate which will in turn affect the vegetation.

Natural fires undoubtedly have been occurring from the earliest appearance of land vegetation. Lightning is a universal natural cause of vegetation fires from the tundra to tropical rain forests. Authentic accounts show a wide variety of non-anthropeic causes, besides lightning, operating occasionally. These include volcanic eruptions, spontaneous combustion and occurrence of sparks when boulders roll down a slope (Daubenmire, 1968).

Man-caused fires apparently were common in prehistoric times. Fire as an aid in hunting, warfare, improving grazing conditions and clearing the land for agricultre was used very early in man's history. Lutz (1930) stated that the use of vegetation fire to facilitate hunting and encourage new growth was widely practiced by North American

Indians and that fire was used by the white settlers to clear the land and improve grazing conditions. Ahlgren and Ahlgren (1960) concluded that fire has been a major factor in the ecology of forests and grasslands in North America. They pointed out that in many places large and profitable forests have developed following fire, and in other places permanent shrub or grassland developed.

Daubenmire (1968) in a review of literature of the ecology of fire in grassland covered much of the information under this topic. He pointed out that despite belated recognition of the importance of fire as a factor of plant environment, a considerable body of literature on vegetation burning has accumulated during the past 25 years. He reviewed the ecology of fire comprehensively and drew some generalizations regarding the environment alterations, the effect on individual species of plants and the effect on the vegetation communities and associated animals. Vallentine (1971) has reviewed the literature of fire use as a tool in range improvement. He discussed the role of fire on rangeland, burning practices and safeguards, and burning effects on soil and vegetation. Wright (1974) summarized some of the information about range burning. He pointed out some of the uses of burning in the management of forests, grasslands and wildlife. He concluded that there are many dangers in using fire, both in its application and in its results. He suggested that to minimize harmful effects fire should never be used during extended dry periods and burns should always take place when soil is damp or wet. He emphasized that the user of fire should be an experienced professional with a thorough knowledge of ecosystems, weather and fire behavior.

In this review most of the information included in the reviews of the above three authors are not repeated unless they have direct relationship to this study.

Effect of burning on the mulch and organic matter:

The immediate effect of fire is that it deprives the soil of its protective cover. Blaisdell (1953) and Sweeny (1956) found that fire did not destroy all the litter. The average loss of litter was estimated to be not more than 75%, depending on the amount of organic matter available for burning and on the fuel matrix and its moisture content.

Together with the decrease in litter cover, burning always changes the amount of organic matter in the soils. Wahlenberg et al. (1939) found that frequent burning of grass beneath pines in the coastal plains of southeastern North America increased organic matter of the upper 10-15 cm of the soil profile. Shantz (1947) pointed out that the reported increases in organic matter represents mainly charcoal fragments, rather than humus. In Nigeria 30 years of annual burning raised the humus content of the upper 20 cm 17% where light burns were made early in the dry season, but lowered the humus by 12% where fires were set later in the dry season and were much hotter (Moore, 1960). In

Kenya grassland, Edwards (1942) reported an increase in organic matter after ten years or more protection from fire.

Daubenmire (1968) concluded that grassland fires are seldom hot enough to directly oxidize organic matter that lies deeper than a few millimeters in the soil profile. He added that with the subsequent increase of direct insolation that warms the soil and stimulates microbial activity, coupled with at least a temporary elimination of the source of humus, it might be anticipated that burning would reduce the humus content of the soil. This is especially true if burning is frequently repeated. On the other hand, the decay of roots of plants killed by fire, any replacement of perennials by annuals, or any increase in primary productivity will tend to have an opposite effect.

Barnette et al. (1930) stated that the most direct effect of the destruction of litter is a marked increase in light intensities which influence vegetative growth and flowering of certain plants. The change in light intensities might also affect germination of certain seeds (Stone, 1951). In agreement with this, Hulbert (1969) explained an increase in yield of big bluestem (Andropogon gerardi) following burning as directly related to the removal of the litter rather than to heat or to fire-induced nutrient changes. Weaver and Rowland (1952) stated that lower herbage production and plant heights on unburned plots were due to excessive litter. Ehrenreich (1959) considered litter removal as the primary factor for forage increase following fire in Iowa.

Effect of burning on the soil physical properties:

It is extremely unlikely that any two fires occurring in the field would be exactly the same, and even within the same fire, different places would be expected to exhibit different ranges and durations of soil temperatures. In the burning of grassland communities it was noted that higher temperatures do not persist at one place more than one minute except in dense tussock (Sweeny, 1956; Lloyd, 1971).

In Derbyshire Dales grassland burning, Lloyd (1971) reported 400°C (752°F) as the highest soil surface temperature. The highest soil surface temperature reached during chaparral fires in California was 1200°F with 630°F and 310°F at the ½ inch and 1½ inch depths, respectively, (Sweeny, 1956). Daubenmire (1968) stated that the highest soil surface temperature reported in grassland dire was 720°C (1328°F) with the next highest being 715°C (1319°F), 669°C (1236.2°F) and 600°C (1112°F), and concluded that the amount and rate of heat released as vegetation burns depend on weather conditions, topography and the kind and amount of fuel. The drier the soil the higher its surface temperature when grass burns, but at the same time low moisture content reduces the downward conduction of heat.

Many burns result in a black charred debris covering the soil surface, causing the burned areas to have higher soil temperatures than unburned areas due to increased absorbed solar radiation. Sweeny (1956) noted that in addition to the increased absorption of the blackened soil surface for solar radiation, the removal of brush cover by fire increased the solar radiation striking the exposed soil and so higher soil temperatures occurred in the burned areas at and just below the soil surface. This caused greater daily and seasonal temperature fluctuations on burned areas as compared to adjacent unburned areas.

Hopkins et al. (1948) observed that at an air temperature of 85°F the surface temperature of yellow mineral soil rose to 125°F while the surface temperature of black charred soil rose to 140°F. Kucera and Ehrenreich (1962) reported that temperature was 2.2 to 9.8°C higher on burned grassland in central Missouri at mid-afternoon during the spring with the differences declining as the plant cover develops during the first post-burn season. These temperature differences exert considerable influence on the germination of seeds and the composition of herbaceous cover. One of the hypotheses accounting for the frequently observed stimulative effects of grassland fires is that the stimulation is more an indirect result of altered temperature than of readily available nutrients freed in the plant ash (Sweeny, 1956; Daubenmire, 1968).

Another important change caused indirectly by burning is the change in soil moisture. It is caused partly through the removal of the litter and partly through the change of vegetational cover. Ehrenreich (1959) stated that mulch intercepts some precipitation, tending to increase snow accumulation, snow melting and infiltration rates. He added that mulch removal might increase the evaporation rate, especially in warmed up burned soil. Auten (1934), studying the effect of forest burning in the Ozarks, estimated the rate of water absorption as six to eight times more in unburned soil than in burned soil. Owensby and Wyrill (1973) suggested that the decrease in water use efficiency caused by burning is due not only to the reduction of the infiltration rate but also to increased evaporation as burning induces higher soil temperatures.

Hanks and Anderson (1957), comparing burned and unburned bluestem prairie, measured soil moisture just before and after an intense late September rain of 4.47 inches. They found a moisture increase of 4 inches on the upper 5 feet of soils in the unburned plots while the increase in the burned plots was only 2.5 inches. In support, Anderson (1965) showed that burning significantly reduced the level of soil moisture at all depths and that the reduction is greater following early burning than late burning and is greater in deeper soil layers than in more shallow ones.

Another factor to be considered in relation to the effect of burning on soil moisture is water repellency in soils. Salih _et al_. (1973) provided experimental evidence that burning sagebrush produces water repellency in soils. They found that maximum repellency occurs at soil temperatures between 1400°F and 1800°F and that repellency is produced as a result of burning of the sagebrush leaf mulch under the shrub rather than the burning of the live plant material. They suggested that the drier the soil and mulch, and hence the hotter the fire, the more likely it is that water repellent spots of soil will be formed.

In some instances higher infiltration rates were reported on burned sites than unburned sites. Torrant (1956), analyzing the effect of burning in ponderosa pine, explained that when the prescribed burn caused a light surface burn in which incorporated humus was not consumed to any significant degree and the fast moving fire burned principally on the fresh litter the soil was not baked or reddened as in burns in heavier fuels. The increase of macroscopic pore volume and percolation rate may possibly have resulted from some burning of individual dead shrubs and grass roots for several inches into the soil. When such roots were removed, the volume of large vertical water channels was increased. Improved soil aggregation caused by liberation of basic materials in the ash may also have contributed to the increase in macroscopic pore volume. Other research work which supported this was done by Scott and Burgy (1956) and Beaton (1959). The latter pointed out that exposure of the soil surface of burned areas to weather may lead to marked reduction of infiltration. In his study of a timber rangeland in British Columbia he found that a period of two years following the burn was necessary for the reduction of infiltration rate to occur.

Effect of burning on the soil chemical properties:

Lloyd (1971) stated that when a plant community is burned, in addition to the damage to the plants and alteration of the physical environment there are considerable changes in the chemical status of the community. He pointed out that there may be a substantial loss of nutrients in the smoke or in wind blown ash and there may be a release of readily soluble nutrients in the deposited ash. The oxidation of organic materials and production of ash by fire are accompanied by the release of bases. Slight increases of pH are frequently observed following fires.

An increase of pH in the upper 38 mm of the soil was reported by Cook (1939) following annual burning of Themeda spp. grassland in South Africa. The pH of Nigerian savanna soil was raised by annual burning from 6.0 to 6.2 if burns are late in dry season and very hot or to 6.3 if the burning was early in the dry season when the temperatures were not so high (Moore, 1960). Increases of pH from 5.8 to 6.1 in the upper 18 mm of the soil were caused by grassland burning in Iowa (Ehrenreich and Aikman, 1963). They found that the increase of the pH tended to be proportional to the amount of litter oxidized. Sampson (1944) concluded that the differences in the pH between burned and unburned soils were slight except for small localized areas of ash accumulation and that change in pH was too slight to affect growth significantly. In agreement with this Sweeny (1956) found that the slight pH increases after fire were temporary and disappeared after the first rains. He found pH ranging from 6.3 to 6.9 on burned areas and from 5.9 to 6.7 for soil samples on unburned areas. He concluded that there was no evidence to assume that the slight change in soil pH as result of fire was any significant factor in determining marked changes in population densities of herbaceous cover. Daubenmire (1968) agreed with this and commented that the degree of change within the pH range characteristics of grassland burning is probably of little significance and usually persists only a year or two.

One of the direct effects of burning is its effect on nitrogen. Nitrogen in the litter is generally unavailable for plant use and may remain so until the litter is decomposed by soil micro-organisms. Burning hastens litter decomposition, but forms nitrogenous compounds which might be lost by volatilization. Total nitrogen in the ecosystem is expected to decrease as a result of burning. On the other hand, total nitrogen in the mineral soil might increase as a combined result of burning litter and standing vegetation and leaching of nitrogen containing compounds. Norman _et al._ (1960) found that in the Northern Territories of Australia frequent burning of native pastures was not likely to constitute a severe drain on the total nitrogen reserves of the soil. He estimated these reserves to be around 3000 lbs. per acre within the root zone of the ground flora. He estimated the loss of nitrogen to the atmosphere due to burning to be in the order of 4 lbs.

per acre where the average dry matter loss was about 1200 lbs. per acre. He further estimated the return of nitrogen from rain water to be around 2 lbs. per acre.

Wahlenberg *et al.* (1939) stated that in the longleaf pine lands, an increase in the soil pH as a result of fire favored the multiplication of bacteria, including nitrifying bacteria and nitrogen fixing bacteria, resulting in an increase in available soil nitrogen. Christensen (1973), studying nitrate concentration following burning chaparral in California, found that higher nitrate concentrations were due to the addition of ammonium and organic matter in the ash. He also pointed out the importance of time of the year and the frequency with which soil samples were taken in such a study. He finally indicated that foliar leaching needed to be assessed to get an accurate account of the nitrates added through burning.

The destruction of vegetation and litter by fire changes the compounds of calcium, potassium, magnesium and phosphorus to more soluble forms, thus increasing these organic nutrients in the soil. These increases might be only temporary because of leaching and because the amounts of these elements returned from burned ash is proportional to the mass of fuel consumed during the burn. Some of the ash is usually lost by wind and water before a new vegetative cover develops. The amount of ash lost from burned sites varies with the area of the burn, the angle of slope, the intensity of the first winds and rains and their continuity in respect to either the absence or the varying density of renewed vegetative cover at or near soil level. The fate of plant nutrients in ash remaining on the soil surface is influenced by the solubility of salts and distribution and intensity of precipitation following the fire (Daubenmire, 1947; Philips, 1965; Lloyd, 1971).

Moore (1960) found that in the Nigerian savanna, mild fires coming at the start of the dry season increased cation exchange capacity, available phosphorus, exchangeable calcium, magnesium and potassium and base saturation percent. In contrast to that, hot fires coming late in the dry season reduced the cation exchange capacity, exchangeable calcium and potassium with available phosphorus remaining unaffected and percent base saturation slightly increased. Ehrenreich and Aikman (1963) stated that although grassland fire in Iowa released sufficient bases to raise the pH of the soil appreciably, no increase in exchangeable potassium could be measured. In a Bouteloua spp. grassland in southeastern Arizona, fire decreased potassium consistently in the upper 25 mm of the soil profile (Reynolds and Bohning, 1956).

In Kansas rangelands, Owensby and Wyrill (1973) stressed the importance of time of burning on the change of chemical properties. They reported that winter burning caused the most changes, with higher pH, organic matter, calcium, magnesium and potassium, and lower nitrogen than with other treatments. They reported that late spring burning had the least effect. The strong influence of earlier burning on pH and certain mineral salts was attributed to reduced infiltration by raindrop action on the bare soil, which reduced salt leaching from the soil.

Nye (1959) working in west African savanna, presented an interesting quantitative comparison between average amounts of nutrients released in burning the herb layer of savanna with the amount released by burning forests:

Elements	Amounts released in savanna	amounts released in forest burning
Phosphorus	8.4 Kg/hectare	16 X as much
Potassium	49.2 Kg/hectare	18 X as much
Calcium	37.2 Kg/hectare	73 X as much
Magnesium	27.6 Kg/hectare	13 X as much

In an overall evaluation of the effect of burning on the fertility of soil, Daubenmire (1968) stated that fire results in an abrupt release of elements that normally would have become available gradually in consequence of the slow decay of litter. However, this fertility is made available at the soil surface where it is subjected to horizontal displacement by wind or water, or perhaps is lost by leaching through the soil profile too quickly for it to be adsorbed or taken up by soil organisms. Lloyd (1971) concluded that the effect of fire in terms of plant nutrition were unimportant in the ecology of grassland communities relative to damage caused to the plants and alteration in the physical environment.

Effect of burning on plant communities:

Fire is one of the basic natural forces that has influenced plant communities over evolutionary periods of time. Certain plant communities require periodic fire to maintain their position in the ecosystem. Clements (1905) stated that local fires initiated a succession in which the plants occurring on the burn were largely derived from those parts of the original formation which had not burned. He also proposed that, if the original formation was mostly or completely destroyed, the first stages of the new vegetation would be made up by "invaders" from adjacent formations. Jarret and Petric (1929) believed that soil will never be sterilized by fire. Some seeds and rhizomes always will be present after the fire and recolonization is mostly from surviving species in the burned areas rather than from migration.

Ahlgren (1959), studying the effect of fire on reproduction and growth of vegetation in northeastern Minnesota, classified herbs and shrubs into three groups based on their occurrence on burned areas. His classification was as follows:

1 - Those which occurred only on unburned areas.

2 - Those appearing only on burned-over lands.

3 - Those which were on both.

He stated that species of the first group were minor associates occurring sporadically in the area. All were vegetatively reproducing perennials and were characteristically shade plants. They did not appear after fire either because their reproductive parts were destroyed or because they were unable to grow and compete with more light-tolerant species. The second group was mostly of seed-reproducing annuals and few vegetatively-reproducing species. These showed tolerance for both light and shade.

The appearance of numerous herbaceous plants is a common occurrence following fires. In many cases annuals and other herbaceous species which were not generally a conspicuous part of the flora become prominent and abundant after fires. This has been explained to be the result of the change of growing conditions which favor these species and make them more capable of competing (Adamson, 1927; Pritchard, 1951; Went _et al._, 1952; Cooper, 1961).

The occurrence of grassland all over the world points to fire as the primary factor that maintains grassland and savanna (Sauer, 1950). This relationship is largely attributed to fire-caused elimination or reduction of woody species that do not sprout from their roots (Cook, 1939; Scott, 1951).

Fire as a tool for range and pasture improvement:

Burning in grassland is applied to achieve different objectives. It is used to eliminate or suppress undesirable shrub species, to prevent the invasion of inferior species and to increase production and hence grazing capacities. Many other goals can be achieved from well planned burning. Included in these goals are improved nutritional values of vegetation, increased palatability, increased utilization, improved wildlife habitat, providing a mineral seedbed, and control of various diseases (Vallentine, 1971; Wright, 1974).

In planning a grassland burn all the components of the ecosystem should be carefully studied and the effects on them of burning should be considered. The complexity of the whole process makes it difficult to reach the right decision. Wright (1974) indicated that although much is known about the effect of fire on western rangelands and its value as a tool for range improvement the information to conduct a specific prescribed burning is generally inadequate or non-existent. He added that the use of fire is frightening to many range managers and many desirable prescribed burns are not applied.

Specific information on the effects of burning on individual species of grasses, forbs and shrubs is still inadequate. Mutch (1970) made an interesting hypothesis that plant species which have survived fire for thousands of years not only have selected survival mechanisms, but also have inherited flammable properties that can contribute to the perpetuation of fire dependant plant communities. He derived this hypothesis experimentally following laboratory combustion tests with litter of eucalyptus, ponderosa pine and tropical hardwood leaves.

Blaisdell (1953) in a study in the upper Snake River plains, stated that all plants were damaged by fire, but if given complete protection from grazing for one season, most recovered. He found that Idaho fescue (Festuca idahoensis) was slower to recover than the other species. He added that rapidity of recovery was much greater among shrubs with sprouting habits and among rhizomatous herbs. It is generally accepted that the effect of burning on forage plants varies according to species, location, condition of range, season of burning, stage of growth and many other characteristics of the range as well as the characteristics of the burn. (McMurphy and Anderson, 1965; Hadley and Kieckhefer, 1963).

Burning the semi-desert grasses and shrubs was found to double the production of annual grasses in Arizona in wet years with little or no increase in dry years (Cable, 1967). This increase of grass production was explained as a result of the reduction of burroweed (Haplopappus tenuisectus). The amount of rainfall is a significant factor in obtaining increased grass production on burned sites. In Iowa, big bluestem, little bluestem (Schizachyrium scoparium) and yellow indiangrass (Sorghastrum nutans) yielded nearly twice as much herbage and several times as many seedstalks on burned as on unburned pasture (Ehrenreich and Aikman, 1957). In a similar study Dix and Butler (1954) reported increases in heights and number of flower stalks in most prairie species the first growing season following fire in Wisconsin. Curtis and Partsch (1948) reported a six-fold increase in number and 60% increase in height of seedstalks on big bluestem. Aikman (1955) reported an average five-fold increase in number and 20% increase in height of seedstalks of dominant and principal subdominant vegetation type grasses as a result of burning in Iowa. In east central Illinois, Old (1969) found that spring burning in tallgrass prairie caused a two- to three-fold increase in herbage production and a ten-fold increase in seedstalk production. An annual spring burn in central Missouri induced a marked increase in dry matter production and mineral composition of prairie vegetation. The numbers of flower stalks were also more in the burned than the unburned plots (Kucera and Ehrenreich, 1962). Similarly, a spring burn of brush prairie savanna in northeastern Wisconsin was reported by Vogl (1965) to produce more than 1000 lbs/acre increase in green herbage, a three-fold increase in grass and forb yield. Hadley and Kieckhefer (1963), studying the effect of burning on Indiangrass and big bluestem, found that living shoot biomass was greater after spring burning than after protection. They suggested this was due to excessive accumulation of litter in protected areas causing a drop in production.

Burning does not always have a favorable effect on grasses. In certain conditions it might have an adverse effect. In Wisconsin prairie, Curtis and Partsch (1948) found that six years of spring burning reduced bluegrass (*Poa* spp) to one-fifth of their original cover. Aldous (1934) reported injury to Kentucky bluegrass (Poa pratensis) from spring burning. Robocker and Miller (1955) reported that early spring burning was harmful to basin wildrye (Elymus cinereus) and concluded that the cool season grasses started growth early and suffered heat damage because of fire, whereas the warm season grasses still in dormancy suffered little or no damage. Reduction in yield as a result of early spring burning was noted by Launchbaugh (1964). He estimated the reduction of buffalograss - blue grama (Buchloe dactyloides - Bouteloua gracilis) mixture by the second season was about 65% while in wheatgrass (Agropyron spp.) ranges reduction was 82%. However, by the third season no differences in production were noticed between the burned and unburned plots. The reduction of yield the second season after burning was explained as a result of the direct effect of fire, which was clearly reflected in lesser heights and vigor in the burned plots.

The season of burning is recognized as the major factor influencing the expected results. This is especially significant in comparing the effects of planned burning and natural burning. While natural and accidental burns have their highest frequency during the driest part of the year, planned burning is often done at other seasons as a means of maximizing desirable fire influences (Komerack, 1965; Wright, 1974).

Grelan and Epps (1967) reported a greater production of total grasses on spring-burned than on winter-burned southern bluestem ranges. In Flint Hills bluestem ranges Anderson (1964) reported that the late spring burn produced the highest increase in forage production compared to burning early in spring and winter. He attributed that to the highest soil moisture level during that period.

Hopkins et al. (1948) reported spring burning in west central Kansas prairie was more harmful than fall burning and caused cover reduction where light grazing was practiced. They explained that light grazing resulted in mulch accumulation and hence more destructive fires.

The role of fire is generally recognized in preventing the infestation of grassland by shrubby species. Thick stands of some shrub species are of little use to livestock and a cover of scrubby trees and brush on land does not provide as good a protective cover for erosion as do grasses. Woody vegetation has been found to require two to four times more water to produce a pound of dry leaves than does grass and in areas where dense stands of useless woody vegetation are established, more water is lost in transpiration than in runoff down the streams and rivers (Allard, 1948; Elwell and Cox, 1950; Philips, 1965).

Box (1967), working in Texas, stated that fire control was an important factor in the increase of shrubby species such as mesquite, oak and juniper. In agreement with this, Daubenmire (1947) stated that originally the vegetation of the sagebrush-grass semidesert of western North America consisted of a dense cover of perennial grasses among which were scattered moderate sized shrubs, chiefly *Artemisia tridentata*. When this vegetation is subjected to heavy grazing the perennial grasses are reduced to scattered stands of weakened plants, whereas the relatively unpalatable sagebrush increases in size and numbers to an extent that is highly objectionable from the grazier's standpoint. He also stated that fire, in contrast to grazing, kills the shrubs but does not injure the grasses when these are aestivating. He concluded that on areas where the grasses have not been too severely depleted, range improvement has been achieved by burning to kill the shrubs, then deferring grazing for a few years until the grasses have multiplied to form a complete cover.

DESCRIPTION OF STUDY AREA

The study area is about 214 acres of which 157 acres are sagebrush grassland type. The dominant shrubs are big sagebrush (*Artemisia tridentata*), silver sagebrush (*Artemisia cana*) and shrubby cinquefoil (*Potentilla fruticosa*). The dominant grasses in this type are onespike danthonia (*Danthonia unispicata*), mountain brome (*Bromus marginatus*), Idaho fescue (*Festuca idahoensis*), slender wheatgrass (*Agropyron trachycaulum*), alpine bluegrass (*Poa alpina*) and green needlegrass (*Stipa viridula*). Sedges (*Carex* spp.) are also dominant in some localities. Many forbs occur in this type of which the following are more common: avens (*Geum triflorum*), northwest cinquefoil (*Potentilla gracilis*), common dandelion (*Taraxacum officinale*), sticky geranium (*Geranium viscossissimum*), crag aster (*Aster scopulorum*), velvet lupine (*Lupinus leucophyllus*), rose pussytoes (*Antennaria rosea*), Virginia strawberry (*Fragaria virginiana*), false dandelion (*Agoseris glauca*), common yarrow (*Achillea millefolium*), tufted phlox (*Phlox caespitosa*) and forget-me-not (*Myosotis sylvatica*).

The rest of the study area is covered by the sedge-willow type (*Salix-Carex*) and lodgepole pine type (*Pinus contorta*). These types were not burned.

The research was done in the sagebrush-grassland type. Two experimental sites were chosen. The lower site (Site 1) is at 6900 ft. elevation while the upper site (Site 2) is at 7200 ft (Figure 1). Both sites were divided into two blocks having one burned and the other protected from burning (Figures 2 and 3). Site 1 is gently sloping

Figure 2. Site 1, Wrangling pasture, Taylor Fork Cattle and horse allotment - Gallatin National Forest.

Figure 3. Site 2, Wrangling pasture, Taylor Fork cattle and horse allotment - Gallatin National Forest.

towards the east while site 2 is sloping towards the northeast. Site 1 is more exposed than site 2 which is surrounded by timber and topographical barriers. This might explain the fact that the snow melted from site 2 almost two weeks later than from site 1.

The soils of site 1 are well drained. Profile has around 7 inches of very dark brown loam surface layer, a yellowish brown, blocky structured, light clay loam subsoil. The soils of site 2 are excessively drained. Profile has a thin, dark grayish brown gravelly loam surface layer, a weak blocky structured, grayish brown, gravelly loam subsoil and calcareous gravelly substratum. Fractured hard bedrock occurs within 10 inches of the surface.

The vegetation on the two sites show some differences. <u>Danthonia unispicata</u> is the dominant grass on site 1 while <u>Bromus</u> <u>marginatus</u> is the dominant grass on site 2. Most of the forbs occurred on both sites but with different relative abundance. However, few species of grasses and forbs occurred in one of the two sites without occurring in the other (Appendix tables 1 and 2).

Weather records for the study area are not available. The nearest weather station is Gallatin Gateway 26 miles SSW (Beaver Cr.). Precipitation and temperature information from this station for the period of May to September are presented in Table 1. Similar information from the West Yellowstone Station, which is about 20 miles southwest of the study area are also presented. These data should provide approximate information of the weather in the study area during the study period.

Table 1. Monthly averages of precipitation and temperature at Gallatin Gateway, 26 miles SSW and West Yellowstone, 1973.1/

Precipitation in inches

Station		May	June	July	August	September
Gallatin Gateway 26 SSW	Total ppt	2.06	2.96	1.00	1.83	2.12
	Departure from normal	-1.09	0.86	-0.66	1.24	1.34
West Yellowstone	Total ppt	1.89	2.95	1.54	2.06	2.65
	Departure from normal	-0.25	0.51	0.28	0.88	1.48

Temperatures in ^{o}F

Station		May	June	July	August	September
Gallatin Gateway 26 SSW	Average Maximum	59.6	68.3	79.6	78.8	65.2
	Average Minimum	26.6	35.1	37.9	38.6	31.5
	Departure from normal 2/	0.2	1.1	0.8	2.1	-2.0
West Yellowstone	Average Maximum	60.0	66.8	77.9	76.1	60.8
	Average Minimum	26.2	35.5	41.5	41.2	32.5
	Departure from normal	-1.1	-0.3	0.1	1.6	-1.6

1/ U.S. Department of Commence, Weather Bureau, 1973.

2/ Departure from monthly average temperatures.

EXPERIMENTAL PROCEDURES

Soil physical properties

Mulch collection: Ten 1 sq. dm plots were located at random in ach site and were used for the collection of mulch. Mulch samples were collected before burning. The dry detached and easily detachable vegetational material was collected in paper sacks. Samples were oven dried at 80°C for 24 hours and weights recorded.

Burn classes determinations: The method devised to estimate the amount of burn occurring on the two different sites was based on the amount of the mulch turned to ash. Three different classes were recognized:

Class 1: Very slightly burned where less than 25% of the mulch was changed to ash

Class 2: Slightly to moderately burned from 25% to 75% of the mulch was changed to ash.

Class 3: Areas severely burned where more than 75% of the mulch was changed to ash.

Two 15-meter transects were randomly located in each site. The different classes were estimated and the amount of each burn class was measured along a stretched tape.

Soil temperature during the burning: "Tempil sticks"[1/] were used to determine the temperature reached during the burn. One set of tempil sticks was placed on the ground surface while another set was buried at a depth of 1 cm.

1/ Tempil sticks are a product of Tempil division, Hamilton Blvd., South Plainfield, N.J. 07080.

Tempil sticks are hard waxes mixed with different chemicals having different melting points. The set of tempil sticks used for the surface temperatures had the following melting points: 800°F, 700°F, 600°F, 500°F, 400°F, 350°F, 300°F and 250°F while those placed at the depth of 1 cm had the following melting points: 350°F, 300°F, 250°F, 200°F, 175°F and 150°F.

The tempil stick waxes were broken in small crumbles and folded carefully in aluminum foils made in rectangular shapes about 1 X ½ inches, allowing very narrow openings on the sides for the gases liberated during the melting process to pass out. The foils were placed carefully and arranged according to their melting points so that they could be easily recognized.

Four replicates were placed in each site before burning.

Soil temperatures following the burning: The temperature of the top centimeter was measured using an ordinary centigrade thermometer. The temperature of the top four centimeters was measured by a special soil thermometer with a metallic probe which was inserted in the soil to the depth of four centimeters. This gives an average of the temperature for the four centimeters depth.

Ten measurements of temperature on each block were taken weekly at every second step along a line located at random. These measurements were taken at two different times, early in the morning (about 6:00 A.M.) and in the afternoon (about 3:00 P.M.).

Soil penetration indices: A 1 cm diameter shaft was forced vertically into the bare mineral soil surface, to a depth of 1 cm and at the rate of about 1 cm/sec. The results are reported as maximum force ($tons/ft^2$) required during penetration. Twenty measurements were taken in each block at 20 randomly distributed points. Measurements were taken biweekly.

Infiltration rates: Two concentric rings were used. The diameter of the outer ring was 10 inches and the inner one was 6 inches and both were one foot high. Both were firmly fixed into the ground to eliminate lateral loss of water through the soil surface. Water was applied simultaneously in both rings and kept at the same level. The time required to complete the absorption of a certain level of water was observed. Only the data from the inner ring were taken to indicate infiltration.

Several measurements were taken on each site. Burned spots were selected to measure infiltration on the burned blocks.

Soil moisture contents: Soil samples were collected by a one-foot long sampling tube. Samples were collected from the top 20 cm of the soil from ten points along a line transect located randomly at each block. The sample taken at each point was put in a tin can and closed tightly. The soil samples were taken to the lab about three hours after collection. They were weighed, put into the oven with cans open for 24 hours at 105°C and then reweighed.

Soil chemical properties

Soil sampling method: On each block, a circle with 3.9 meter radius was used to collect soil samples. The center of the circle, which is approximately the center of the block, was marked by a metal post. A string of the same length as the radius of the circle (3.9 m.) was tied to the metal post and its other end was used to mark the circumference of the circle. Cores of soil were collected every two steps along the circumference of the circle. The cores were divided into 0 to 2 cm, 8 to 10 cm and 18 to 20 cm depths. About 15 cores were taken around the circumference with the soil from each depth being composited, thus providing a composite sample for each depth in one traverse of the circle. Three traverses were made to provide three replications before and after burning. The before-burning samples were collected in mid-May while the after-burning samples were collected in mid-June.

In addition to the above samples, 20 soil sample cores were collected from completely burned areas within each of the burned blocks. The soil samples from 0-2 cm and 8-10 cm were separated from each core. The cores were composited for each depth. In the same manner 20 soil cores were collected from the areas not affected by fire within the burned plots. One sample of the ash materials (above the soil) was collected from the burned areas in each block. These samples were not replicated.

The soil samples were collected in plastic bags which were put into a freezer within three hours of the collection and until they were delivered to the lab. The chemical analysis was done by the Montana State University Soil Testing laboratory.

The samples were thoroughly mixed, oven dried and sieved.

The pH was determined by a pH meter.

Oxidizable organic matter was determined by adding 10 ml. 1N. potassium dichromate to 1 g. dry soil followed by adding 20 ml. of conc. H_2SO_4 (Graham, 1948). After 30 minutes, 100 ml. of distilled water was added to the solution which on cooling was filtered and read on a spectrophotometer at 600 mu. wave length.

Exchangeable potassium, calcium and magnesium were determined by adding 50 ml. of 1N. ammonium acetate to 2 g. of air dry soil, shaking for 10 minutes and then filtering. The filtrates were analyzed on an atomic absorption spectrophotometer.

Available phosphorus was determined by adding 50 ml. of acid ammonium flouride mixture solution ($NH_4F.HCl$) to 1 g. of air dry soil (Bray and Kurtz, 1954). The mixture was shaken for 5 minutes and filtered. To 5 ml. of the filtrate 12.5 ml. of distilled water, 5 ml. ammonium molybdenite and 2.5 ml. stannous chloride were added. The solution was allowed to react for 5 minutes then analyzed in a colorimeter at 600 mu. wave length.

For nitrate analyses, 10 g. of dry soil were added to 50 ml. extracting solution (20 g. $CaSO_4$- 1L. 0.60N Ag_2SO_4 diluted to 10 1. with distilled water). This was shaken for 10 minutes; 0.4 g. $Ca(OH)_2$ was added and shaken for 5 minutes; 1 g. $MgCO_3$ was added and then filtered. Ten ml. of the filtrate was evaporated to dryness on a hot plate and allowed to cool; 3 ml. of phenol disulfonic acid was added and allowed to react for 10 minutes; 15 ml. of deionized water was added with stirring and allowed to cool; 6N NH_4OH was added until the solution became alkaline (yellow color) then 3 ml. was added. The solution was transfered to 100 ml. volumetric flask and deionized water was added. Transmission was read at 420 mu.

Vegetational analyses

Basal cover: Basal vegetational cover was estimated weekly on the four experimental blocks. Two 15 meter transects were used in each block. The starting point of each transect was determined randomly by throwing a frame and starting from where it fell stretching a 15 meter tape. Ten 4 X 5 dm. plots were located along the stretched tape at 1.5 m. intervals. Basal covers of the different species within the 4 X 5 dm. plots were estimated using one sq. dm. and 4 sq. dm. plots to make the estimations.

The 4 X 5 dm. plots were chosen instead of the 2 X 5 dm. plots because it was found that by increasing the area of the plot lesser numbers would be needed to provide a better vegetational analysis (Payne, 1972).

In estimating the canopy-cover of the shrubs the dead shrubs or parts of shrubs within plots were estimated separately from the living shrubs. Also, on the burned block the ash was estimated separately from the litter.

The vegetational measurements were started in mid-June and terminated on the first week of September.

Vegetational development: The above process of establishing transects was followed for vegetational development measurements. Ten plots were located weekly on every experimental block. The dominant species within each plot were measured. The culm heights of grasses and sedges and leaf length of forbs were measured and floral development was recorded. Observations on vegetational development on some of the completely burned areas were recorded.

Productivity measurements: One 15 meter transect was located at random in each plot. Ten 4 X 5 dm. plots were placed at 1.5 m. intervals along the transects. The vegetation within the plot was clipped to ground level. Each species was segregated separately, whenever it was represented in reasonable quantities. Only the current year's growth was collected discarding much of the growth of previous years as practicable. The clipped herbage from each plot was bulked in paper sacks to constitute one sample for each species or several species of the same forage class which were not represented in appreciable amounts. The samples were oven dried at 80°C for 24 hours and then weighed.

Estimation of the big sagebrush killed by the burn: The whole burned area was mapped roughly into areas with different percentages of mortality of sagebrush. Four mortality classes were used: 0 to 25%, 25 to 50%, 50 to 75% and 75 to 100%. The mapping was done by ocular estimation while walking through the burned area.

Four transects were run on every mortality class area. Each transect was 100 double-steps which started from one end of the mortality class area towards a distant tree or fence mark. At every double-step the percentage mortality on the first sagebrush to the right was estimated and recorded. The survey was done towards the end of the summer. *Artemisia cana* was sprouting and it was possible to differentiate between this species and *Artemisia tridentata*.

At every fifth double-step fecal droppings of game animals were looked for on a 9.6 sq. ft. circular plot. This was abandoned after running several transects because the number of droppings was very few. In six transects only four groups were found. Computing the deer use from these figures shows that it was around 12 deer-day/acre for the months of the summer which makes it clear that the use of the study area by game animals is not important.

RESULTS AND DISCUSSIONS

Soil physical properties

Burn classes and mulch measurements: Table 2 shows the burn classes of the mulch measurements. These measurements indicate major differences between the nature of the burns in the two experimental sites. In site 1, although the mulch was very limited, the fire was severe and consumed most of the available mulch in many areas. In those areas the burned shrubs and undetached dry matter added to the fuel consumed. Although the volume of mulch in site 2 was considerably more than site 1, the fire was very light and resulted in very few severely burned areas. This probably was due to the fact that site 2 was not as dry as site 1 (Figure 4).

Soil temperatures: The maximum temperatures reached during the burn at site 1 were between 350 and 400°F at the soil surface and between 150 and 175°F at the depth of 1 cm. Two tempil stick groups, out of the four groups placed in site 1, were subjected to fire while no fire effect was visible around the areas in which the tempil sticks were placed in site 2.

The averages of the soil temperature measurements for the three month period following burning reflect a general pattern (Tables 3 and 4). In both sites the afternoon soil temperatures were higher in the burned blocks than the unburned blocks. The morning temperatures were about the same in the burned and unburned blocks. However, none of the

Table 2. Meters and percentages of burn classes[1/] of mulch per 30 meters of transect, site 1 and site 2 burned blocks.

Site 1

Class 1 -	4.92m
Class 2 -	3.48m
Class 3 -	6.05m
Total burned length	14.45m
Class 1 -	34%
Class 2 -	24%
Class 3 -	42%

The average mulch weight - 2.8 g/sq dm.[2/]

Site 2

Class 1 -	10.43m
Class 2 -	6.4m
Class 3 -	0.8m
Total burned length	17.63m
Class 1 -	59%
Class 2 -	36%
Class 3 -	5%

The average mulch weight - 10.8 g/sq dm.

1/ Class 1 burn - less than 25% of the mulch was burned
Class 2 burn - from 25% to 75% of the mulch was burned
Class 3 burn - more than 75% of the mulch was burned

2/ The mulch values are averages of ten measurements before burning.

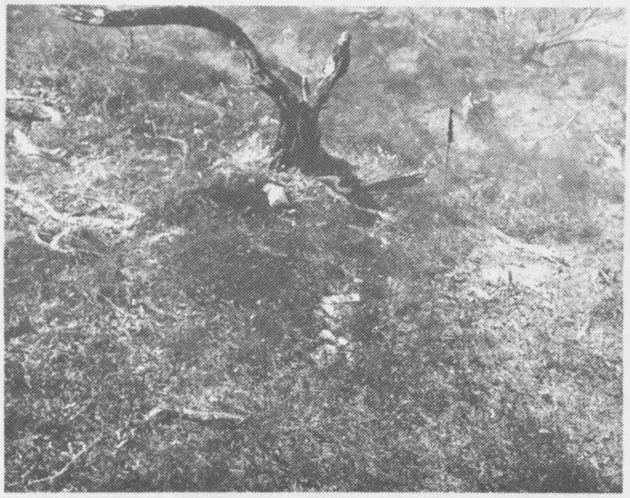


Figure 4. A Burned area in site 1 (upper photograph) and a burned area in site 2 (lower photograph). Photographed one month after the burn.

Table 3. Temperatures of the top 1 cm and top 4 cm of soil on burned and unburned blocks at intervals of one to two weeks through the summer, Site 1.

Soil temperatures of the top 1 cm of the soil

Dates	Soil temperature at 6:00 a.m. Unburned	Soil temperature at 6:00 a.m. Burned	Soil temperature at 3:00 p.m. Unburned	Soil temperature at 3:00 p.m. Burned
	°F	°F	°F	°F
6/23	47.5	49.6**	79.7	86.2**
6/28	45.0	47.0**	74.3	81.9**
7/5	48.0	50.9**	83.0	80.6n.s.
7/11	45.5	45.9n.s.	69.0	69.5n.s.
7/22	52.1	52.3n.s.	75.2	79.2*
7/28	43.6	43.4n.s.	80.5	84.3*
8/16	38.4	36.9**	82.3	86.4**
8/30	41.5	40.8n.s.	74.3	79.5**
Averages	45.2	45.9n.s.	77.3	81.0n.s.

Soil temperatures of the top 4 cm of the soil

Dates	Soil temperature at 6:00 a.m. Unburned	Soil temperature at 6:00 a.m. Burned	Soil temperature at 3:00 p.m. Unburned	Soil temperature at 3:00 p.m. Burned
	°F	°F	°F	°F
6/23	46.5	48.5**	73.1	79.2**
6/28	45.1	45.0n.s.	74.4	83.2**
7/5	47.5	49.2*	85.4	83.0n.s.
7/11	47.5	45.8**	63.6	63.9n.s.
7/22	50.7	50.7n.s.	78.8	84.6**
7/28	39.0	35.4**	86.4	89.3**
8/16	44.0	44.5n.s.	81.1	87.0**
8/30	40.8	41.5n.s.	74.9	78.8**
Averages	45.1	45.1n.s.	77.2	81.1n.s.

* Significant differences at the 0.05 probability level
** Significant differences at the 0.01 probability level
n.s. non-significant

Values are averages of ten measurements.

Table 4 . Temperatures of the top 1 cm and top 4 cm of soil on burned and unburned blocks at intervals of one to two weeks through the summer, Site 2.

Soil temperatures of the top 1 cm of the soil

Dates	Soil temperature at 6:00 a.m.		Soil temperature at 3:00 p.m.	
	Unburned	Burned	Unburned	Burned
	°F	°F	°F	°F
6/21	51.4	50.5n.s.	72.5	75.2**
6/27	48.7	47.5**	84.2	77.0**
7/4	44.4	46.5**	67.0	73.8**
7/13	48.2	49.6*	75.6	77.0n.s.
7/21	49.5	48.6n.s.	78.3	85.0**
7/28	47.5	46.7n.s.	73.2	77.5n.s.
8/5	--	--	72.3	76.6**
8/17	45.2	45.2n.s.	77.5	83.8**
8/29	36.2	36.8n.s.	66.8	70.8**
Averages	46.4	46.4n.s.	74.2	77.4n.s.

Soil temperatures of the top 4 cm of the soil

Dates	Soil temperature at 6:00 a.m.		Soil temperature at 3:00 p.m.	
	Unburned	Burned	Unburned	Burned
	°F	°F	°F	°F
6/21	47.9	49.3**	70.5	74.0*
6/27	46.5	46.4n.s.	74.5	72.2*
7/4	42.5	43.7**	74.4	71.0**
7/13	44.2	48.8**	77.2	80.8**
7/21	46.4	48.0n.s.	73.4	80.5**
7/28	49.9	48.8**	74.0	75.2n.s.
8/5	--	--	72.4	71.9n.s.
8/17	45.0	44.7n.s.	78.3	82.9n.s.
8/29	38.7	38.0n.s.	69.4	70.4n.s.
Averages	45.1	46.0n.s.	73.8	75.4n.s.

* Significant differences at the 0.05 probability level
** Significant differences at the 0.01 probability level
n.s. Non-significant.

Values are averages of ten measurements.

differences between the burned and unburned blocks averages were statistically significant.

Most of the average weekly measurements follow this general pattern with some variations occurring at both sites at different weeks. Someof these variations are probably due to sampling. The lower afternoon temperatures measured in the burned blocks than the unburned blocks in the 5th of July measurements, site 1, and the 27th of June measurement, site 2, were probably due to the effect of some showers. More evaporation of water from the burned areas might produce a cooling effect on the soil. This cannot be confirmed due to the lack of precipitation records for the area.

The soil temperature differences between the burned and unburned blocks were not great because of the limited amount of mulch consumed and hence the limited amount of the black ash added to the soil surface. The number of measurements taken of soil temperatures was not adequate to detect the differences between the burned and unburned blocks. In many cases measurements in the burned blocks were taken in areas not subjected to the effect of fire.

Soil penetration indices: Table 5 presents the averages of the 20 biweekly soil penetration measurements for both sites. In both sites slightly higher values were measured in the burned than the unburned blocks with the exception of the measurements taken on the 28th of July, when penetration values were higher in the unburned than the burned

Table 5. Soil penetration index biweekly measurements of burned and unburned blocks, site 1 and site 2 - values are averages of 20 measurements.

Dates	Site 1 Unburned Tons/ft^2 1/	Site 1 Burned Tons/ft^2	Site 2 Unburned Tons/ft^2	Site 2 Burned Tons/ft^2
6/27	1.97	2.08	1.57	1.70
7/13	1.97	2.10	2.08	2.27
7/28	2.20	2.10	2.70	2.68
8/17	2.21	2.21	2.30	2.24
8/29	3.64	3.87	2.08	2.52
Averages	2.40	2.47	2.15	2.28

The differences between the soil hardness averages of the burned and unburned blocks are not significant at the 0.05 probability level.

1/ 1 ton/ft^2 = 8.16×10^5 Kg/cm^2.

blocks on both sites. The measurements of the 17th of August also reflected some variations showing equal values in both the burned and unburned block in site 1 and slightly higher values in the unburned than the burned block in site 2. However, none of the differences between the burned and unburned blocks were statistically significant. The sampling was not adequate to detect the differences between the burned and unburned blocks.

Infiltration rates: The infiltration rates measured for both sites are listed in Table 6. In site 1 higher values were obtained for the burned areas and in site 2 higher values were obtained in the unburned areas.

The differences between the two sites are probably due both to the natural variations between them and to the different effects of burning. The higher values of infiltration rates in the burned areas in site 1 are similar to results reached by Torrent (1956) on a study about the effect of burning on ponderosa pine (Pinus ponderosa). He concluded that when the fire caused a light surface burn in which the incorporated humus was not consumed to any significant degree and the fast moving fire burned principally on the fresh litter, the soil was not baked or reddened as in fire burns in heavier fuels. An increase of macroscopic pore volume and percolation rate may possibly have resulted from some burning of individual dead shrubs and grass roots for several inches into the soil. When such roots are removed, the

Table 6. Infiltration rates measurements of burned and unburned areas, site 1 and site 2, taken during the first week of August.

Site 1		Site 2	
Unburned Areas Infiltration Rate inches/hour	Burned Areas Infiltration Rate inches/hour	Unburned Areas Infiltration Rate inches/5 min.1/	Burned Areas Infiltration Rate inches/5 min.
3.50	4.50	14.00	8.30
5.50	5.00	10.00	7.50
3.00	6.00	30.00	15.00
3.00	8.75	40.00	15.00
3.00	5.50	10.00	10.00
3.60	5.95	20.80	11.20

1/ Infiltration rates were measured for less than five minutes. Rates per five minutes were computed from the measured values to make comparison easier.

The differences between the infiltration rates of the burned and unburned areas are not significant at the 0.05 probability level.

volume of large vertical water channels is increased. This may have happened in site 1 while in site 2 the burn was too mild to produce such effects. The lower values of infiltration rates in the burned areas than unburned areas in site 2 are probably induced by the materials released in the burn and carried into the minute channels of the deeper soil layers causing a partial sealing of the percolatory system. In this site the burn did not consume all the mulch and did not result in bare spots in which the reduction of infiltration rate could be attributed to the effect of the beating of the rainstorms on the bare unprotected soil surface causing the closure of the porous structure.

Soil moisture content: Soil moisture measurements are presented in table 7. The samples of the burned block showed significantly higher moisture content than the samples of the unburned block in site 1. In site 2 a slightly higher moisture content was found in the unburned block but the difference was not statistically significant.

It might be of interest to point out that there is a consistent pattern between the infiltration rates and soil moisture measurements in site 1. The significantly higher moisture content of the soil samples of the burned block in site 1 substantiates the findings about the higher infiltration rates. However, it would be improper to project these conclusions as the final effect of the burn. Beaton (1957) in a study of the influence of burning on the soil in a timber range area of Lac Le Jeune, British Columbia, found that reduction of

Table 7. Soil moisture percentages of the top 20 cm. in burned and unburned blocks of site 1 and site 2 1/.

Site 1		Site 2	
Unburned block	Burned block	Unburned block	Burned block
%	%	%	%
12.7	20.0	17.2	12.7
13.8	17.7	15.7	15.4
15.1	25.8	15.0	17.5
15.3	20.8	13.9	16.4
18.6	12.4	16.9	17.3
14.8	14.6	16.1	11.3
12.5	16.1	11.4	14.5
16.2	19.4	15.5	15.2
14.5	16.6	16.3	14.0
11.8	13.3	17.3	16.4
14.5	17.7*	15.5	15.1

* Significant differences at the 0.05 probability level.

1/ Samples were collected towards the end of summer.

infiltration rates did not occur directly following burning and that more than two years after the burn were necessary for the infiltration rate reduction to occur. He explained that exposure of the burned surface to the different weather elements is one of the controlling factors in decreasing infiltration rates.

Chemical properties of the soils

Site 1: Average values of the soil chemical properties are shown in Table 8. Appendix Tables 3 and 4 contain the complete data. By comparing the before- and after-burning data of both the burned and unburned blocks the changes caused by the burning can be noted.

Significant increases of pH following burning were observed at the 0-2 cm and 8-10 cm depths of the burned blocks. The 18-20 cm samples of the burned block showed a non-significant increase. The 0-2 cm and 8-10 cm of the unburned blocks reflected slight increases with a slight decrease in the 18-20 cm samples of which none was significant (Figure 5). The significant increases of the pH in the upper two depths in the burned block probably were due to the release of bases from the burned ash.

A non-significant increase in phosphorus occurred at 0-2 cm depth in the burned block while the unburned block showed no change. A considerable decrease occurred in the 8-10 cm samples of both blocks. The decrease was statistically significant only in the burned block. The 18-20 cm from the burned block showed a slight decrease while the

Table 8 . Soil chemical properties of the burned and unburned blocks before and after burning, site 1, at the 0-2 cm, 8-10 cm and 18-20 cm depths (values are averages of three replicates).

Depth in cm			pH	PPM. P	PPM. K	PPM. NO3-N	millimohs Salts	% O.M.	Milliequivalent/100g Ca	Milliequivalent/100g Mg	Milliequivalent/100g Na
0 - 2	Unb.[1]	Before[1]	6.00	56	812	0.8	1.9	11.75	22.3	3.99	0.50
		After	6.03	56	715*	1.8**	0.7**	5.80**	19.7*	3.24	0.83*
	B	Before	6.07	43	838	0.8	1.7	8.48	19.5	4.29	0.56
		After	6.37*	49	848	2.8**	0.9**	5.97	21.9	4.05	0.89**
8 - 10	Unb.	Before	6.20	40	635	0.0	0.9	4.87	13.1	2.57	0.50
		After	6.23	32	615	0.5	0.5**	4.47	15.0*	1.94*	0.82**
	B	Before	6.26	21	661	0.0	0.8	4.57	13.4	3.48	0.69
		After	6.37*	11*	575	0.5	0.5**	4.40	15.4**	3.31*	0.88**
18 - 20	Unb.	Before	6.40	31	585	0.0	0.8	4.20	12.3	2.65	0.56
		After	6.33	34	502*	1.4**	0.4**	3.33**	14.1**	2.54	0.84**
	B	Before	6.37	07	532	0.0	0.7	3.27	12.3	4.04	0.71
		After	6.47	06	442	0.5	0.3**	2.40**	14.5**	3.63	0.96*

1/ Unb: Unburned plot
B: Burned plot
Before: Before burning
After: After burning
* Significant differences at the 0.05 probability level
** Significant differences at the 0.01 probability level.

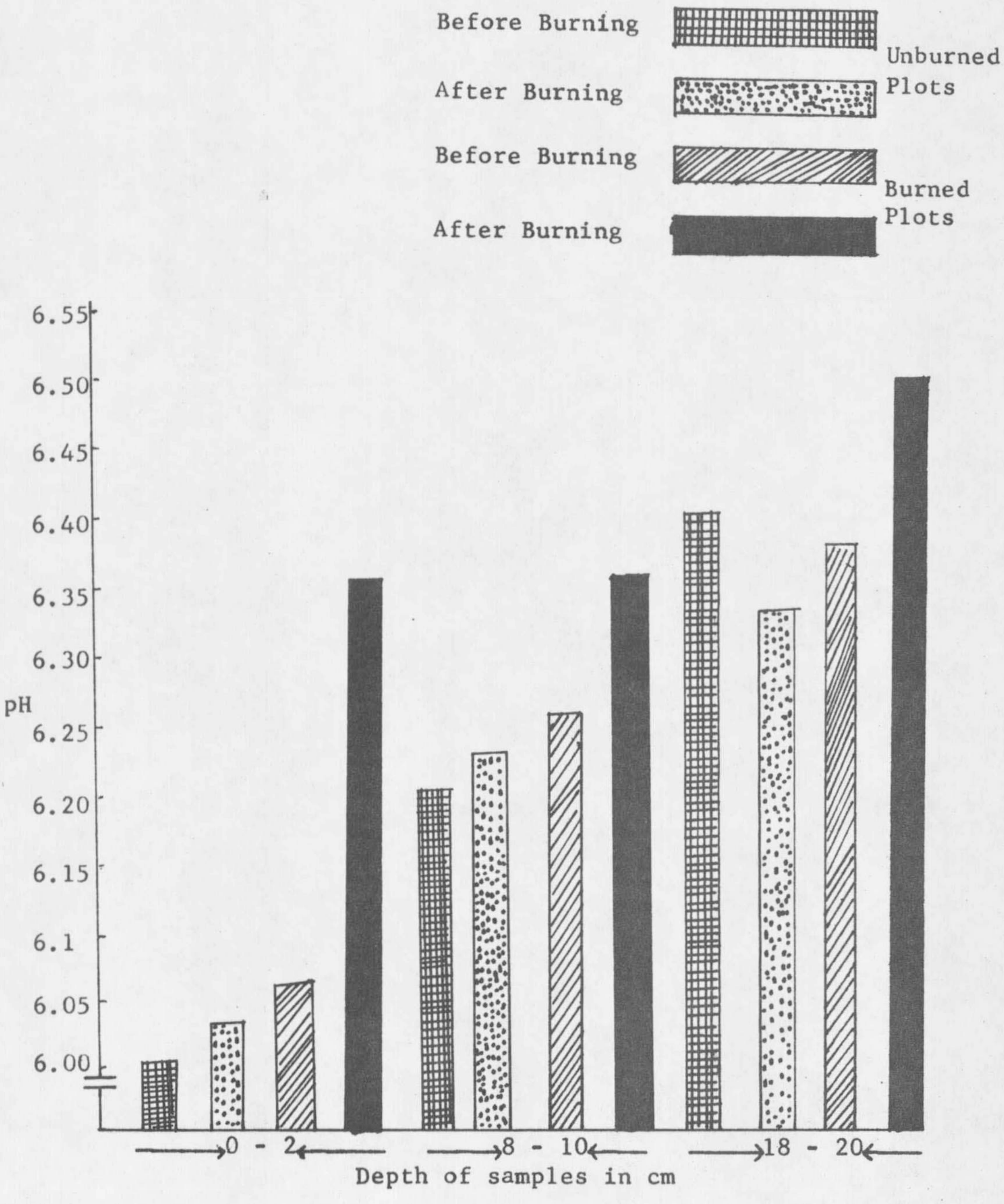


Figure 5. pH of the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

sample of the unburned block increased slightly (Figure 6). The phosphorus increase in the 0-2 cm samples was probably due to the burning while the comparable decreases in the 8-10 cm samples of both blocks are more likely due to biological activities such as soil micro-organism multiplications and green plant growth induced by the environmental changes after the snow melted.

The potassium data showed a non-significant increase in the samples of 0-2 cm depth in the burned block while the samples of the unburned block showed a significant decrease. Samples collected at the 8-10 cm in both blocks had non-significant decreases. The 18-20 cm samples showed a non-significant decrease in the burned block and a significant decrease in the unburned block. Probably these decreases in potassium were due to biological activities which occurred in both burned and unburned blocks but were less pronounced in the burned block because of release of some potassium from the burned ash (Figure 7).

Consistent highly significant decreases occurred in salts in the burned and unburned blocks at all depths samples (Figure 8). It can be concluded that burning did not have any effect on soil salts.

A non-significant decrease in organic matter was detected at 0-2 cm depth in the burned block while in the unburned block the decrease was highly significant. In the 8-10 cm samples the decreases were non-significant while in the 18-20 cm samples the decreases were highly significant for both blocks (Figure 9). Due to the similar

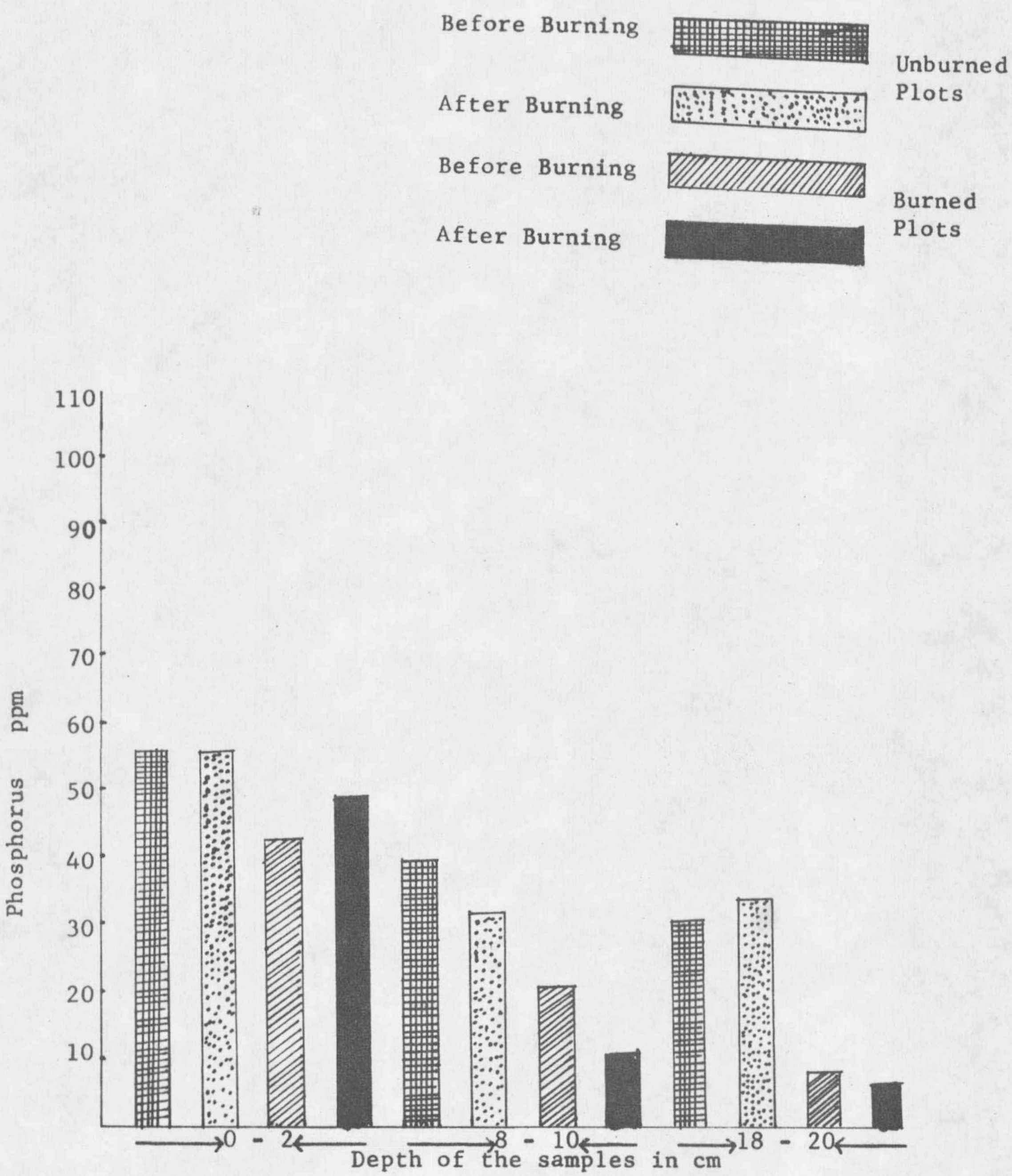


Figure 6. Phosphorus in the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

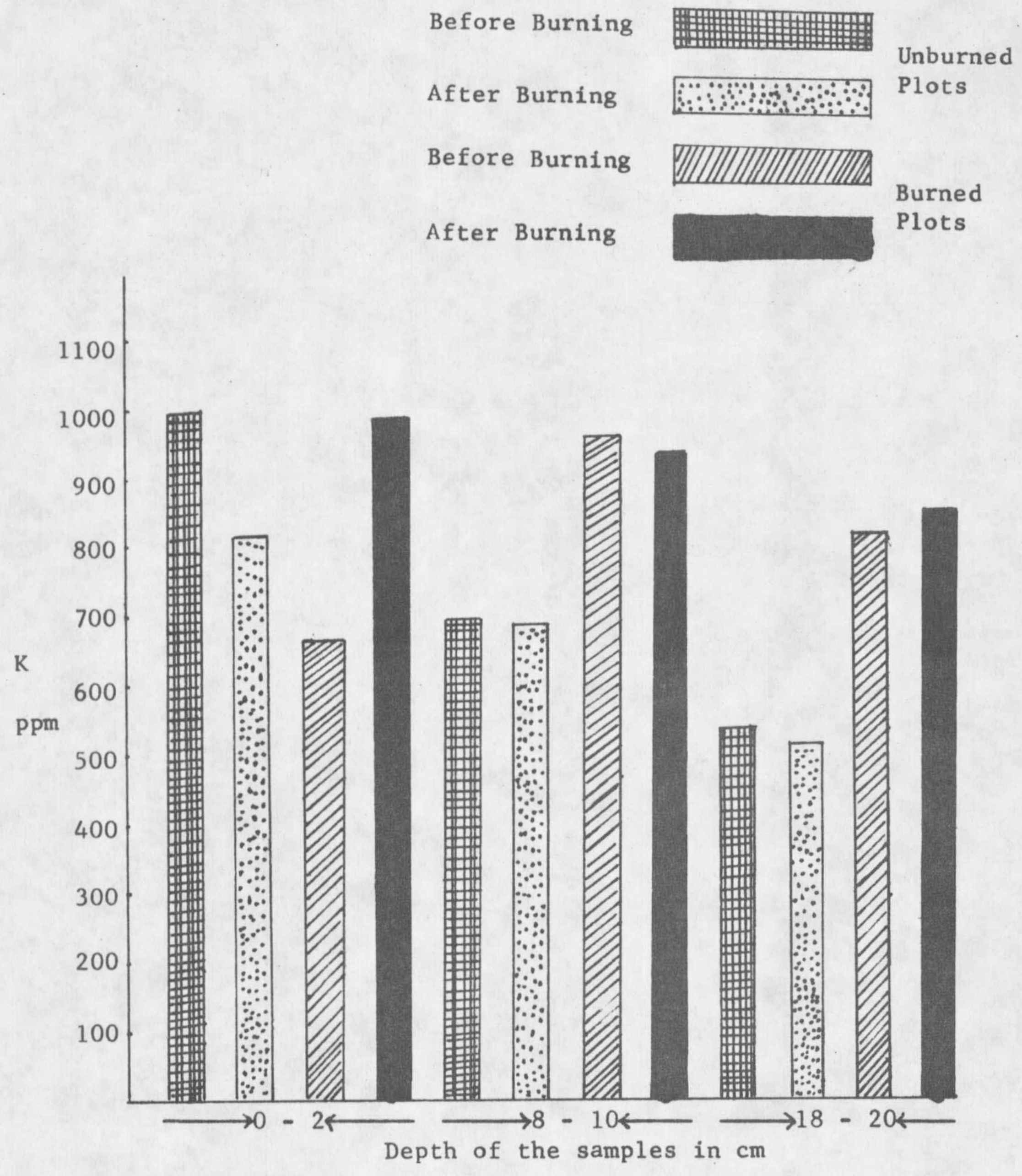


Figure 7. Potassium in the soil of the unburned and burned blocks before and after burning, site 1, at three depths.

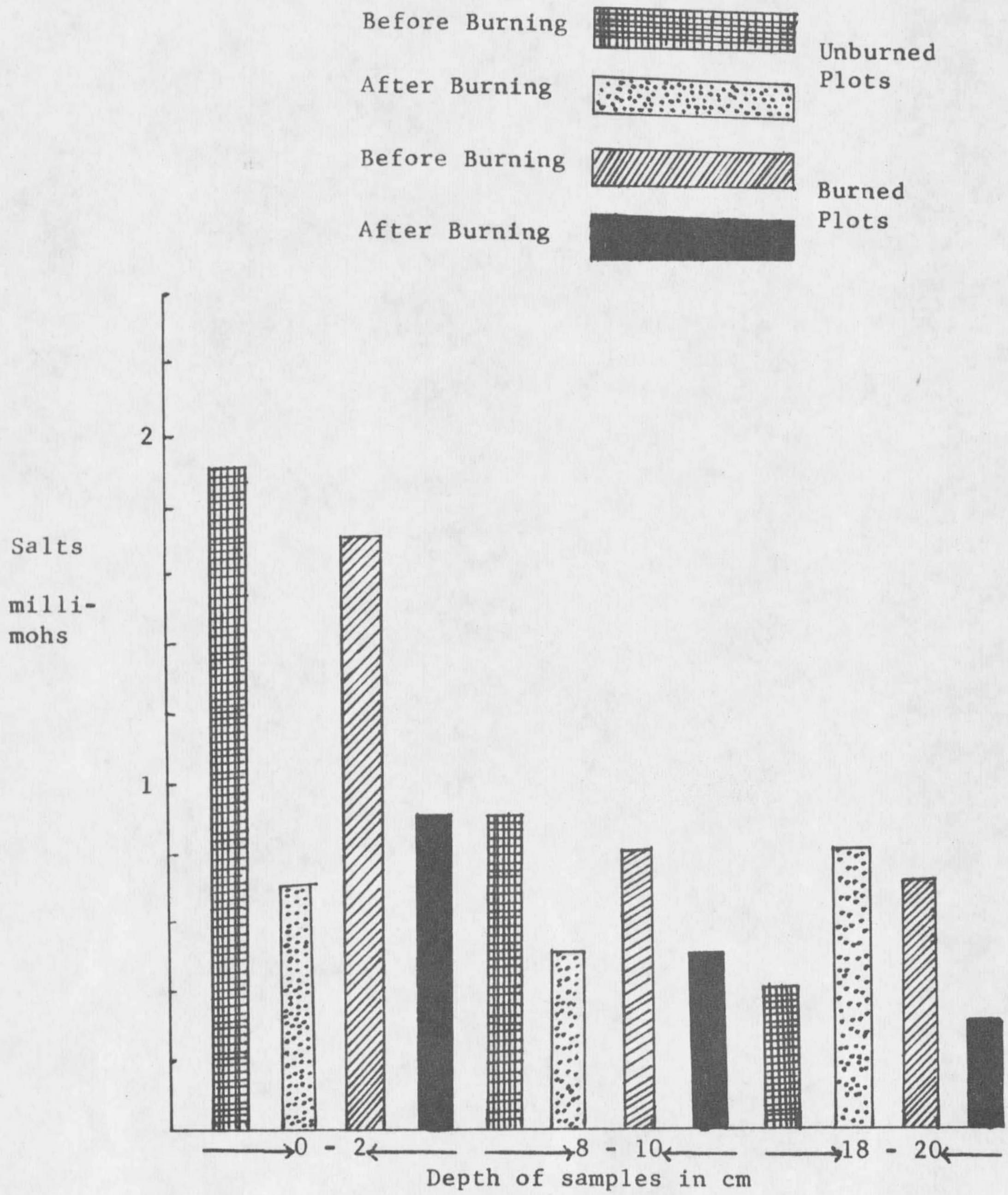


Figure 8. Salts in the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

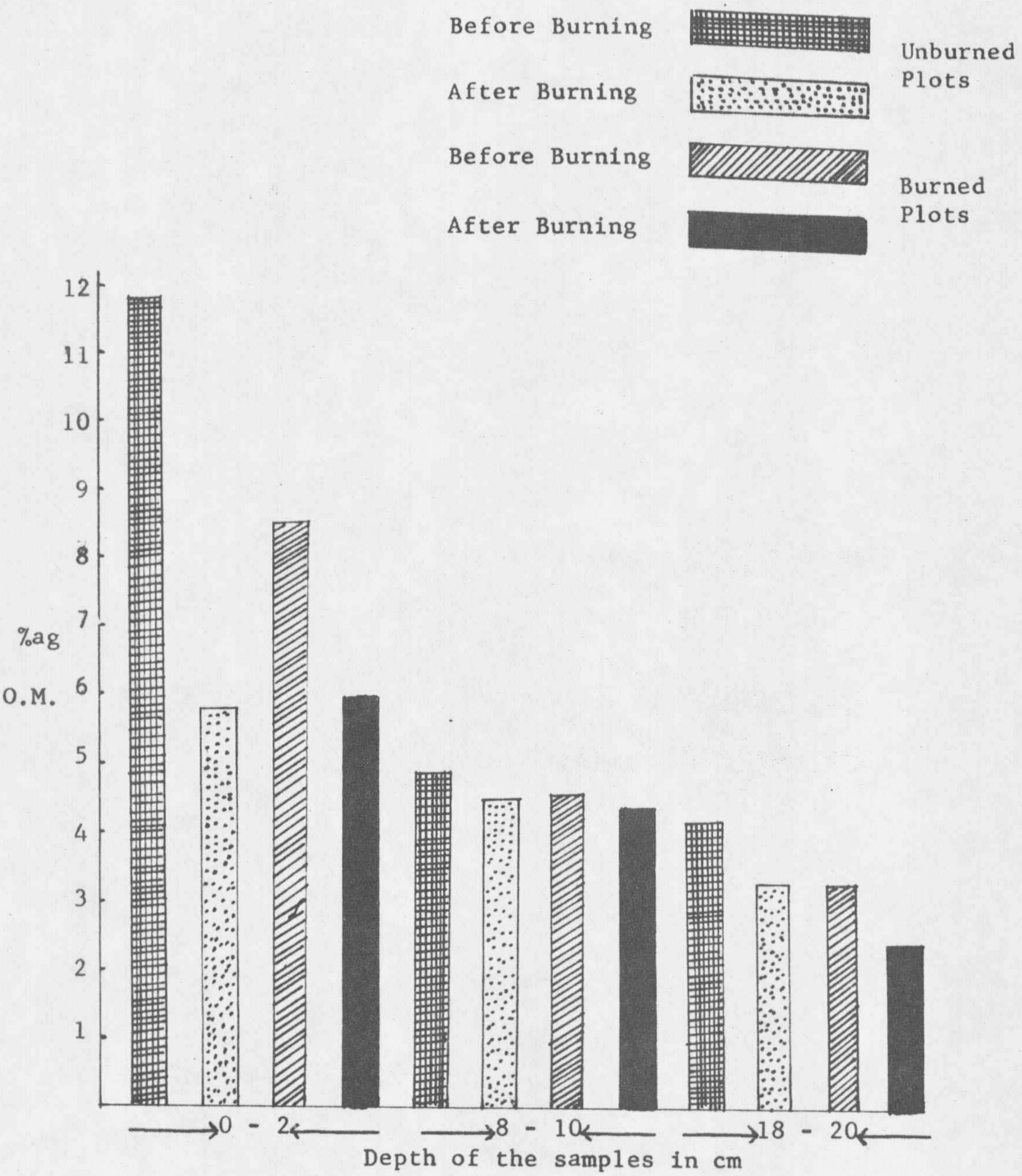


Figure 9. Percentages organic matter of the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

pattern of changes in organic matter in both the burned and unburned blocks the burning effect could be considered of no importance in accounting for them. The large decreases in organic matter cannot be attributed to biological decomposition. They are probably due to sampling or error in analyses.

A non-significant increase in calcium was detected in the 0-2 cm samples of the burned block with a significant decrease occurring in the unburned block. The samples of the 8-10 cm depth showed highly significant and significant increases in the burned and unburned blocks, respectively. Both blocks had highly significant increases at the 18-20 cm depths (Figure 10). Decreases in magnesium occurred in both blocks at all depths sampled. The decreases were statistically significant only in the 8-10 cm samples of both blocks (Figure 11). Highly significant and significant increases in sodium were detected at the three depths of both blocks (Figure 12). The similarity of the pattern of these changes of magnesium, sodium and calcium in both the burned block and unburned block makes it clear that the burning effect is not of any significance in accounting for them.

Increases occurred in nitrates in the three depths of both blocks. The increases were highly significant in the 0-2 cm samples of both blocks and the 18-20 cm samples of the unburned blocks (Figure 13). The increases of nitrates are probably totally induced by the environmental changes and their effect on the nitrifying bacteria.

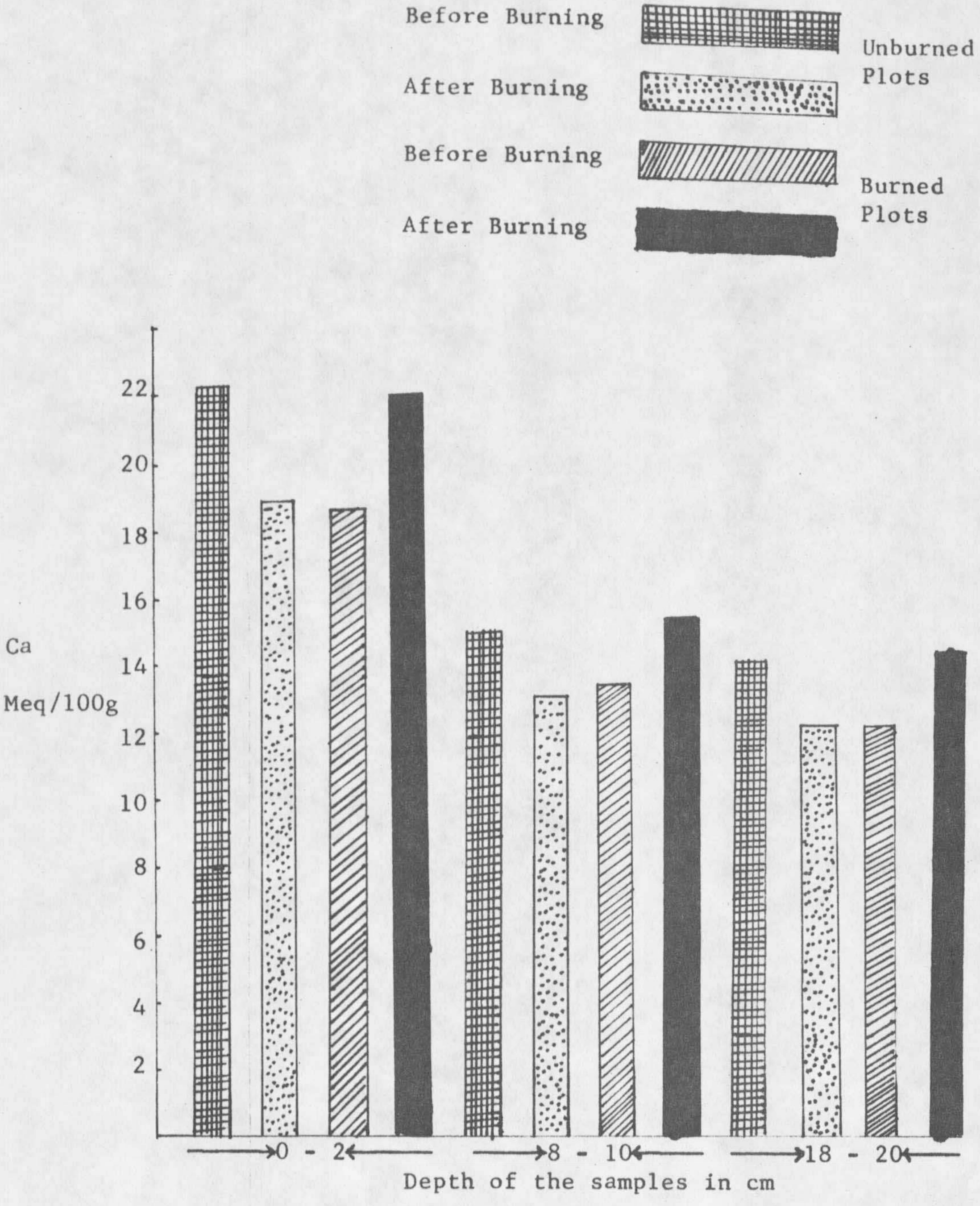


Figure 10. Calcium in the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

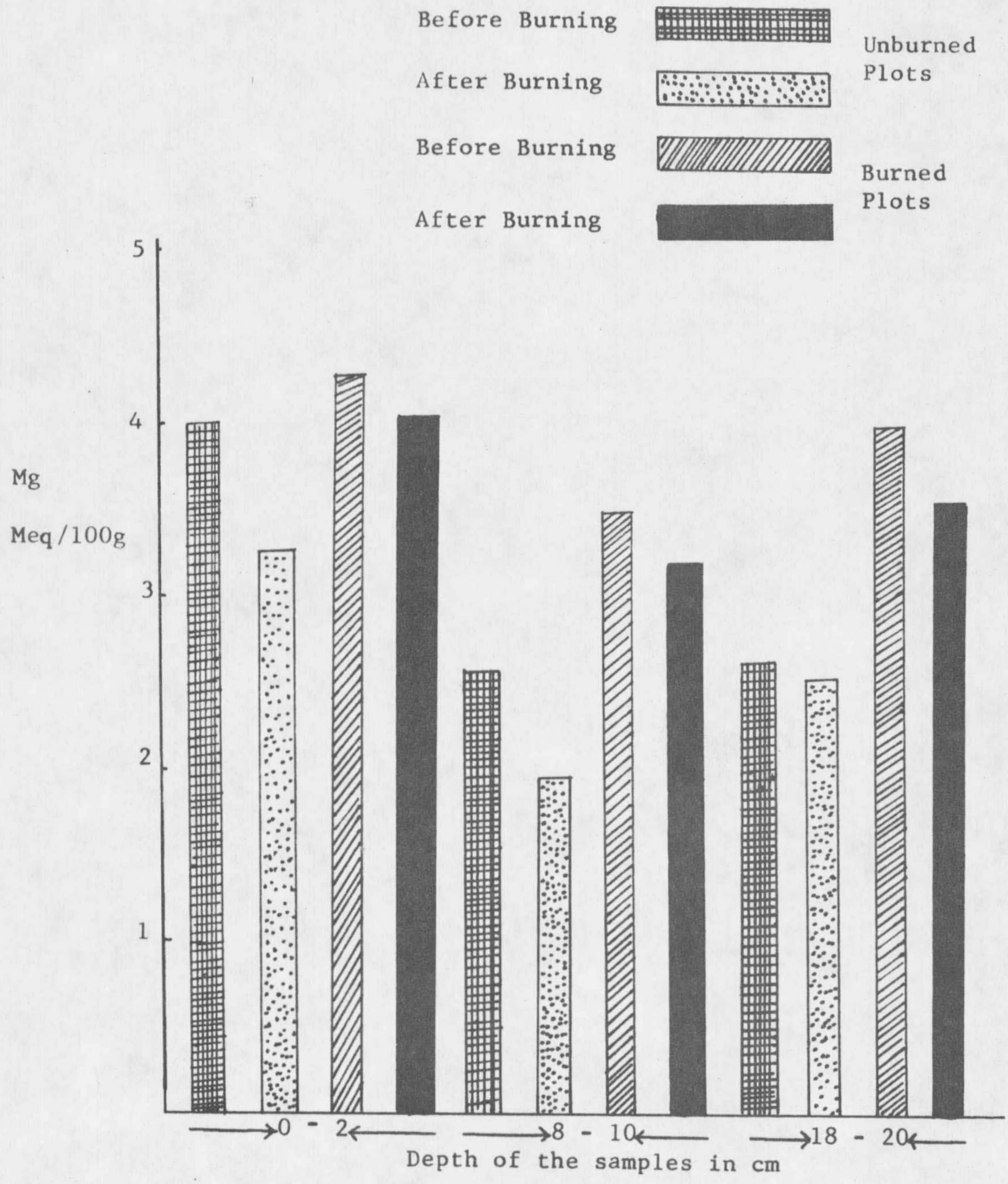


Figure 11. Magnesium in the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

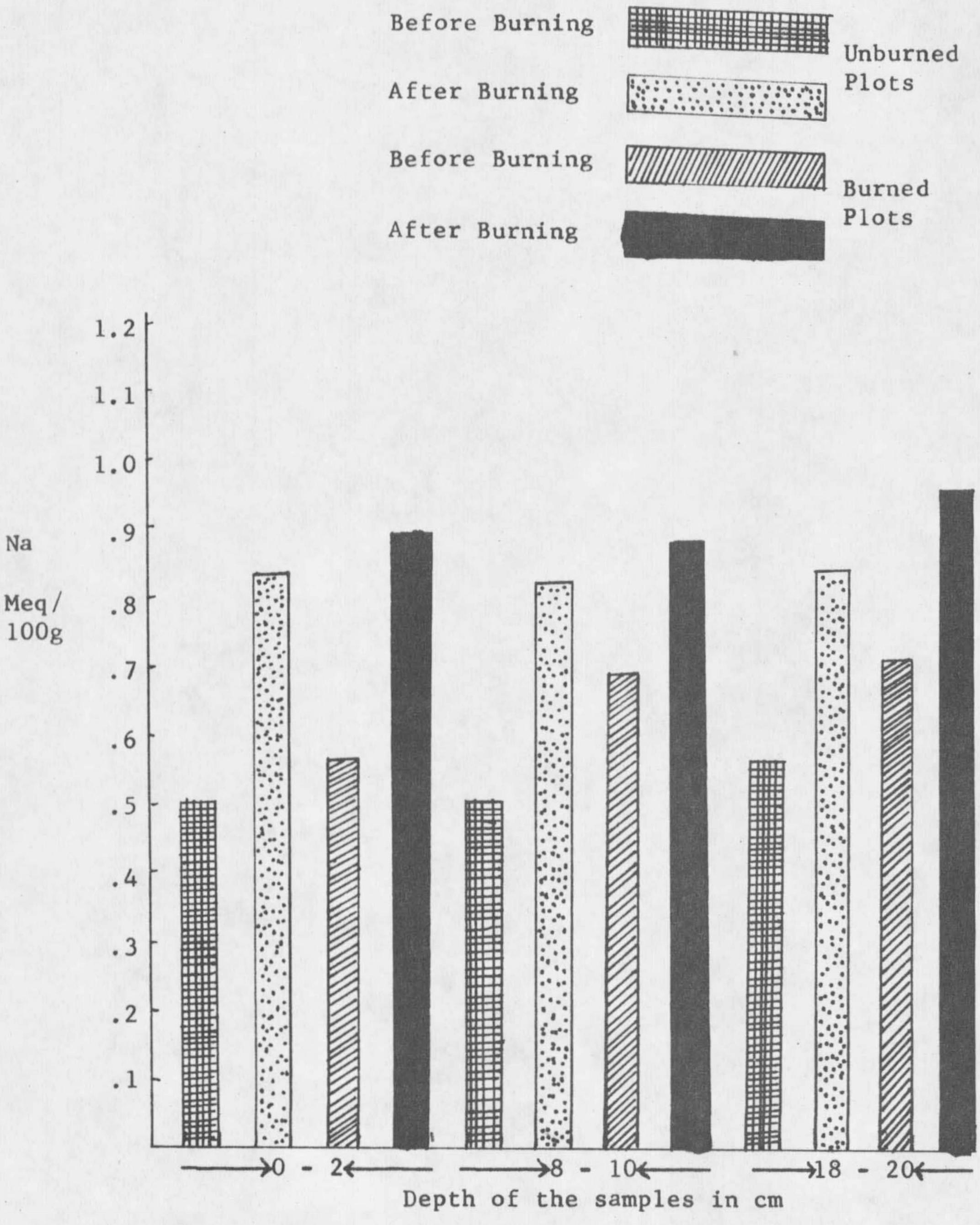


Figure 12. Sodium in the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

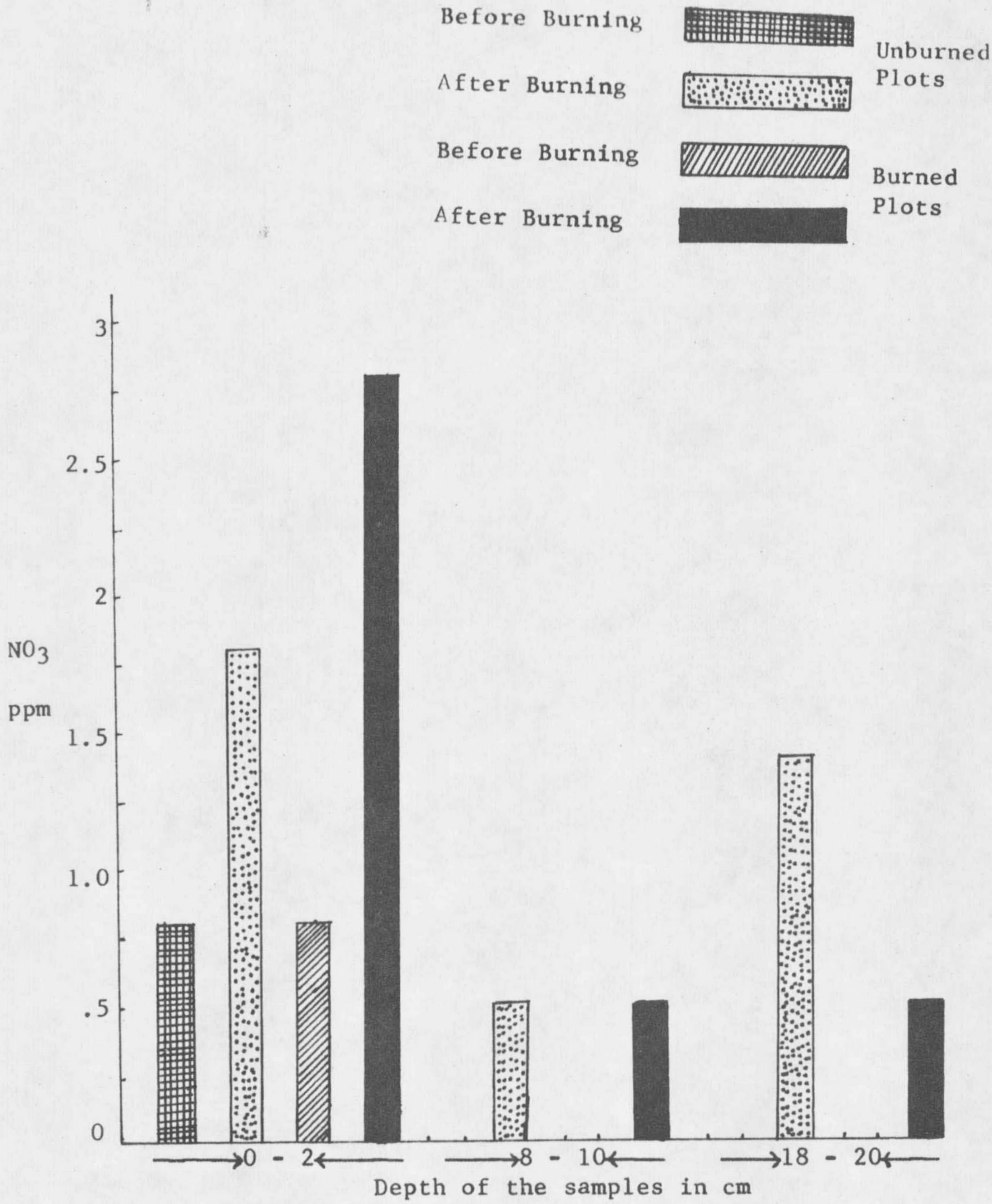


Figure 13. Nitrates in the soils of the unburned and burned blocks before and after burning, site 1, at three depths.

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Site 2: Average values of the soil chemical properties are shown in Table 9. Appendix Tables 5 and 6 contain the complete data.

No significant changes in pH were detected. This was probably due to lesser burning effect and accordingly a lower quantity of bases released from the burned ash than in site 1 (Figure 14).

The phosphorus data showed highly significant and significant increases in the 0-2 cm samples of the burned and unburned blocks, respectively. In the 8-10 cm samples a significant increase occurred in the burned block with a non-significant increase in the unburned block. The 18-20 cm depth showed a non-significant increase in the burned block and a significant increase in the unburned block (Figure 15). Although the changes in the burned and unburned blocks are not identical, it is still difficult to conclude that these variations in changes are due to the burning. These variations are more likely due to sampling.

The potassium data showed a highly significant increase in the 0-2 cm samples in the burned block while the unburned block had a non-significant decrease. The data of the other depths showed non-significant decreases in both burned and unburned blocks except in the 18-20 cm samples from the burned block which showed a slight increase (Figure 16). The increase in potassium at the 0-2 cm depth of the burned block is likely caused by release from the ash.

No significant changes in salts were detected (Figure 17).

Table 9. Soil chemical properties of the burned and unburned blocks before and after burning, site 2, at the 0-2 cm, 8-10 cm and 18-20 cm depths (values are averages of three replicates).

Depth in cm			pH	PPM. P	PPM. K	PPM. NO_3-N	milli-mohs Salts	% O.M.	Milliequivalent/100g Ca	Milliequivalent/100g Mg	Milliequivalent/100g Na
0 - 2	Unb.1/	Before1/	6.17	50	1002	0.5	0.7	6.06	21.1	4.73	0.49
		After	6.17	66*	914	1.7	0.9	5.87*	25.1	4.69	0.55
	B	Before	6.30	66	655	0.2	0.7	6.00	19.8	4.51	0.55
		After	6.33	89**	980**	2.2**	0.7	5.83*	18.9	3.24**	0.63
8 - 10	Unb.	Before	6.10	28	690	0.0	0.4	5.80	15.2	3.49	0.51
		After	6.00	38	682	1.3**	0.4	5.60	15.1	2.54**	0.49
	B	Before	6.17	41	962	0.0	0.4	5.46	14.7	3.31	0.55
		After	6.07	54*	932	1.3	0.5	5.36*	15.3	2.54**	0.69
18 - 20	Unb.	Before	6.10	29	525	0.0	0.4	4.0	13.7	3.23	0.51
		After	6.00	37*	508	1.8**	0.3	3.7	11.8	2.19*	0.50
	B	Before	6.10	37	815	0.0	0.5	5.0	13.4	3.26	0.51
		After	5.93	58	852	0.8**	0.4	3.96*	13.3	2.13**	0.75**

1/ Unb: Unburned plot
B: Burned plot
Before: Before burning
After: After burning
* Significant differences at the 0.05 probability level
** Significant differences at the 0.01 probability level.

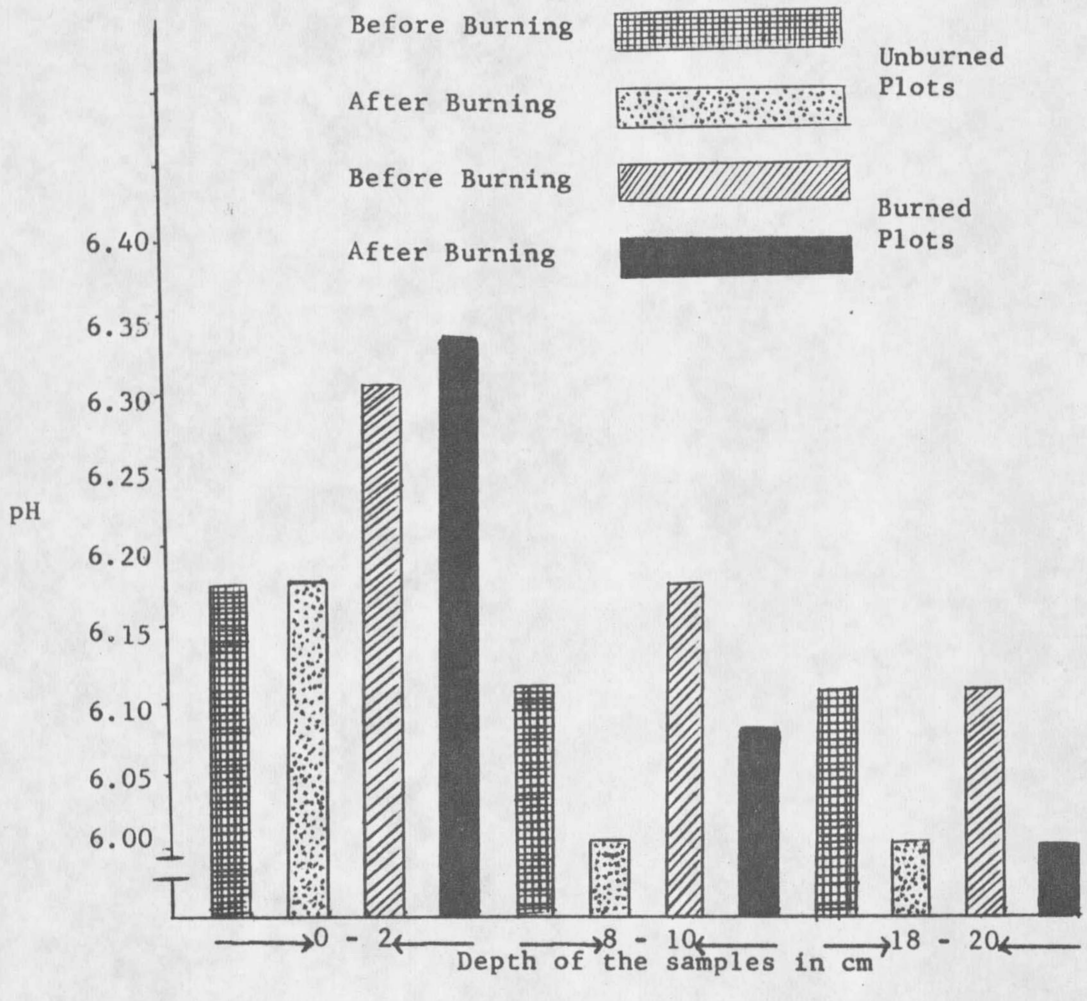


Figure 14. pH of the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

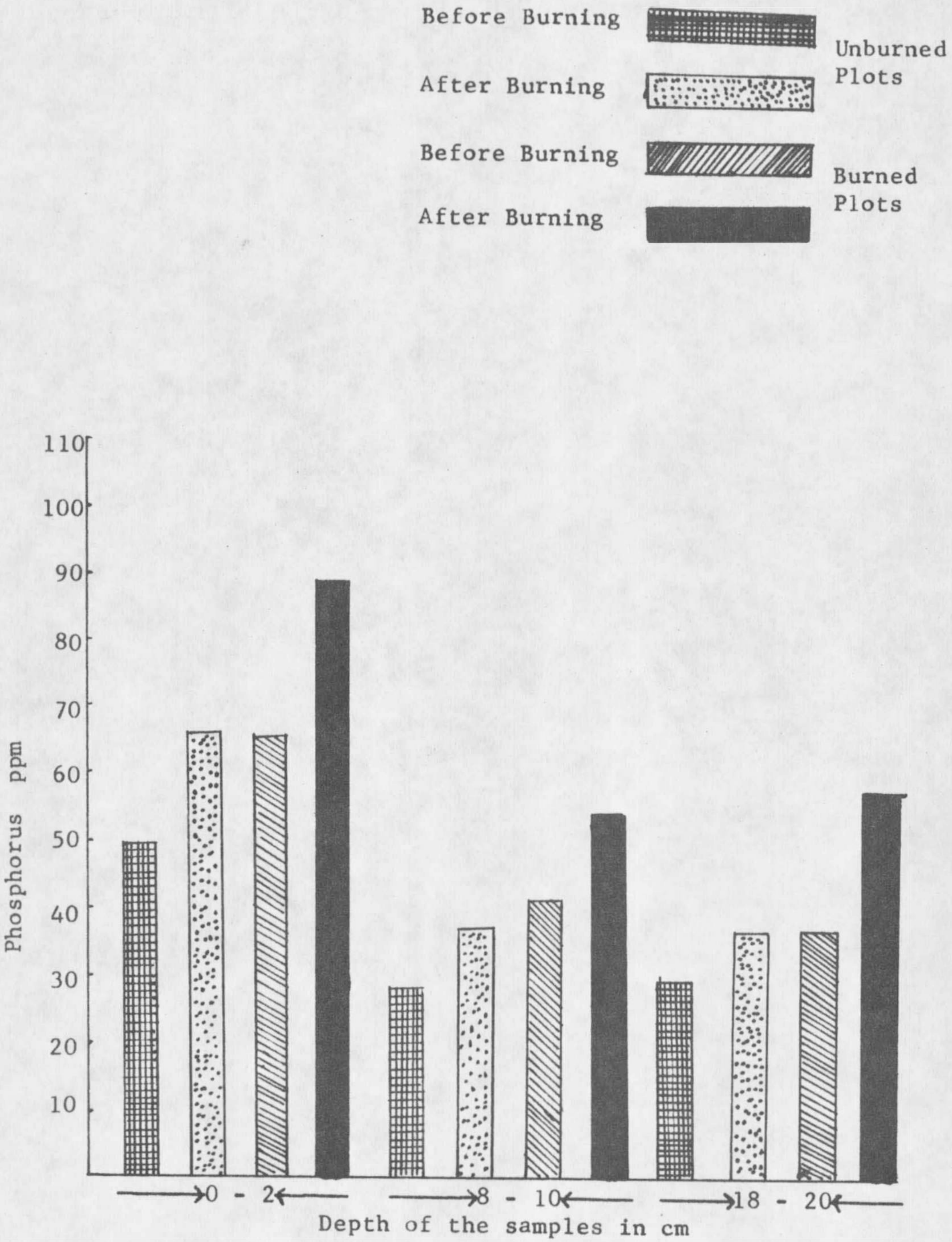


Figure 15. Phosphorus in the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

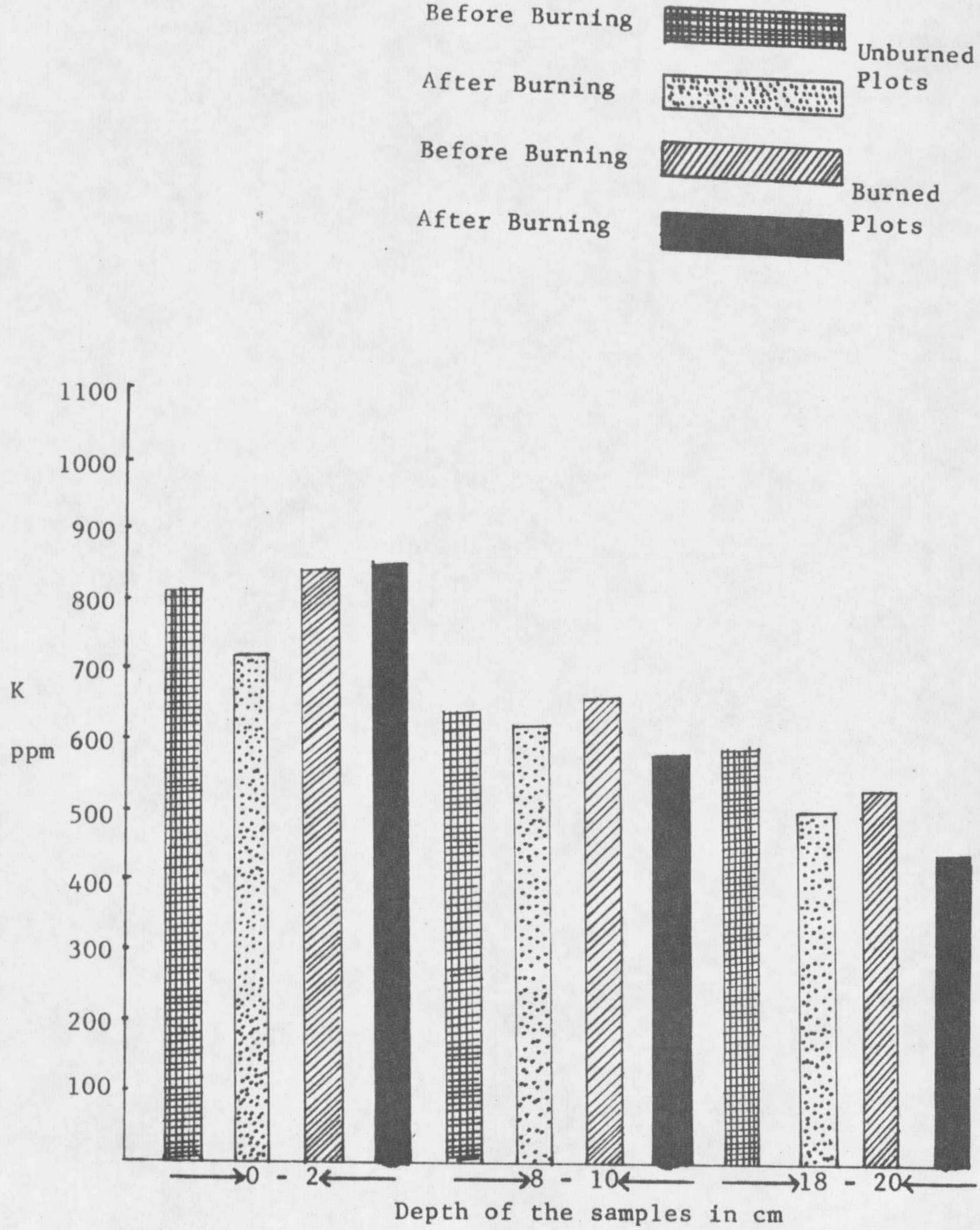


Figure 16. Potassium in the soil of the unburned and burned blocks before and after burning, site 2, at three depths.

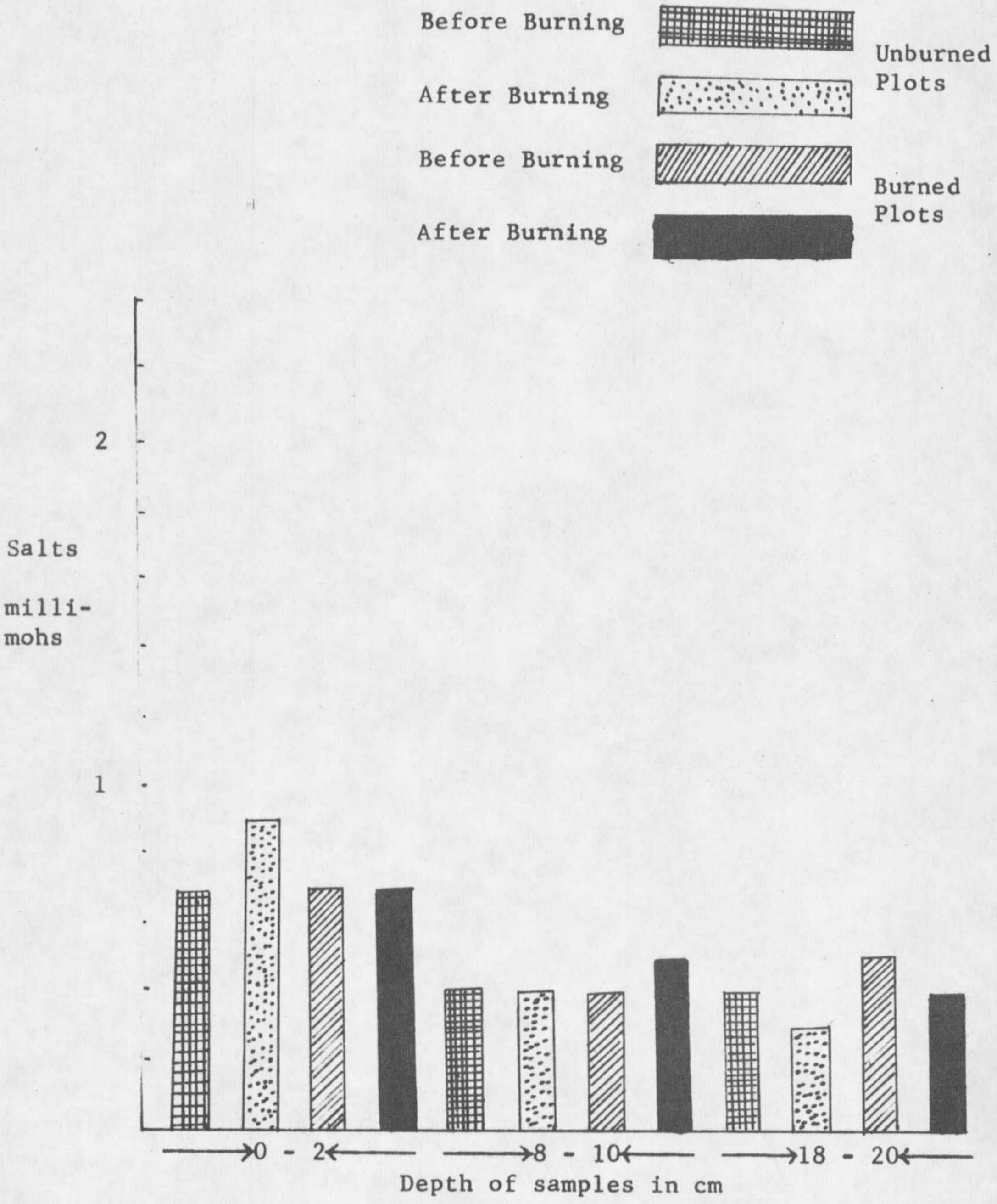


Figure 17. Salts in the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

The organic matter data showed decreases at all depths in both blocks. The decreases were significant at the 0-2 cm in both blocks and in the other two depths of the burned block (Figure 18). The significant decrease at the 0-2 cm in both blocks shows that burning is not the factor that induced these decreases in organic matter. Variation between changes at other depths are probably due to sampling.

Calcium data showed no significant changes (Figure 19). Highly significant decreases in magnesium occurred at all the three depths in the burned block. In the unburned block the decrease was non-significant at the 0-2 cm depth and highly significant and significant at the other two depths (Figure 20). No significant changes in sodium were detected except for a highly significant increase in the 18-20 cm samples of the burned block (Figure 21). The variations between the burned and unburned blocks in magnesium at the 0-2 cm depth and in sodium at the 18-20 cm depth are more likely due to sampling than to the burning effect.

Nitrates increased at all depths in both blocks. The increases were highly significant in the 0-2 cm samples of the burned block, 8-10 cm of the unburned block and 18-20 cm of both blocks (Figure 22). The increases of nitrates are probably totally induced by the environmental changes and their effect on the nitrifying bacteria.

Comparison between the two sites: The differences between the effects of burning on soil chemical properties in the two sites is

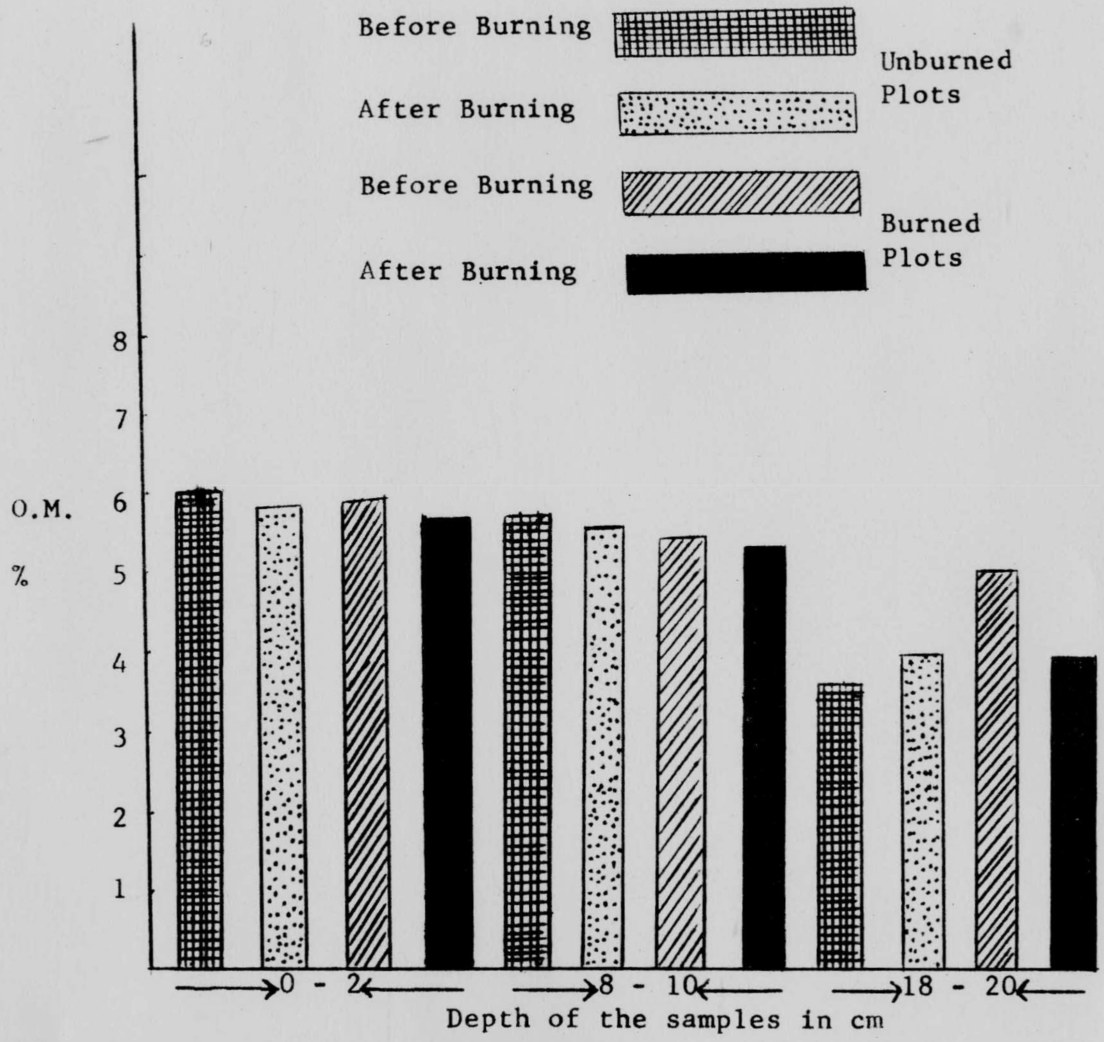


Figure 18. Percentage organic matter in the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

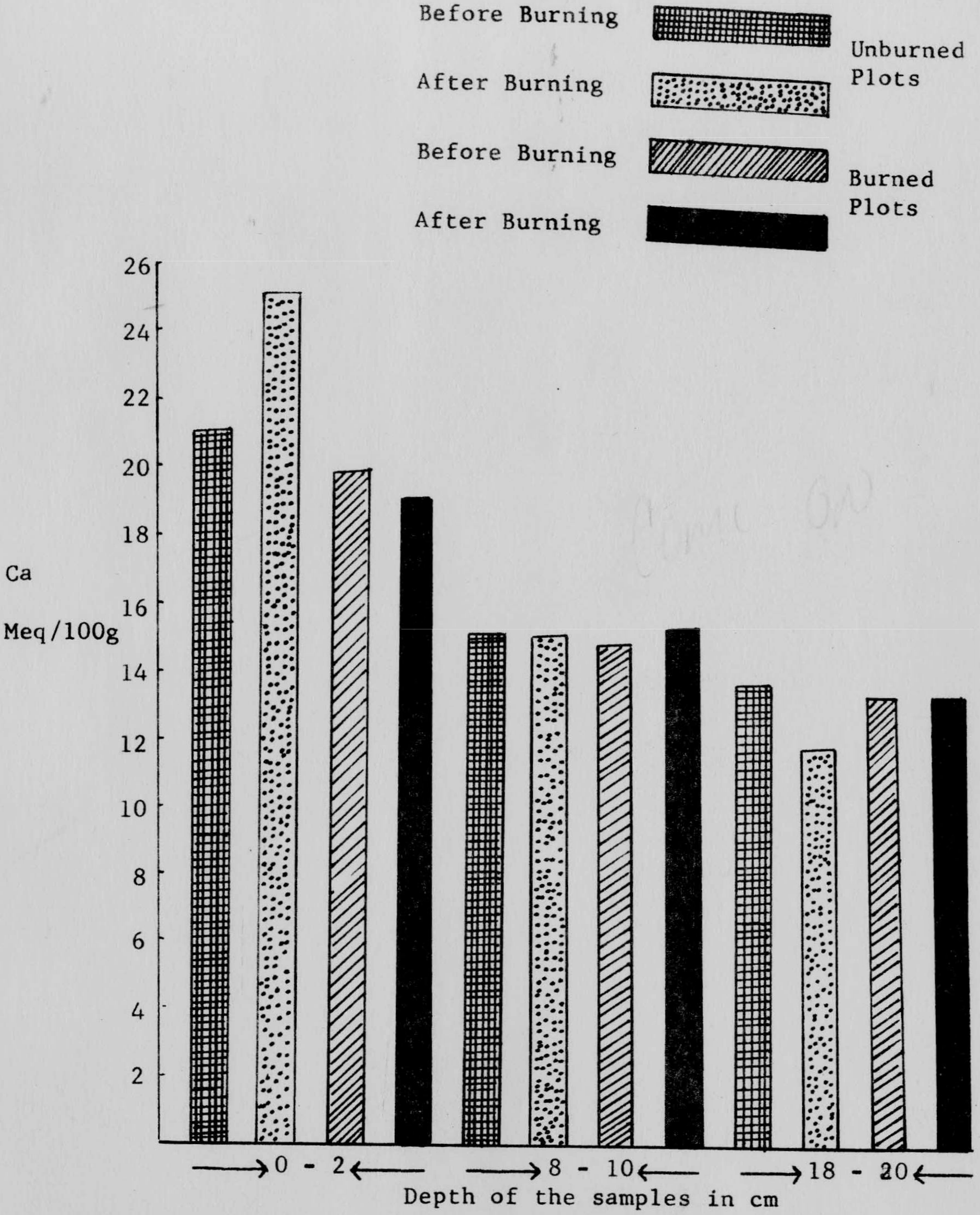


Figure 19. Calcium in the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

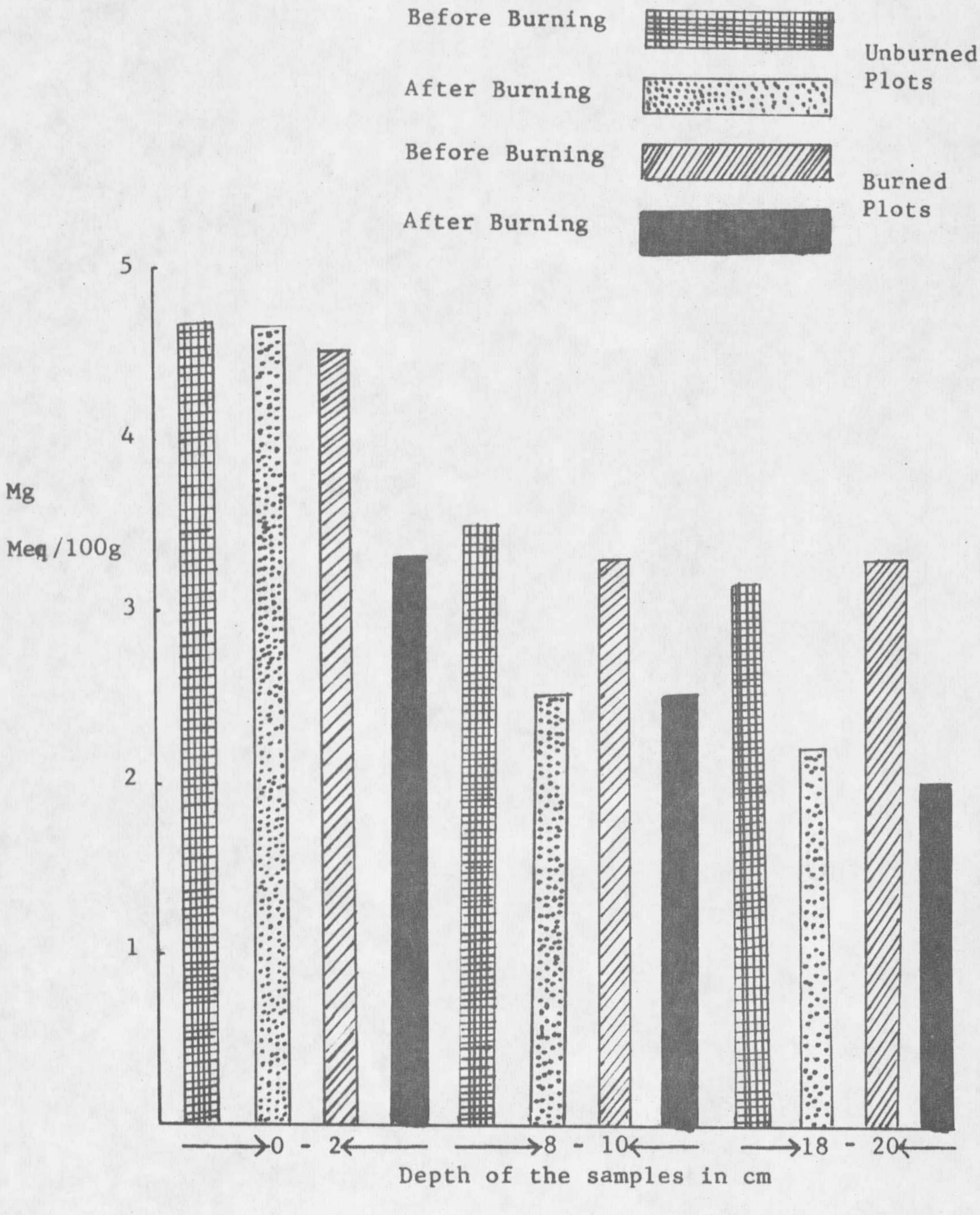


Figure 20. Magnesium in the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

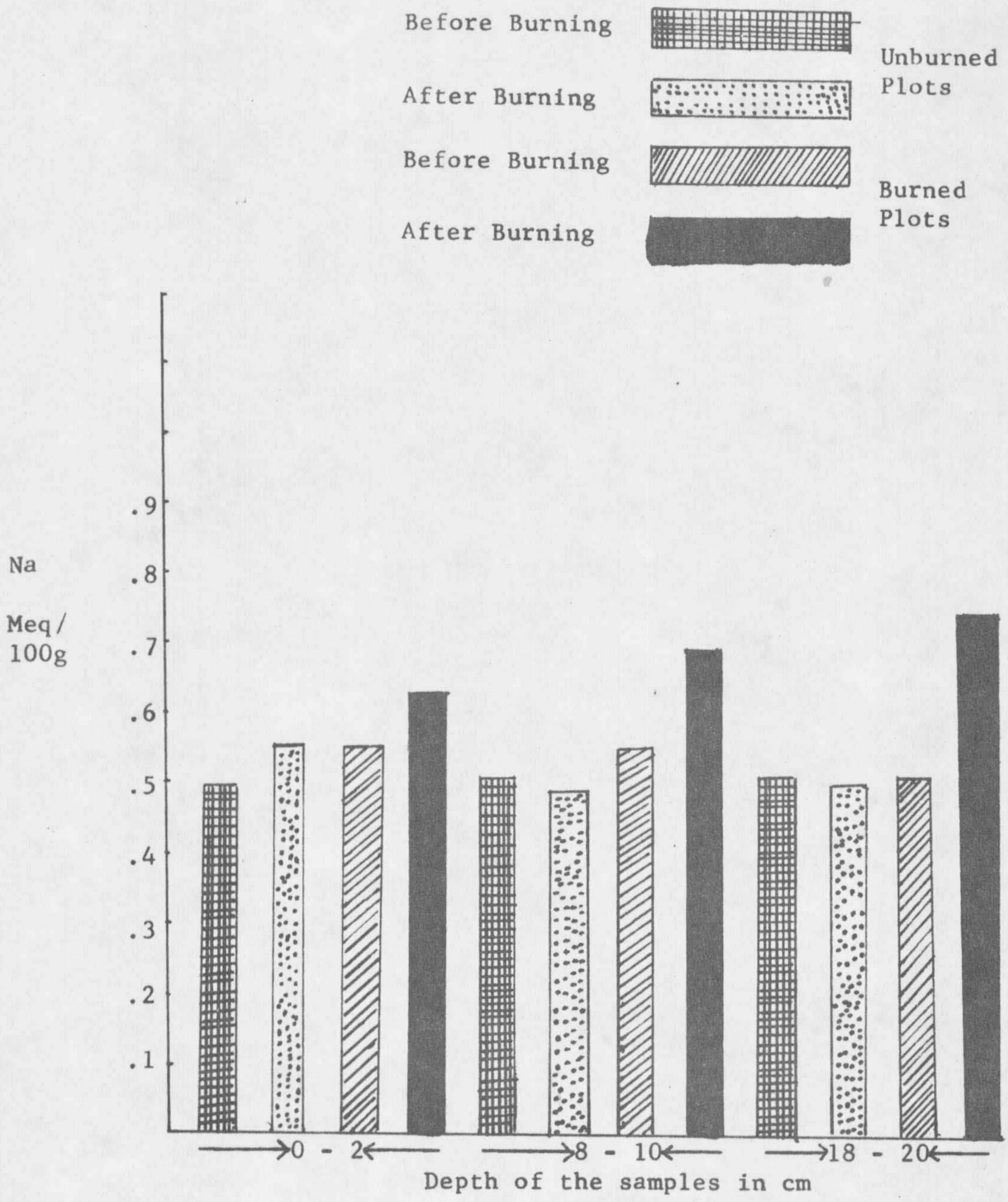


Figure 21. Sodium in the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

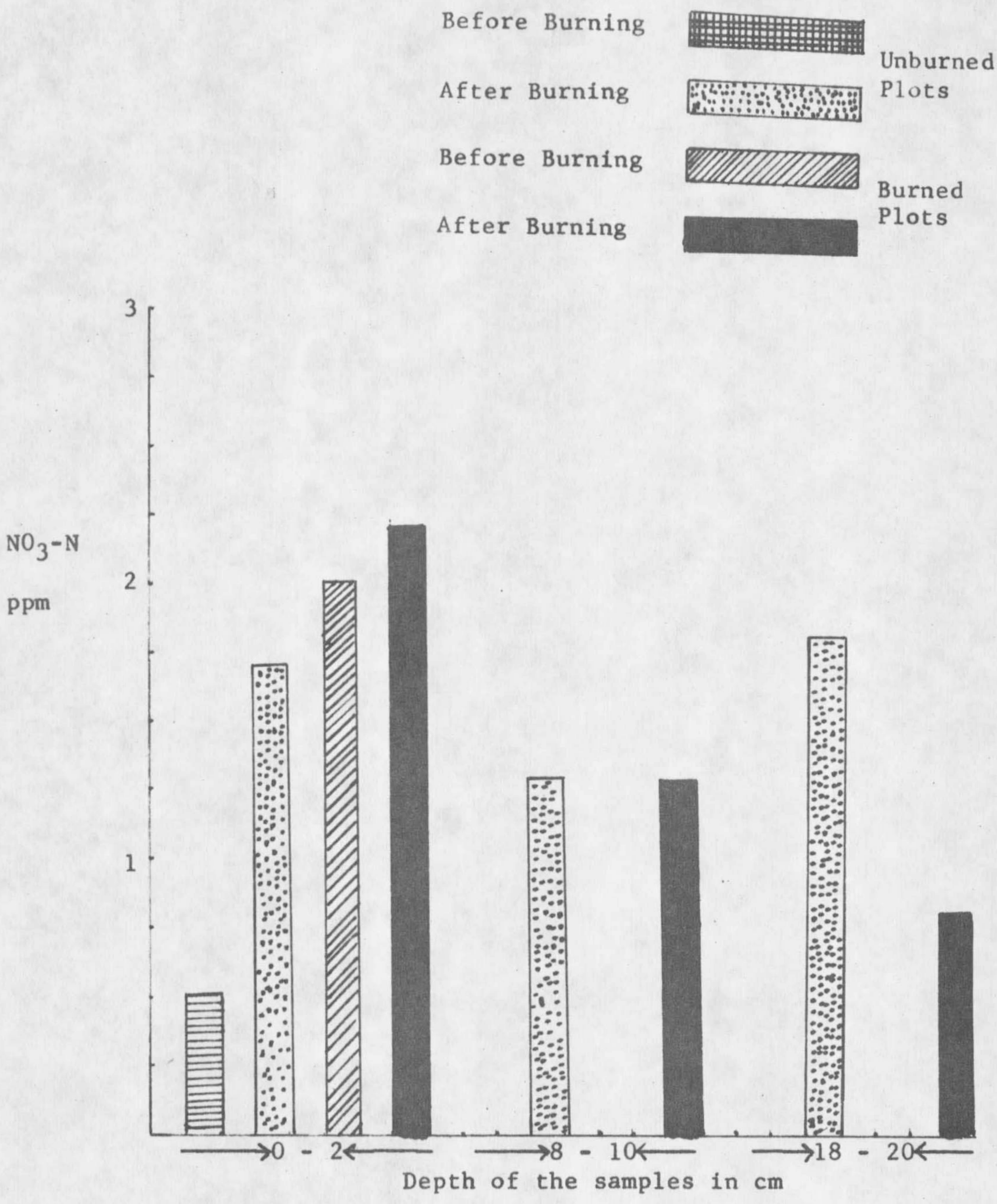


Figure 22. Nitrates in the soils of the unburned and burned blocks before and after burning, site 2, at three depths.

attributed to natural differences between them and to the different degree of burning occurring in each site.

The time of collection of soil samples was very important in affecting the chemical properties. The "before burning" soil samples were collected around mid-May, just after the snow melted while the "after burning" samples were collected at the beginning of summer when some biological activities were operating in the soil. This very likely explains the similar changes observed in both burned and control blocks.

The higher values of pH in the upper two depths of the burned block in site 1 can be attributed to the effect of burning as no significant changes occurred in the unburned block. The highly significant increases in potassium at the 0-2 cm depth of the burned block in site 2 can also be attributed to the burning effect. On the other hand, the consistent lower values in magnesium at all depths in burned and unburned blocks of both sites can only be explained as that they were induced by factors other than burning. These decreases were probably due to biological activities in the soil induced by the environmental changes.

The complexity of factors involved in those changes in soil chemical properties make them difficult to interpret. Besides the original highly significant differences between the two sites and some of the significant differences between the two experimental blocks within the same site, the significant changes between the before- and after-burning samples add to the complexity of these changes (Appendix Table 7). However, it can be concluded that the magnitude of the changes due to biological reasons or reasons other than the burn were greater than the changes due to the burn. It can be pointed out that perhaps the use of another sampling method which accounts for some of the biological changes might make it possible to detect the burning effect more precisely.

A theoretical calculation of the expected changes in some soil nutrients due to the burn (Appendix A, pages 136 to 139) substantiated the findings of this study. The average calculated release on the top 15 cm of the soil of 2 ppm of calcium, .09 ppm of phosphorus, 2.6 ppm of potassium in site 1 and 3 ppm of calcium, 0.2 ppm of phosphorus, 5 ppm of potassium and 2 ppm of magnesium in site 2 should not be expected to bring any significant increase of these nutrients in the soil.

Soil analyses of the burned and unburned areas within the burned blocks: These samples were collected strictly from the completely burned and completely unburned areas within the burned blocks. No randomization was followed in collecting these samples and no replicates were collected within each block and hence no statistical analyses are possible. However, these samples justify the purpose of their collection in showing the drastic variations within the same burned block.

Tables 10 and 11 show the soil analyses of the burned and unburned areas in the burned block in site 1 and 2, respectively. In both sites

Table 10. Chemical analyses of the soil of the burned and unburned areas within the "burned" block, site 1 (samples collected from 0-2cm and 8-10cm depths and all samples picked from burned spots).

Depth in cm		pH	PPM. P	PPM. K	PPM. NO_3-N	milli-mohs Salts	% O.M.	Milliequivalent/100g Ca	Milliequivalent/100g Mg	Milliequivalent/100g Na
0 - 2	Unb.[1/]	6.1	37	715	2.5	0.6	5.97	17.0	3.77	0.51
	B	6.5	57	895	4.4	0.8	6.03	18.6	4.43	0.64
8 - 10	Unb.	6.2	15	595	0.5	0.3	4.5	13.8	3.61	0.59
	B	6.5	79	725	1.0	0.6	5.2	15.8	3.94	0.64
	Ash	--	123	1520	--	--	--	31.4	7.13	0.51

1/ Unb.: Samples collected from spots completely unaffected by burn within the burned block.

B.: Samples collected from spots where most of the mulch was turned to ash.

Table 11. Chemical analyses of the soil of the burned and unburned areas within the "burned" block, site 2 (samples collected from 0-2cm and 8-10cm depths and all samples picked from burned spots).

Depth in cm		pH	PPM. P	PPM. K	PPM. NO_3-N	milli-mohs Salts	% O.M.	Milliequivalent/100g Ca	Milliequivalent/100g Mg	Milliequivalent/100g Na
0 - 2	Unb.[1/]	6.2	66	985	1.5	0.5	5.80	18.2	3.36	0.48
	B	6.3	82.5	1120	3.3	0.6	6.03	19.0	3.48	0.54
8 - 10	Unb.	6.1	45	855	1.0	0.4	5.87	16.2	2.87	0.51
	B.	6.1	57	865	2.0	0.5	5.87	16.6	3.03	0.54
	Ash	--	475	1520	--	--	--	31.4	7.13	0.51

1/ Unb.: Samples collected from spots completely unaffected by burn within the burned block.

B.: Samples collected from spots where most of the mulch was turned to ash.

the burned areas showed much higher values than the unburned areas for all the properties tested. The burned areas values were also higher than the maximum values obtained when sampling the entire burned blocks (Tables 8 and 9). The analyses of ash samples from the two sites yielded the same results except for phosphorus which was considerably higher in site 2 than in site 1. All the elements analyzed except sodium were higher in the ash than in the soil of the burned areas. These values were much higher than the calculated expected release of these elements in both sites. This is probably due to the fact that in the areas which were completely burned the fire consumed the dry undetached matter and burned shrubs added considerably to the fuel.

The results of these analyses reflect the difficulty of sampling in such burns. Sampling the localized burned areas only does not provide a clear picture of the effect of fire on the whole block. On the other hand, sampling the whole block might overlook the effect of fire on the localized burned areas. However, larger samples on the whole block should provide better information about the overall effect of fire.

Vegetational Analyses

Basal Cover:

Site 1: The analyses of basal cover data of site 1 are shown in Table 12. The basal cover differences between the burned and unburned blocks for the different species are shown in Table 13. The complete data are presented in Appendix Table 8.

Table 12. Statistical analyses of weekly basal cover measurements of burned and unburned blocks, Site 1 (measurements were taken for 12 weeks following burning).

Species	Treatments	Dates	Dates X Treatments
Agropyron trachycaulum	**	**	**
Carex spp.	**	**	n.s.
Danthonia unispicata	n.s.	**	**
Festuca idahoensis	**	**	n.s.
Poa alpina	**	**	**
Stipa viridula	n.s.	**	n.s.
Total grasses and sedges	**	**	**
Achillea millefolium	n.s.	n.s.	n.s.
Agoseris glauca	n.s.	**	n.s.
Antennaria rosea	n.s.	**	*
Dodecatheon pauciflorum	n.s.	*	*
Fragaria virginiana	n.s.	n.s.	n.s.
Geum triflorum	**	*	n.s.
Lupinus leucophyllus	n.s.	**	n.s.
Phlox caespitosa	**	**	**
Potentilla gracilis	n.s.	n.s.	n.s.
Taraxacum officinale	**	**	**
Miscellaneous forbs	**	**	n.s.
Total forbs	**	**	**
Artemisia tridentata	**	n.s.	n.s.
Potentilla fruticosa	**	n.s.	n.s.
Dead Artemisia tridentata	**	n.s.	n.s.
Dead Potentilla fruticosa	n.s.	n.s.	n.s.
Ash	**	n.s.	n.s.
Bare soil	n.s.	n.s.	n.s.
Lichen	**	**	*
Litter	**	**	**
Rock	**	n.s.	n.s.

* Significant differences at the 0.05 probability level
** Significant differences at the 0.01 probability level
n.s. ~~non-significant~~
no-shit

Table 13. Basal cover differences between the burned and unburned blocks, site 1, means of 12 weeks measurements (values are in sq dm/20 sq dm).

Species	Unburned	Burned	Differences
Agropyron trachycaulum	0.15	0.25	+0.10**
Carex spp.	0.49	0.31	-0.18**
Danthonia unispicata	2.49	2.70	+0.21
Festuca idahoensis	0.27	0.13	-0.14**
Poa alpina	0.40	0.10	-0.30*
Stipa viridula	0.16	0.15	-0.01
Total grasses and sedges	3.95	3.65	-0.30**
Achillea millefolium	0.00	0.01	+0.01
Agoseris glauca	0.09	0.04	-0.05
Antennaria rosea	0.37	0.30	-0.07
Dodecatheon pauciflorum	0.02	0.00	-0.02
Fragaria virginiana	0.13	0.20	+0.07
Geum triflorum	1.70	0.90	-0.80**
Lupinus leucophyllus	0.14	0.17	+0.03
Phlox caespitosa	0.42	0.21	-0.21**
Potentilla gracilis	0.15	0.19	+0.04
Taraxacum officinale	0.03	0.21	+0.18**
Miscellaneous forbs	0.84	0.54	-0.30**
Total forbs	3.90	2.78	-0.12**
Artemisia tridentata	2.05	0.29	-1.76**
Potentilla fruticosa	0.65	0.15	-0.50**
Dead *Artemisia tridentata*	1.28	1.94	+0.66**
Dead *Potentilla fruticosa*	0.01	0.07	+0.06
Ash	0.00	2.46	+2.46**
Bare Soil	0.62	0.49	-0.13
Lichen	0.44	1.06	+0.62**
Litter	10.99	9.54	-1.45**
Rock	0.00	0.12	+0.12**

* Significant differences at the 0.05 probability level

** Significant differences at the 0.01 probability level.

Total grasses and total forbs showed highly significant lower values in the burned block when compared to the unburned block. Highly significant changes were observed among the values for total grasses and total forbs measured at different dates. The interaction between treatment effect and dates of measurements was highly significant.

Festuca idahoensis, Poa alpina and Carex spp. showed highly significant lower values in the burned block than the unburned block. The only grass species which reflected a significantly higher value in the burned block than the unburned block was Agropyron trachycaulum.

The change of grass values among different dates was significant for Agrostis alba and highly significant for the other species. The interaction between treatment effect and dates of measurements was highly significant for Danthonia unispicata, Agropyron trachycaulum and Poa alpina (Figure 23).

Three forbs showed highly significant differences in basal cover between the burned and unburned blocks. Geum triflorum and Phlox caespitosa had lower values while Taraxacum officinale had higher values in the burned than the unburned blocks.

The change of cover values between the different dates of measurements was highly significant for Phlox caespitosa, Antennaria rosea, Lupinus leucophyllus, Taraxacum officinale and Agoseris glauca, and was significant for Geum triflorum (Figure 23). The interaction between treatment effect and dates of measurements was highly significant for

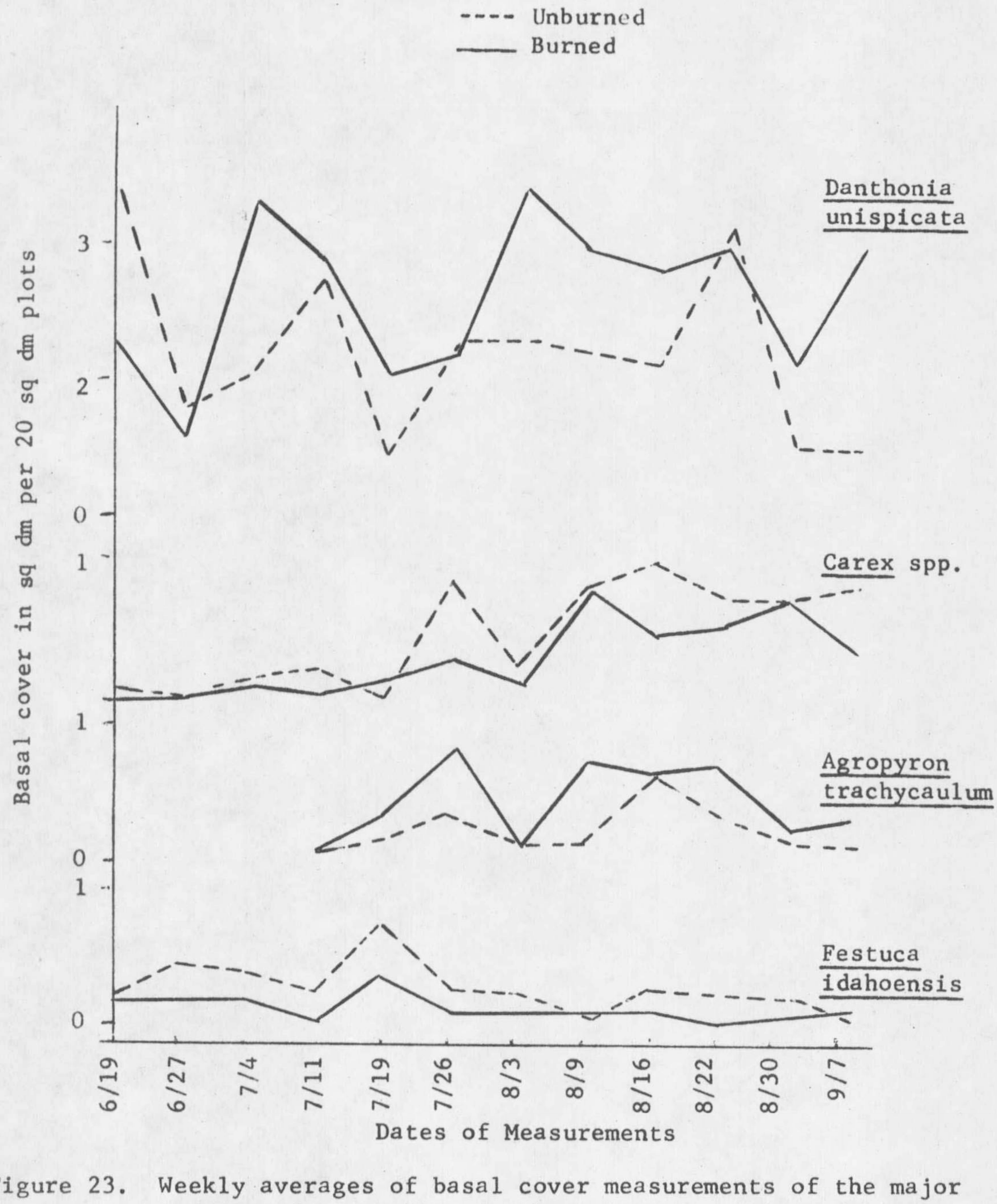


Figure 23. Weekly averages of basal cover measurements of the major species of vegetation in the unburned and burned blocks, site 1.

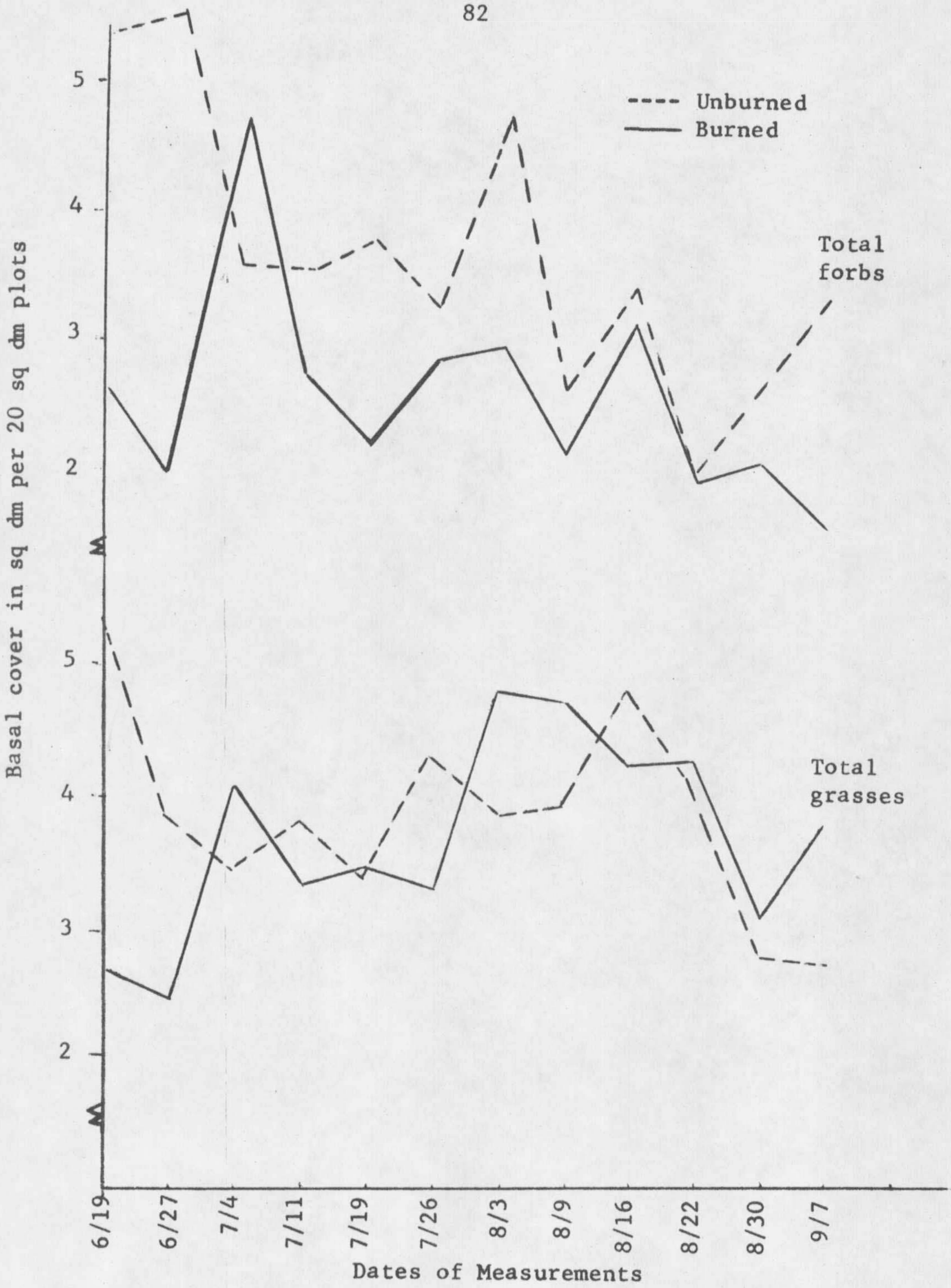


Figure 23 (Continued).

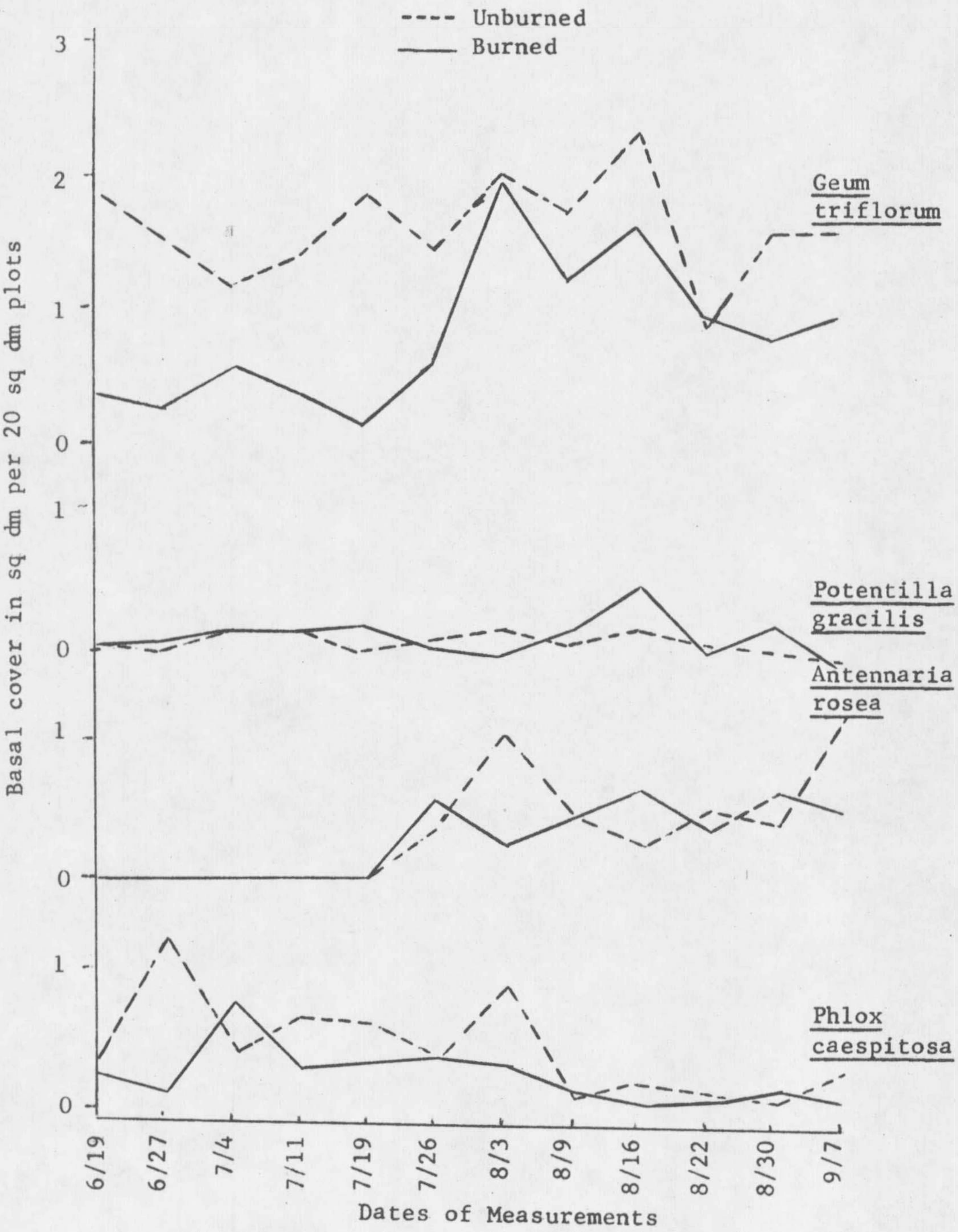


Figure 23 (Continued).

Phlox caespitosa, *Taraxacum officinale* and significant for *Dodecatheon pauciflorum*.

The two shrubs in site 1 both showed highly significant lower values in the burned block. The measurements of dead *Artemisia tridentata* showed a highly significant increase in the burned block. The measurements of live and dead shrubs showed no significant changes due to dates of observations.

The values measured for litter were highly significantly lower in the burned block. Lichens, ash and rock measurements showed highly significantly higher values on the burned block while bare soil reflected a non-significantly lower value. This lower value for bare soil is due to the measurement of the ash covered ground separately.

The dates of observations and the interaction between the dates of observations and treatment effect were significant for litter and lichen and not significant for bare soil, ash and rock.

Site 2: The analyses of basal cover data of site 2 are shown in Table 14. The basal cover differences between the burned and unburned blocks for the different species are shown in Table 15. The complete data are presented in Appendix Table 9.

The slightly lower basal cover of total grasses and sedges in the burned block was not statistically significant. The basal cover showed highly significant changes between the dates of observations. The

Table 14. Statistical analyses of weekly basal cover measurements of burned and unburned blocks, Site 2 (measurements were taken for 12 weeks following burning).

Species	Treatments	Dates	Dates X Treatments
Agropyron trachycaulum	*	**	n.s.
Agrostis alba	n.s.	**	**
Bromus marginatus	*	*	n.s.
Carex spp.	n.s.	**	*
Danthonia unispicata	n.s.	*	n.s.
Festuca idahoensis	n.s.	n.s.	n.s.
Poa alpina	n.s.	**	n.s.
Stipa viridula	n.s.	*	n.s.
Total grasses and sedges	n.s.	**	**
Achillea millefolium	**	*	*
Agoseris glauca	n.s.	**	n.s.
Antennaria rosea	n.s.	**	n.s.
Aster scopulorum	**	**	**
Fragaria virginiana	n.s.	**	n.s.
Geranium viscossissimum	n.s.	**	*
Geum triflorum	n.s.	n.s.	n.s.
Lupinus leucophyllus	n.s.	*	n.s.
Myosotis sylvatica	n.s.	**	**
Potentilla gracilis	*	**	**
Taraxacum officinale	*	**	n.s.
Miscellaneous forbs	n.s.	**	n.s.
Total forbs	n.s.	**	*
Artemisia tridentata	**	n.s.	n.s.
Dead Artemisia tridentata	n.s.	n.s.	**
Litter	**	**	n.s.
Lichen	n.s.	*	*
Bare soil	**	**	n.s.
Rock	n.s.	n.s.	n.s.

* Significant differences at the 0.05 probability level
** Significant differences at the 0.01 probability level
n.s. non-significant

Table 15. Basal cover differences between the burned and unburned blocks, site 2, means of 12 weeks measurements (values are in sq dm/20 sq dm).

Species	Unburned	Burned	Differences
Agropyron trachycaulum	0.11	0.19	+0.08*
Agrostis alba	0.18	0.08	-0.10
Bromus marginatus	0.72	0.55	-0.17*
Carex spp.	0.44	0.42	-0.02
Danthonia unispicata	0.03	0.05	+0.02
Festuca idahoensis	0.69	0.66	-0.03
Poa alpina	0.12	0.12	0.00
Stipa viridula	0.30	0.30	0.00
Total grasses and sedges	2.52	2.38	-0.14
Achillea millefolium	0.14	0.37	+0.23**
Agoseris glauca	0.32	0.34	+0.02
Antennaria rosea	0.07	0.15	+0.08
Aster scopulorum	0.24	0.43	+0.19**
Fragaria virginiana	0.01	0.04	+0.03
Geranium viscossissimum	0.62	0.49	-0.13
Geum triflorum	0.29	0.20	-0.09
Lupinus leucophyllus	0.32	0.34	+0.02
Myosotis sylvatica	0.28	0.26	-0.02
Potentilla gracilis	1.16	1.41	+0.25*
Taraxacum officinale	0.73	0.56	-0.17*
Miscellaneous forbs	0.84	0.74	-0.10
Total forbs	5.06	5.36	+0.30
Artemisia tridentata	1.46	0.08	-1.38**
Dead Artemisia tridentata	1.49	1.54	+0.05
Lichen	0.02	0.00	-0.02
Litter	10.63	8.61	-2.02**
Bare soil	1.54	3.56	+2.02**
Rock	0.08	0.03	-0.05

* Significant difference at the 0.05 probability level

** Significant difference at the 0.01 probability level.

interaction between treatment and dates of observations was highly significant.

The slightly higher total basal cover of total forbs in the burned blocks was not significant. On the other hand, the changes in basal cover between the dates of observations were highly significant. The interaction between treatment effect and dates of observations was significant.

Bromus marginatus showed a significant decrease while Agropyron trachycaulum showed a significantly higher value in the burned than the unburned block. The basal cover measurements showed significant changes among the dates of observations for Bromus marginatus, Stipa viridula and Danthonia unispicata, and the changes were highly significant for Carex spp., Agropyron trachycaulum, Poa alpina and Agrostis alba (Figure 24). The interaction between treatment effects and dates of observations was significant for Carex spp. and highly significant for Agrostis alba.

Potentilla gracilis was significantly more in the burned block than the unburned block while Taraxacum officinale was significantly less. Achillea millefolium and Aster scopulorum showed highly significantly higher basal cover in the burned block than the unburned block.

The change of the basal cover between the dates of observations for Potentilla gracilis, Taraxacum officinale, Geranium viscossissimum, Myosotis sylvatica, Aster scopulorum, Agoseris glauca, Antennaria rosea

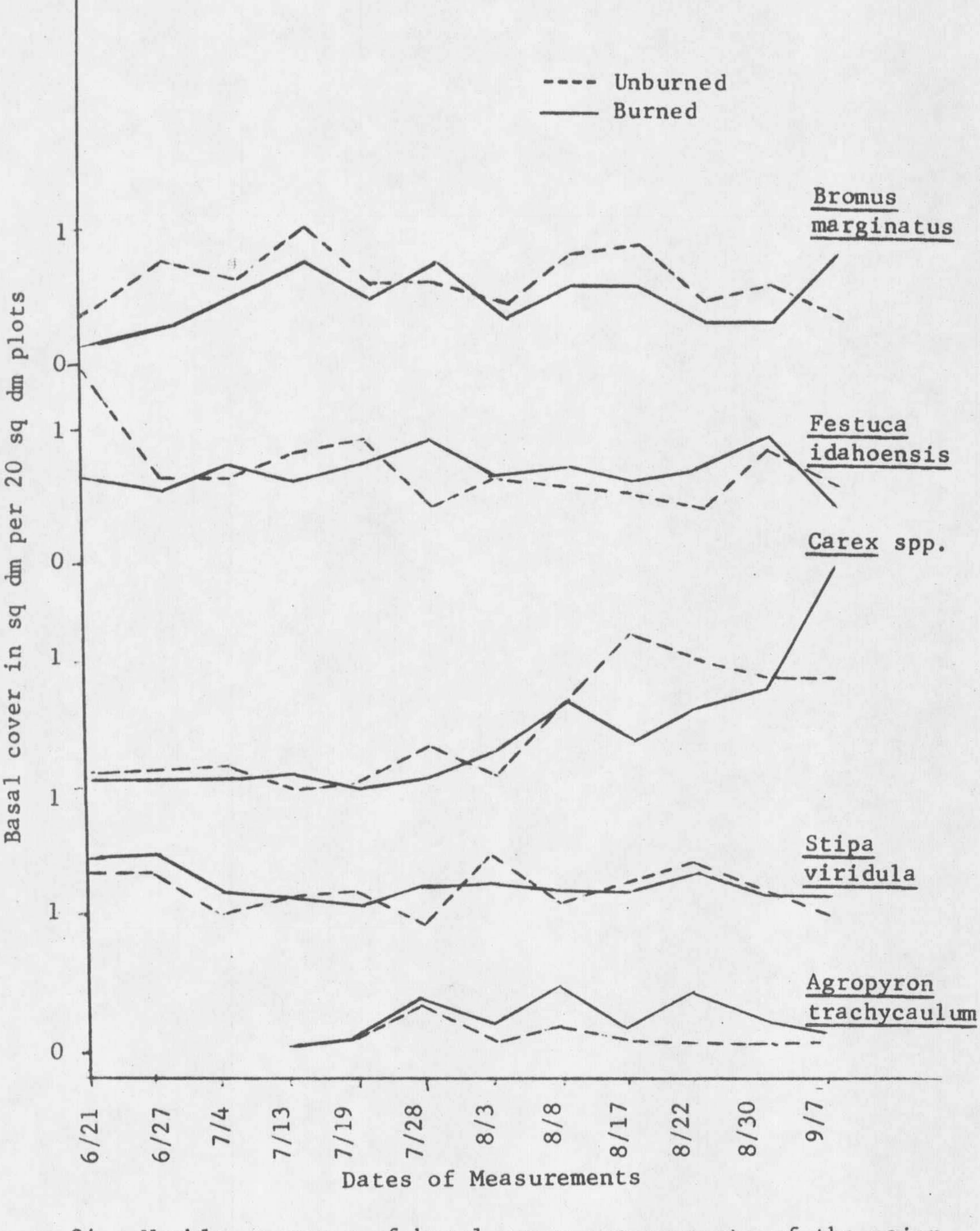


Figure 24. Weekly averages of basal cover measurements of the major species of vegetation in the unburned and burned blocks, site 2.

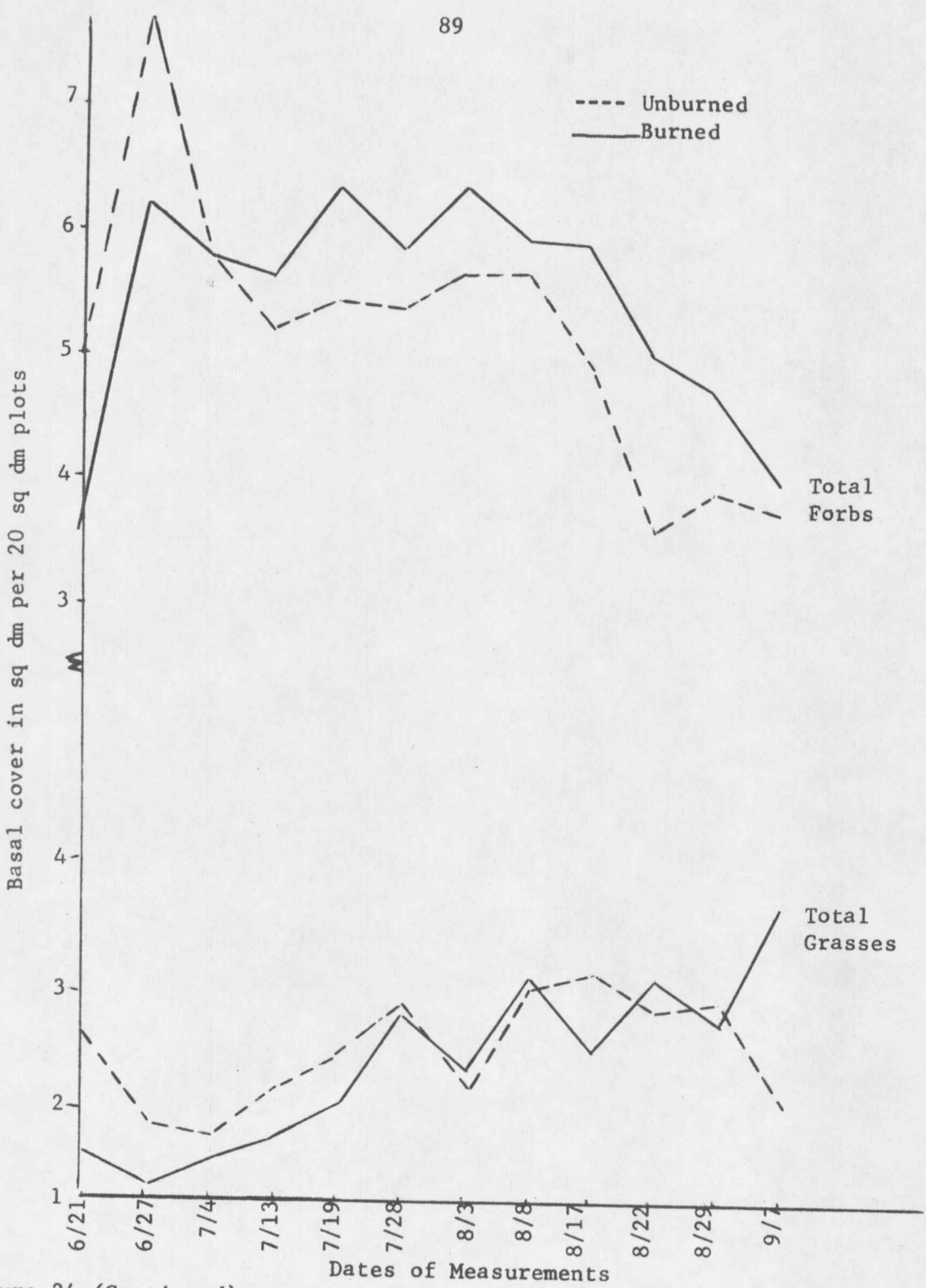


Figure 24 (Continued).

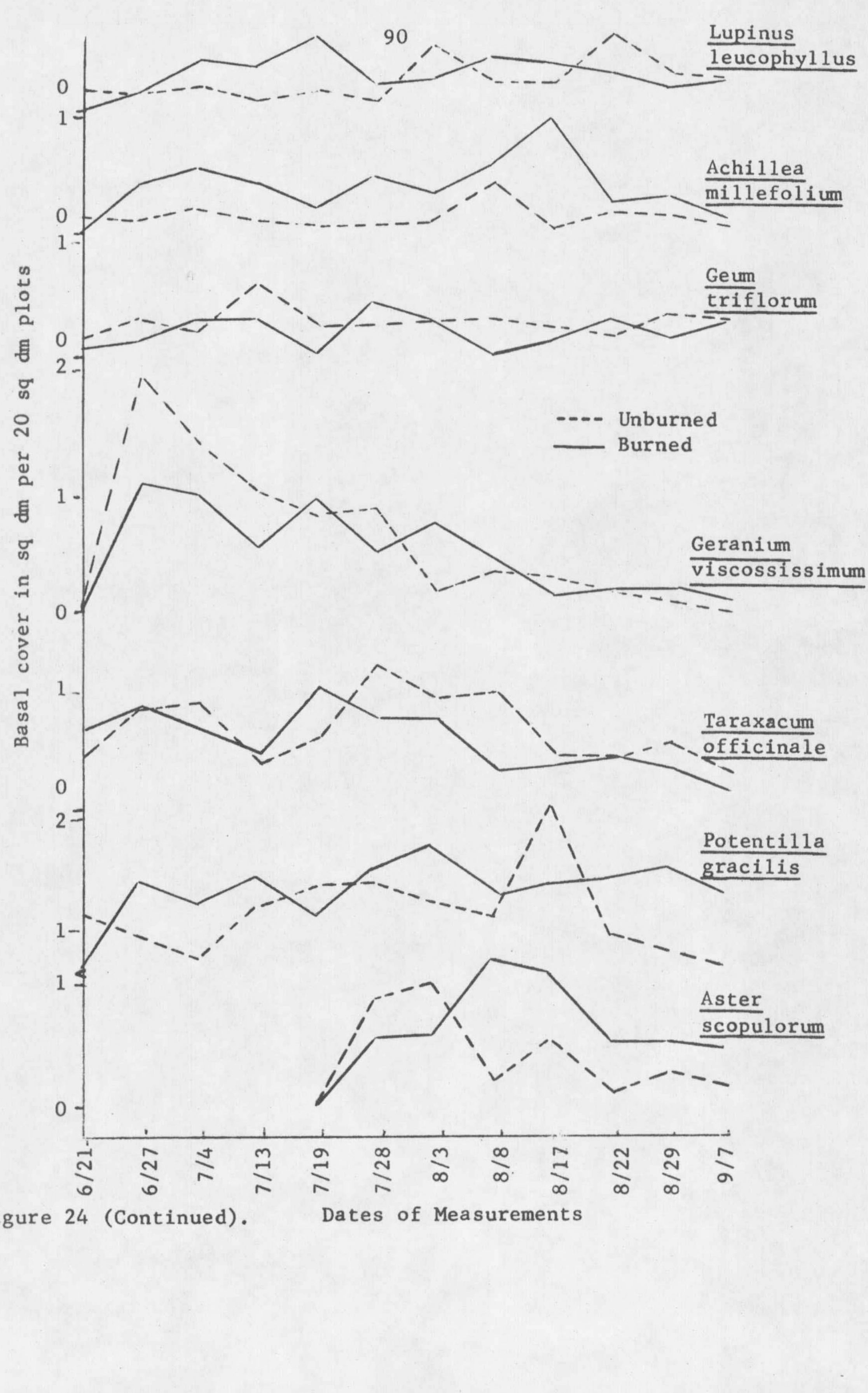


Figure 24 (Continued).

and Fragaria virginiana was highly significant. The change of the basal cover of Achillea millefolium and Lupinus leucophyllus among the dates of observations was significant (Figure 24). The interaction between treatment effect and dates of observations was highly significant for Potentilla gracilis, Myosotis sylvatica and Aster scopulorum and was significant for Achillea millefolium and Geranium viscossissimum.

Artemisia tridentata showed a highly significantly lower value in the burned block but the dead Artemisia tridentata was not significantly higher in the burned block than the unburned block.

The litter and the bare ground areas showed highly significant difference between the burned and unburned blocks. The litter was lower in the burned block and the bare ground was equally higher.

Comparison between the two sites: The differences between the basal cover data of the two sites are due to the initial differences between the two sites and to the different degrees of burning that affected each site. The highly significant changes observed between the weekly measurements of the basal cover of most of the species were not surprising. The changes reflected the weather changes throughout the study period and their effect on the natural phenological stages of growth of the different species. The change pattern was variable between species and for the same species in the two sites.

The effect of burning on the different grass species showed some similarities on the two sites. Significantly lower values were observed in the basal cover of Festuca idahoensis and Poa alpina in the burned block in site 1. In site 2 these two species showed non-significantly lower values in the burned block. Carex spp. showed highly significantly lower values in the burned blocks than the unburned blocks in site 1. In site 2 Carex spp. was non-significantly lower in the burned block than the unburned block.

Agropyron trachycaulum showed significantly higher values in the burned blocks than the unburned blocks in both sites. The higher values of Agropyron trachycaulum in the burned blocks might be attributed to the fact that the first measureable basal cover of Agropyron trachycaulum in the burned and unburned blocks at both sites was recorded later than mid-July. It could be concluded that since Agropyron trachycaulum started to develop later in the growing season it was not damaged by the fire and that the growing conditions were more favorable for it in the burned blocks than the unburned blocks.

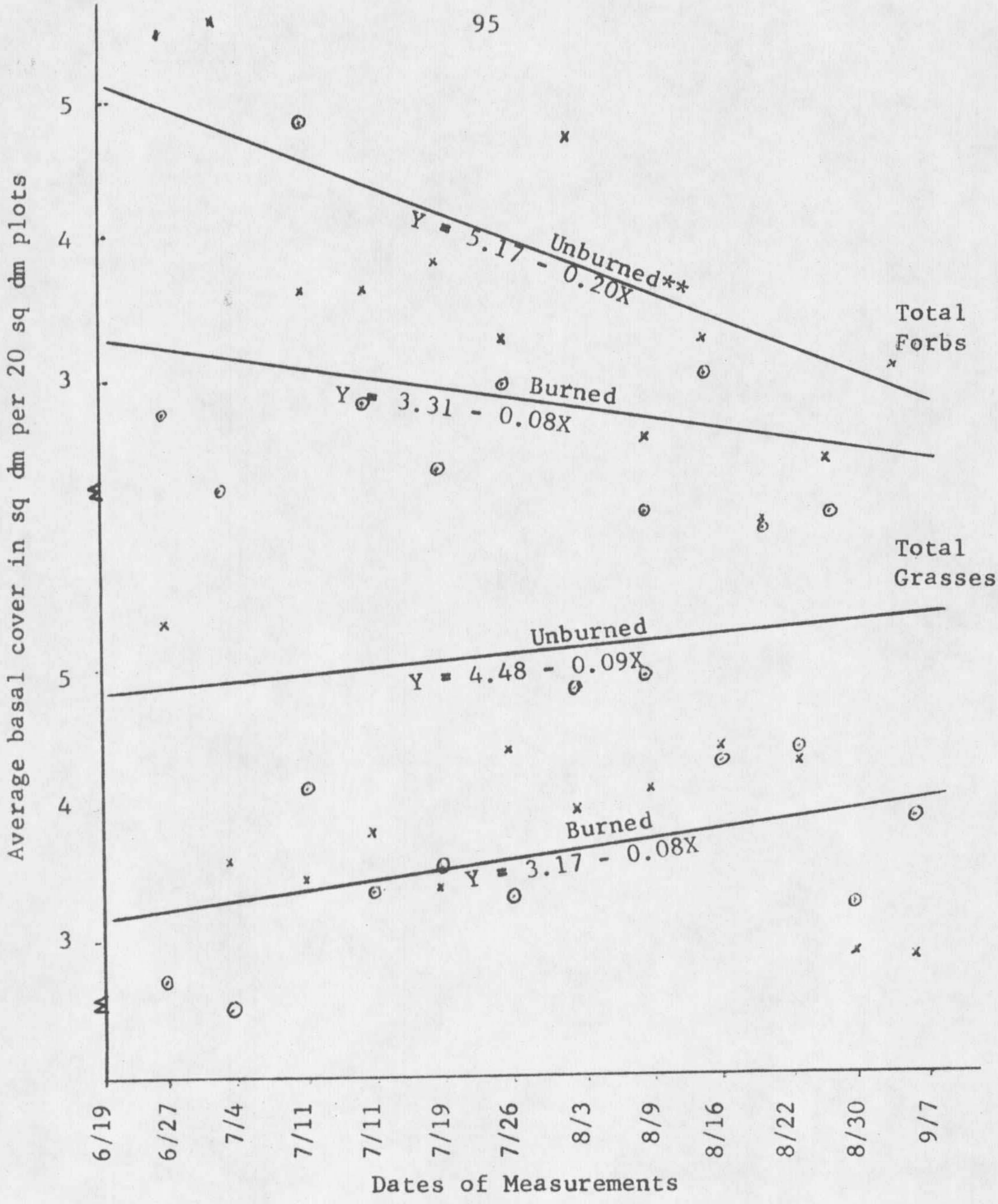
The effect of burning on forbs showed some variations. In site 1 the total forbs value was significantly lower in the burned block than the unburned block. In site 2 the total forbs value was non-significant higher in the burned block. Achillea millefolium and Potentilla gracilis showed higher basal cover in burned than unburned blocks in both sites. The higher values were only statistically significant for Achillea millefolium in site 2. Aster scopulorum, which occurred in site 2 only, showed a highly significantly higher value in the burned block than the unburned block. Taraxacum officinale had a highly significantly higher value in the burned block than the unburned block. In site 2 Taraxacum officinale had a significantly lower value in the burned block than the unburned block. The result with Taraxacum officinale in site 1 is a better indicator of the reaction of this species to fire as the fire in site 2 was very light.

Geum triflorum showed lower values in the burned blocks than the unburned blocks in both sites. These values were highly significant in site 1 and not significant in site 2. Phlox caespitosa, which occurred in site 1 only, reflected highly significantly lower values in the burned block than the unburned block.

The consistency of the pattern of changes of basal cover for most of the above species in both sites make it possible to draw definite conclusions about the reaction of each species to fire regardless of the fact that in some cases the differences were not statistically significant. The lack of statistical significance in these cases can be attributed to inadequacy of sampling.

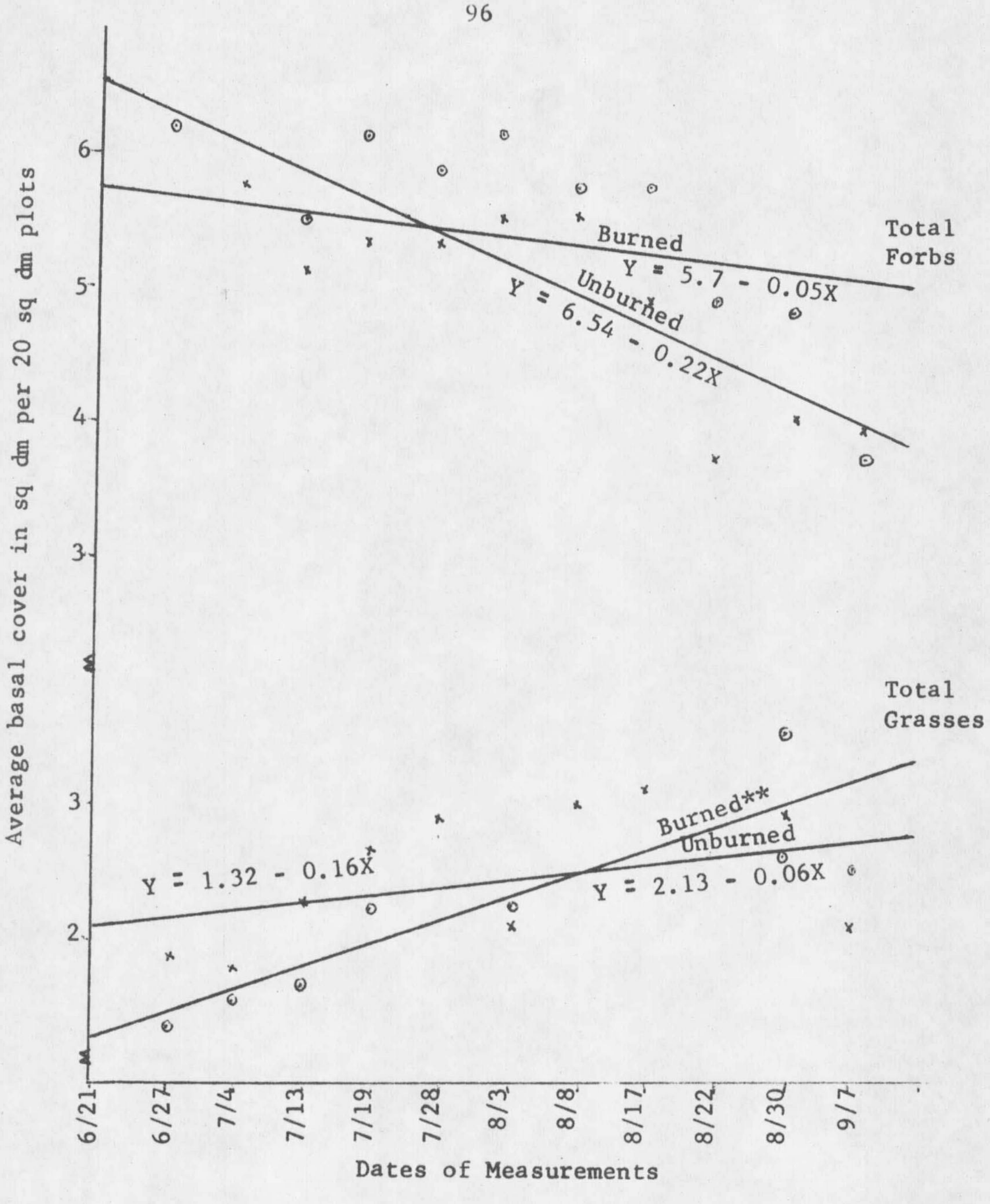
Species damaged by fire	Species favored by fire
Carex spp.	Agropyron trachycaulum
Festuca idahoensis	Achillea millefolium
Poa alpina	Aster scopulorum
Geum triflorum	Potentilla gracilis
Phlox caespitosa	Taraxacum officinale
Artemisia tridentata	
Potentilla fruticosa	

The significant interaction between burning effect and dates of observations point out that these factors are not independent of each other. Regression lines were plotted for the data of total grasses and total forbs of both sites to reflect the relationship between the basal cover measurements and the dates of observations (Figures 25 and 26). The statistical significance of variation due to regression was highly significant for total forbs in site 1 and total grasses in site 2 and it was not significant in the other two cases. Nevertheless, a general pattern is evident from these regression lines. Following fire a decrease in basal cover occurred in the burned blocks. As the season advanced the differences between burned and unburned blocks decreased. This was more evident in site 2 where after five and seven weeks the forbs and grasses basal cover values were higher in the burned block than unburned block. In site 1 by the 12th week the difference between the basal cover of the forbs in the burned block and unburned blocks were very much less than the initial difference. The regression lines for grasses in site 1 did not show the above pattern but the original data for grasses shows that by the last two weeks the basal cover in the burned block exceeded that for the unburned block.



** Highly significant variation due to regression

Figure 25. Regression lines for the relationships between the total grasses and total forbs average basal covers and dates of measurements, site 1.



** Highly significant variation due to regression.

Figure 26. Regression lines for the relationships between the total grasses and total forbs average basal covers and dates of measurements, site 2.

Vegetational Development

The summaries of the vegetational development data are presented in Tables 16 and 17 for site 1 and 2. The vegetational development measurements are difficult to interpret because of the difficulty of applying any statistical analysis to them. The number of observations was quite variable weekly and among species. The number of measurements taken for some species was not adequate. This is due to the sampling method used which was meant to reduce the personal bias in selecting individual plants of each species for measurement. It is clear that with this sampling method a larger number of samples should be measured. Nevertheless, the floral development stages can be useful as good indicators for any differences induced by burning effects on plants.

Most grasses and forbs showed better vegetative growth in the unburned blocks than the burned blocks during the first few weeks of measurements. The lesser vegetative growth in the burned blocks can be explained as a direct effect of the damage caused by burning. However, most species recovered in short time and the measurements were comparable after five or six weeks.

Poa alpina and *Festuca idahoensis* were consistently shorter in the burned block than the unburned block in site 1. This might explain the lower basal cover values for these species in the burned blocks.

Table 16. Weekly averages of vegetational development measurements of the unburned and burned blocks, site 1 (Culm lengths of grasses and leaf lengths of forbs, measured in cm).

Species		Dates of Observations											
		5/31	6/13	6/20	6/28	7/4	7/12	7/19	7/27	8/5	8/16	8/22	8/30
Agropyron	Unb.	---	---	---	---	---	---	---	20.2	20.5	19.8	---	---
trachycaulum	B	---	---	---	---	---	---	18.3 (A)1/	17.3	17.7	17.3	22.7	17.5
Carex	Unb.	---	---	15.0	---	21.0	---	---	---	23.5	34.6	4.25	32.8
spp.	B	---	---	---	19.0	---	---	13.0	---	24.3	28.4	51.3	57.5
Danthonia	Unb.	5.5	8.4	10.4	(A) 11.6	(A) 11.6	(A) 10.9	17.8	22.3	18.5	24.7	24.4	22.6
unispicata	B	4.8	6.3	6.0	9.8	11.2 (A)	9.4	17.8	18.7	20.4	21.8	18.3	18.8
Festuca	Unb.	5.6	---	6.0	20.0	(A) 14.5	(S) ---	26.3	9.3	---	---	10.0	---
idahoensis	B	3.5	---	---	---	8.5 (T)	5.5 (S)	---	6.7	5.0	6.0	---	---
Poa	Unb.	7.5	11.1	14.1	14.8	15.0	(T) 19.1	27.7	17.0	---	---	---	---
alpina	B	---	7.5	7.3	14.6	13.8	15.6 (A)	16.0	---	---	---	---	---
Stipa	Unb.	9.6	11.0	---	13.7	20.0	17.6	(A) 27.7	---	---	---	---	---
viridula	B	7.3	10.5	6.5	13.0	---	15.0	27.3 (A)	---	---	---	---	---
Achillea	Unb.	6.2	---	8.5	10.0	11.0	7.7	---	---	10.7	10.0	---	---
millefolium	B	---	5.5	4.0	7.0	7.0	6.9	--- (B)	8.8	6.3	8.0	---	4.5

Growth stages: (D) bud, (B) bloom, (T) boot, (A) Anthesis, (S) seed maturing.

Table 16. (Continued)

Species		Dates of Observations											
		5/31	6/13	6/20	6/28	7/4	7/12	7/19	7/27	8/5	8/16	8/22	8/30
					(S)	(S)							
Agoseris	Unb.	---	---	6.5	7.0	---	---	---	---	---	---	---	---
glauca	B	4.7	---	5.6	---	---	---	---	---	---	---	---	---
				(S)	(S)								
						(B)							
Fragaria	Unb.	---	---	---	---	8.0	8.0	---	6.0	---	---	---	6.0
virginiana	B	3.0	---	---	---	6.0	4.0	---	5.0	3.0	---	---	4.0
						(B)							
					(D)	(D)	(D)						
Geum	Unb.	7.8	12.0	11.8	10.1	13.5	12.0	12.3	11.9	10.8	11.4	7.0	9.8
triflorum	B	6.3	7.6	7.0	9.7	9.2	9.0	11.0	10.8	11.8	8.4	8.0	11.3
					(D)	(D)	(D)						
				(B)	(B)	(B)	(B)						
Phlox	Unb.	---	---	---	---	---	---	---	---	---	---	---	---
caespitosa	B	---	---	---	---	---	---	---	---	---	---	---	---
				(B)	(B)	(B)							
					(D)	(D)	(B)			(B)			
Potentilla	Unb.	6.8	8.0	10.0	8.0	10.0	8.8	9.0	10.7	13.0	9.0	7.5	13.0
gracilis	B	2.5	---	5.4	4.0	10.0	6.0	5.5	9.0	7.3	8.0	11.0	6.5
						(D)	(B)		(B)	(B)			
					(S)	(S)							
Taraxacum	Unb.	6.3	---	7.6	7.5	8.0	12.0	---	7.0	15.0	---	---	---
officinale	B	2.9	4.3	5.0	3.9	---	---	---	---	7.0	---	---	---
					(B)								
						(D)	(B)			(B)			
Potentilla	Unb.	---	---	---	---	---	---	---	---	---	---	---	---
fruticosa	B	---	---	---	---	---	---	---	---	---	---	---	---

Table 17. Weekly averages of vegetational development measurements of the unburned and burned blocks, site 2 (Culm lengths of grasses and leaf lengths of forbs, measured in cm).

Species		Dates of Observations													
		5/29	6/13	6/22	6/27	7/4	7/13	7/19	7/28	8/3	8/9	8/17	8/22	8/29	9/7
Agropyron trachycaulum	Unb.	---	---	---	---	---	---	(A) ---	(A) 44.5	42.5	51.0	59.3	60.0	48.5	41.0
	B	---	---	---	---	---	---	36.3 (A)	46.0	53.2	51.0	44.0	49.3	49.0	48.2
Bromus marginatus	Unb.	8.4	12.0	17.8	19.4	(A) 22.1	(A) 25.9	32.0	44.0	46.7	51.6	63.7	52.4	55.8	46.8
	B	---	12.5	15.0	19.4	23.8	21.8 (A)	35.5	43.3	41.0	52.3	60.7	49.4	49.7	40.0
Carex spp.	Unb.	---	15.0	---	---	(T) 24.0	---	44.0	33.0	37.5	61.2	52.8	41.0	44.9	55.0
	B	---	---	---	---	---	---	---	45.5	35.0	4.0	50.3	36.3	37.4	34.4
Danthonia unispicata	Unb.	---	---	---	---	---	11.0	---	---	---	30.0	---	---	28.5	---
	B	---	---	---	---	---	---	---	32.0	---	---	30.0	35.0	30.0	27.0
Festuca idahoensis	Unb.	10.4	15.0	(T) 17.9	(T) 20.7	(A) 22.5	(A) 30.4	32.0	22.0	31.0	52.4	41.2	40.8	43.4	56.3
	B	6.6	8.0	15.8	18.2	19.0	19.9 (A)	28.8	21.5	28.3	32.0	46.6	48.0	46.0	31.2
Poa alpina	Unb.	9.6	14.0	---	15.0	21.0	26.3	30.0	---	---	43.0				
	B	---	11.8	13.6	---	22.5	---	25.0	---	--- (S)	53.5	---	---		
Stipa viridula	Unb.	---	12.0	---	(T) 16.0	22.0	(T) 30.0	(A) 31.8	58.3	59.0	76.0	65.8	88.0	82.5	70.7
	B	6.0	10.0	15.0	16.2	18.0	29.0	45.0	62.2	53.8	71.4	55.2	76.4	59.7	62.3

Growth stages: (D) bud, (B) bloom, (T) boot, (A) Anthesis, (S) seed maturing.

Table 17 (Continued)

Species		Dates of Observations													
		5/29	6/13	6/22	6/27	7/4	7/13	7/19	7/28	8/3	8/9	8/17	8/22	8/29	9/7
					(B)					(B)		(B)			
Achillea	Unb.	6.0	11.6	13.0	15.5	16.2	15.8	---	10.3	14.6	16.0	13.5	---	---	---
millefolium	B	---	7.0	9.7	10.8	12.0	15.4	14.2	11.6	15.2	12.3	15.8	12.8	17.0	---
							(B)								
				(B)											
Agoseris	Unb.	7.6	11.0	17.1	17.2	18.3	16.0	19.5	---	---	---	---	---	---	---
glauca	B	---	8.2	13.6	15.9	16.0	17.3	17.7	14.3	---	---	---	---	---	---
												(B)			
Aster	Unb.	---	---	---	---	---	---	---	19.0	19.0	---	17.3	---	20.0	---
scopulorum	B	---	---	---	---	---	---	---	16.4	17.5	16.6	18.8	17.0	18.4	18.0
										(B)		(B)			
					(D)	(B)	(B)								
Geranium	Unb.	5.7	17.0	14.0	14.6	15.1	19.3	16.8	15.7	19.0	16.6	17.0	11.0	---	---
viscossissimum	B	3.0	---	10.0	9.8	16.8	17.4	18.8	16.0	18.8	19.0	14.0	---	---	---
							(B)	(B)							
Geum	Unb.	8.8	12.4	11.7	13.7	15.5	15.4	16.8	17.0	14.3	19.0	---	12.0	15.4	8.5
triflorum	B	5.8	12.0	14.5	14.0	15.0	15.3	16.0	14.5	13.0	17.0	---	14.0	12.0	22.0
								(S)							
						(B)		(B)	(S)						
Lupinus	Unb.	---	---	---	---	---	---	---	---	---	---	---	25.0	---	---
leucophyllus	B	---	---	---	---	---	---	---	---	---	---	17.0	---	---	---
							(B)	(S)	(S)	(B)	(S)				
							(S)	(S)	(D)	(B)	(B)				
Myosotis	Unb.	---	---	2.8	3.6	---	---	---	---	---	---	---	---	---	---
sylvatica	B	---	---	4.3	4.8	---	---	---	---	---	---	---	---	---	---
			(B)		(B)	(B)	(S)					(B)			

Table 17. (Continued)

Species		Dates of Observations													
		5/29	6/13	6/22	6/27	7/4	7/13	7/19	7/28	8/3	8/9	8/17	8/22	8/29	9/7
<u>Potentilla gracilis</u>	Unb.	6.6	9.9	12.7	---	15.0	(B) 16.9	(B) 16.3	14.9	14.7	18.1	(B) 18.3	13.3	15.7	11.6
	B	4.3	7.1	7.9	---	111.8	14.8 (B)	14.6	14.2	13.1 (B)	15.4	14.8	12.7	13.9	10.8
<u>Taraxicum officinale</u>	Unb.	6.6	12.3	(B) 13.0	(B) 17.9	(S) 17.3	(S) 17.6	19.4	19.8	21.5	24.4	24.3	21.3	23.8	17.8
	B	---	7.4 (B)	8.1	12.6	16.7	19.3	17.2	18.4	16.6	18.3	19.4	18.7	21.0	18.3

No clear differences were noticed in the floral developments between the burned blocks and unburned blocks in the two sites. However, it is noticed that a slower development of the different species of vegetation was occurring in the burned areas than the surrounding unburned areas. Very few incidents of floral development were observed within the completely burned areas in both sites. Most plant growth within these completely burned areas remained green throughout the period of observations while all vegetational growth in the unburned areas was starting to dry in mid-August and was almost completely dry by the beginning of September.

The following species were common in the completely burned areas in site 1: Agropyron trachycaulum, Carex spp., Danthonia unispicata, Geum triflorum, Potentilla gracilis, Taraxacum officinale, Fragaria virginiana and Lupinus leucophyllus. The species which were common in the completely burned areas in site 2 are: Agropyron trachycaulum, Taraxacum officinale, Myosotis sylvatica, Potentilla gracilis, Achillea millefolium, Geranium viscossissimum, Agoseris glauca and Antennaria rosea. In both sites forbs appeared in the burned areas more than grasses.

Forage production: Tables 18 and 19 show the average forage production of sites 1 and 2. As the clipping was done only once at mid-August these results are not goot indicators of total productivity. In site 1 by the time of clipping most of the forbs had already completed

Table 18. Foliage production on the unburned and burned blocks, site 1. (Values are average oven dry weights of ten plots clipped in the last week of August).

Species	Unburned g/20 sq. dm 1/	Burned g/20 sq. dm	Difference g/20 sq. dm
Agropyron trachycaulum	0.17	0.38	+0.21
Carex spp.	0.82	1.46	+0.64
Danthonia unispicata	9.34	8.85	-0.49
Festuca idahoensis	0.68	0.40	-0.28
Stipa viridula	0.56	0.13	-0.43
Total grasses	11.57	11.22	-0.35
Achillea millefolium	0.00	0.02	-0.02
Antennaria rosea	0.47	0.96	+0.49
Fragaria virginiana	0.22	0.24	+0.02
Geum triflorum	5.88	0.63	-5.25**
Phlox caespitosa	0.92	0.51	-0.41
Potentilla gracilis	0.49	0.30	-0.19
Miscellaneous forbs	0.53	2.10	+1.57
Total forbs	8.53	4.74	-3.79
Total forage	20.10	15.96	-4.14

None of the differences are significant at the 0.05 probability level.

1/ Multiply these values by 50 to get the production in Kg/h.

Table 19. Foliage production on the unburned and burned blocks, site 2. (Values are average oven dry weights of ten plots clipped in the last week of August.

Species	Unburned g/20 sq. dm	Burned g/20 sq. dm	Difference g/20 sq. dm
Agropyron trachycaulum	0.21	0.14	-0.07
Agrostis alba	0.25	0.03	-0.22
Bromus marginatus	3.75	1.65	-2.10
Carex spp.	1.56	1.79	+0.23
Festuca idahoensis	1.51	1.13	-0.38
Poa alpina	0.22	0.04	-0.18
Stipa viridula	1.22	0.78	-0.44
Miscellaneous grasses	1.08	0.60	-0.48
Total grasses	9.80	6.16	-3.64*
Achillea millefolium	0.00	0.37	+0.37
Antennaria rosea	0.00	0.65	+0.65
Aster scopulorum	3.65	1.53	-2.12
Geranium viscossissimum	0.00	2.43	+2.43
Geum triflorum	0.88	1.17	+0.29
Lupinus leucophyllus	0.61	1.98	+1.37
Myosotis sylvatica	0.71	0.98	+0.27
Potentilla gracilis	5.49	5.56	+0.07
Taraxacum officinale	1.77	2.91	+1.14
Miscellaneous forbs	2.89	1.13	-1.76
Total forbs	16.00	18.71	+2.71
Total forage	25.80	24.87	-0.93

* Significant difference at the 0.05 probability level.

1/ Multiply these values by 50 to get the production in Kg/h.

their life-cycles and their upper parts disintegrated. If the clipping had been done earlier, the contributions of forbs to the total forage production in site 1 would have been greater. Also, the effect of trampling over these experimental blocks through measurements and data collection should be considered as harmful to the natural vegetational development and total productivity. It can be concluded that the applicability of these results to estimate productivity is somewhat limited, but the use of these data for comparative investigations between the burned and unburned plots is still possible.

The production measurements of site 1 reflected some differences between the burned and unburned blocks. The total forage production was 20% lower in the burned block. The total grass production was about the same in both blocks but the forb production was 44% less in the burned block than in the unburned. None of these differences was statistically significant.

In site 2 the total grass production was 37% less in the burned block. The total forb production was 17% higher in the burned block. The total forage production was almost the same.

All the species with the exception of _Geum triflorum_ in site 1 did not show any statistically significant differences between burned and unburned blocks, but for a few species certain patterns of change were evident. _Carex_ spp. showed higher production in the burned blocks in both sites while _Festuca idahoensis_ and _Stipa viridula_ had lower values in the burned than the unburned blocks. The different forbs did not show any similar pattern of change in the two sites. This was possibly due to the fact that most of the forbs completed their growth in site 1 before the clipping was done while in site 2 some forbs were still green. Geum triflorum had highly significantly lower value in the burned block than the unburned block in site 1. The lower production for Geum triflorum is consistent with the basal cover value which was lower in the burned than the unburned block.

Sagebrush mortality estimations: The estimate of the sagebrush mortality are shown in Table 20. The different mortality classes are mapped in Figure 27. The mortality classes were mapped by estimation before the establishment of the transects. The approximate locations of the four transects within each mortality class are shown in the map. The average of the estimations of mortality percentages in the transects of mortality classes one and four were in agreement with the estimations used in mapping. On the other hand, the estimations used in mapping mortality classes two and three were either higher or lower than the averages of the transects estimations. The average mortality of sagebrush in the 16 transects was found to be 44.3%. However, the percentage of Artemisia cana should be excluded from this ratio as it is capable of resprouting and is not completely damaged by burning as is Artemisia tridentata.

Table 20. Estimations of percentage mortality of sagebrush (*Artemisia tridentata* and *Artemisia cana*) in the burned area - Averages calculated from 100 estimates on each of 16 transects.

Transect Numbers	% Sagebrush Mortality
1	5.0
2	7.8
3	11.9
4	16.3
5	52.9
6	42.0
7	27.7
8	57.5
9	52.2
10	26.0
11	42.3
12	46.5
13	46.0
14	84.6
15	94.7
16	94.9
Average	44.3

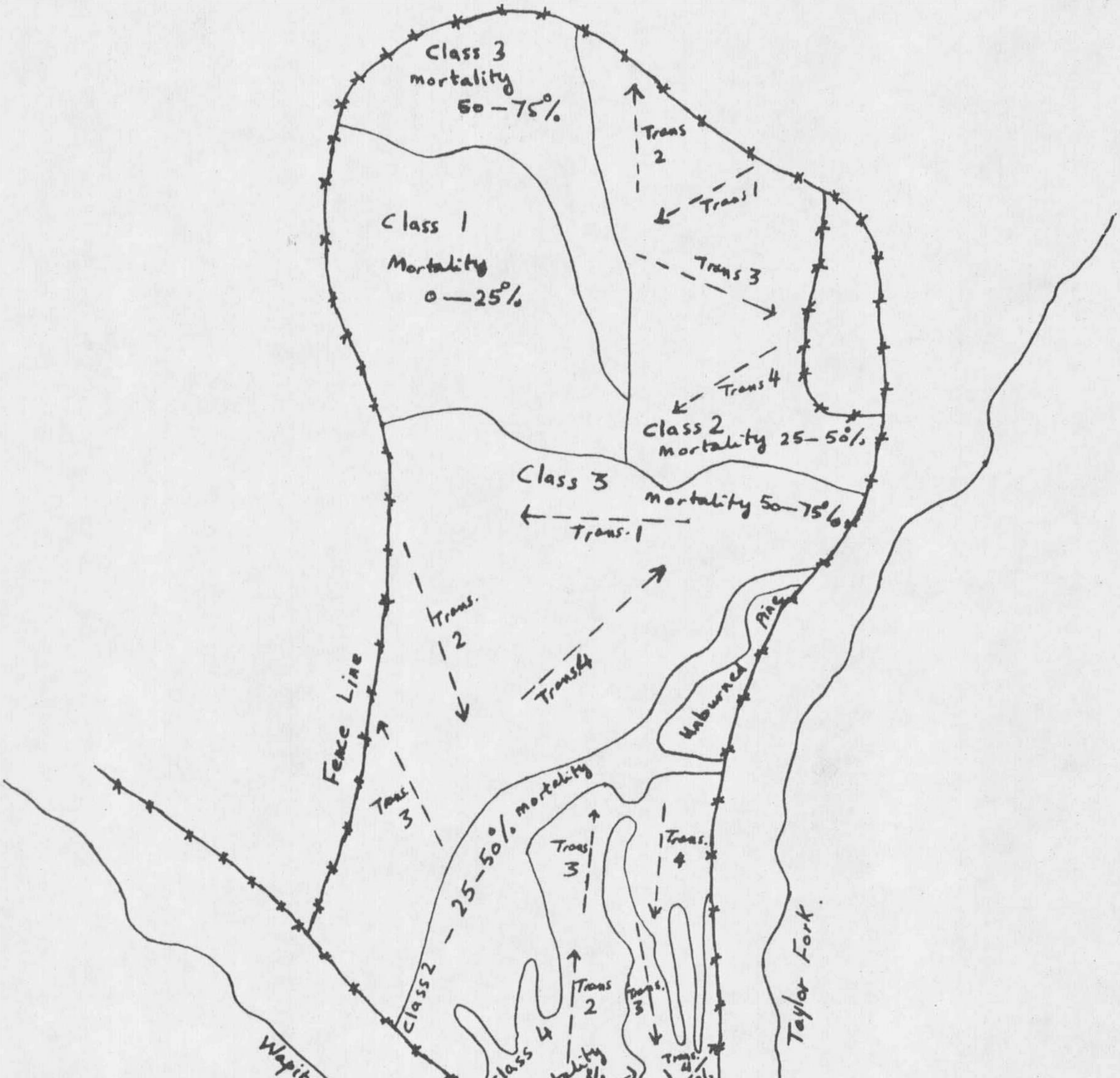


Figure 27. Sagebrush mortality classes with the approximate locations of the mortality estimation transects.

Counts were done in eight transects to find the percentage of Artemisia cana of the one hundred sagebrushes of each transect. This count was not done in all the transects because in class four mortality it was not possible to distinguish Artemisia cana from Artemisia tridentata as the burning destroyed most of the brushes and no sprouting had started by the time of the count. The counts made in the mortality classes two and three were considered adequate for making an estimate of Artemisia cana. Based on these counts Artemisia cana was estimated to be around 25% of the sagebrush in the burned area. Subtracting this figure from the overall average mortality of sagebrush it can be estimated that the mortality of Artemisia tridentata was around 30-35%.

CONCLUSIONS

The most important factor which affected the results of this study is the nature of the burn. The burn was not a typical shrub-grassland burn in which all or most of the fuel was oxidized to ash, and hence contributed to the physical and chemical properties of the soil. As the burn was started in unfavorable weather conditions and after a considerable green growth had developed, it resulted in localized burned areas with surrounding areas not affected at all. The drastic variations between the localized burned and unburned areas within the burned blocks are best illustrated by the chemical properties of the burned areas and the vegetational observations of some of the completely burned areas which show major differences from the measurements of the entire burned blocks. In most of the sampling methods followed in this study, the overall effect on the "burned blocks" was evaluated. In some cases not many of the localized burned areas were sampled in the whole sample from the burned block.

In addition, to the natural differences between the two sites, the nature of burn experienced in each site was quite different. In site 1 severe fire occurred resulting in many localized severely burned areas while in site 2 the burn was light. These differences make it difficult to compare the effect of burning in the two sites.

The soil physical properties did not show major changes induced by the burn. Changes in soil temperatures, soil penetration indices and infiltration rates might have been better reflected if more intensive measurements had been taken. The slight changes of the soil physical properties reported are not expected to trigger immediate wide scale changes in the vegetation.

The complexity of factors involved in the changes of the chemical properties of soil make it exceptionally difficult to interpret. Besides the original highly significant differences between the two sites and some of the significant differences between the two experimental blocks within the same site, the significant changes between the before and after burning samples add to the complexity of the interpretation of these changes. The "before burning" soil samples were collected around mid-May just after the snow melted while the after burning samples were collected at the beginning of the summer when some biological activities were much more active in the soil. It can be pointed out that perhaps the use of other sampling methods which might account for some of the biological changes could make it possible to detect the burning effect more accurately. However, it can be concluded that the magnitude of the changes due to biological reasons were greater than the changes due to the burning effect. The theoretical calculation of the expected changes in some of the soil nutrients substantiated the above findings about the minor nature of the change in nutrients due to the burn. That was mainly because of the limited fuel consumed by the burn on both sites which can hardly contribute to any considerable change in the chemical properties of the soil.

Burning resulted in a considerable reduction of the basal cover of most of the vegetation. The reduction is mainly attributed to the direct damage caused by the fire. The differences between the burned and unburned blocks decreased as the season advanced.

The measurement of individual species show that the basal cover of _Festuca idahoensis_ was significantly lower while that of _Agropyron trachycaulum_ was significantly higher in the burned than the unburned blocks. This points out that burning sites of dominant _Festuca idahoensis_ might not bring favorable effects.

The estimated 35% mortality of big sagebrush shows that no considerable control of big sagebrush was achieved by the burn and that the planning of another burn might be necessary.

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APPENDIX

Appendix Table 1. Species of plants occurring in site 1.

Agropyron trachycaulum Malte.
Carex spp.
Danthonia unispicata (Thurb)
Festuca idahoensis Elmer
Poa alpina L.
Stipa viridula Trin.

Achillea millefolium L.
Agoseris glauca (Pursh)
Antennaria rosea
Dodecatheon pauciflorum (Durand) Greene, Pitt.
Fragaria virginiana Duchense.
Geum triflorum Pursh.
Lupinus leucophyllus Dougl.
Phlox caespitosa Nutt.
Potentilla gracilis Dougl.
Taraxacum officinale Weber.

Artemisia tridentata Nutt.
Potentilla fruticosa

Appendix Table 2. Species of plants occurring in site 2.

Agropyron trachycaulum Malte.
Agrostis alba
Bromus marginatus Shear.
Carex spp.
Danthonia unispicata (Thurb)
Festuca idahoensis Elmer.
Poa alpina L.
Stipa viridula Trin.

Phleum pratensis L.

Achillea millefolium L.
Agoseris glauca (Pursh)
Antennaria rosea Greene, Pitt.
Aster scopulorum Gray.
Fragaria virginiana Duchense.
Geranium viscossissimum (Tydb)
Geum triflorum Pursh.
Lupinus leucophyllus Dougl.
Myosotis sylvatica Hoffm.
Potentilla gracilis Dougl.
Taraxacum officinale Weber.

Artemisia tridentata Nutt.

Appendix Table 3. Soil chemical properties of the unburned and burned blocks prior to burning, site 1, at the 0-2 cm, 8-10 cm and 18-20 cm depths (three replicates at each depth).

Depth in cm		No. of Samples	pH	PPM P	PPM K	PPM NO_3-N	milli-mohs Salts	% O.M.	Milliequivalent/100g Ca	Milliequivalent/100g Mg	Milliequivalent/100g Na
0 - 2	Unb.	1-1	5.9	57	845	1.0	2.2	12.19	23.00	4.26	.67
		1-2	6.1	54	825	0.5	1.8	12.26	23.00	4.26	.54
		1-3	6.0	57	765	1.0	1.6	10.80	21.00	3.44	.30
	B	2-1	6.1	37	875	1.0	2.0	13.40	21.00	4.43	.64
		2-2	6.1	48	875	1.0	1.4	6.07	19.00	4.51	.54
		2-3	6.0	43	745	0.5	1.8	5.97	18.60	3.94	.51
8 - 10	Unb.	1-1	6.3	43	665	0.0	.8	5.00	13.40	2.71	.48
		1-2	6.1	40	585	0.0	1.0	4.90	12.20	2.30	.48
		1-3	6.2	37	655	0.0	.9	4.70	13.80	2.71	.54
	B	2-1	6.3	31	695	0.0	.8	4.90	13.80	3.48	.69
		2-2	6.2	15	665	0.0	.8	4.30	13.40	3.48	.67
		2-3	6.3	18	625	0.0	.8	4.50	13.00	3.48	.72
18 - 20	Unb.	1-1	6.3	25	555	0.0	.8	4.20	12.20	2.59	.54
		1-2	6.4	40	605	0.0	.8	4.10	12.00	2.71	.54
		1-3	6.5	28	595	0.0	.8	4.30	12.20	2.71	.59
	B	2-1	8.4	8	435	0.0	.6	3.30	12.20	4.10	.64
		2-2	6.3	5	645	0.0	.8	3.20	12.20	3.77	.72
		2-3	6.4	8	515	0.0	.7	3.30	12.60	4.26	.76

Appendix Table 4. Soil chemical properties of the unburned and burned blocks following burning, site 1, at the 0-2 cm, 8-10 cm and 18-20 cm depths (three replicates at each depth).

Depth in cm		No. of Samples	pH	PPM P	PPM K	PPM NO_3-N	millimohs Salts	% O.M.	Milliequivalent/100g Ca	Mg	Na
0 - 2	Unb.	1-1	6.0	51	745	1.5	0.8	5.60	19.40	3.48	.87
		1-2	6.0	60	695	2.0	0.8	5.90	20.20	3.20	.87
		1-3	6.1	57	705	2.0	0.6	5.90	19.40	3.03	.76
	B	2-1	6.5	54	945	3.3	1.0	6.00	20.20	4.10	.91
		2-2	6.3	43	745	2.5	0.7	5.90	23.00	4.10	.85
		2-3	6.3	51	855	2.5	0.9	6.00	22.60	3.94	.91
8 - 10	Unb.	1-1	6.2	28	575	0.0	0.6	4.60	14.60	2.30	.85
		1-2	6.1	37	605	0.5	0.5	4.20	15.40	1.80	.80
		1-3	6.4	31	665	1.0	0.4	4.60	15.00	1.72	.80
	B	2-1	6.3	13	605	0.0	0.6	4.80	15.40	3.36	.91
		2-2	6.4	13	525	1.0	0.5	4.00	15.80	3.20	.87
		2-3	6.4	8	595	0.5	0.4	4.40	15.00	3.36	.85
18 - 20	Unb.	1-1	6.4	31	515	1.5	0.4	3.40	13.80	2.46	.76
		1-2	6.4	34	495	1.8	0.5	3.40	14.60	2.71	.85
		1-3	6.2	37	495	1.0	0.4	3.30	13.80	2.46	.91
	B	2-1	6.4	8	445	0.5	0.3	2.40	14.60	4.10	1.00
		2-2	6.6	8	395	0.5	0.3	2.40	15.00	4.26	1.00
		2-3	6.4	3	485	0.5	0.3	2.40	13.80	2.54	.87

Appendix Table 5. Soil chemical properties of the unburned and burned blocks prior to burning, site 2, at the 0-2 cm, 8-10 cm and 18-20 cm depths (three replicates at each depth).

Depth in cm		No. of Samples	pH	PPM			milli-mohs Salts	% O.M.	Milliequivalent/100g		
				P	K	NO_3-N			Ca	Mg	Na
0 - 2	Unb.	1-1	6.2	43	985	0.5	0.7	5.97	21.40	4.84	.48
		1-2	6.2	51	1020	0.5	0.6	6.13	21.00	4.67	.54
		1-3	6.1	57	1000	0.5	0.9	6.07	21.00	4.67	.44
	B	2-1	6.3	66	685	0.0	0.7	6.07	20.00	4.51	.51
		2-2	6.3	69	655	0.5	0.7	5.97	19.80	4.51	.51
		2-3	6.3	63	625	0.0	0.6	5.97	19.00	4.51	.64
8 - 10	Unb.	1-2	6.1	31	685	0.0	0.4	5.90	14.60	3.36	.51
		1-3	6.1	25	695	0.0	0.4	5.70	15.80	3.61	.51
	B.	2-1	6.1	43	975	0.0	0.4	5.40	14.60	3.36	.48
		2-2	6.1	40	945	0.0	0.4	5.60	15.00	3.36	.64
		2-3	6.3	40	965	0.0	0.4	5.40	14.60	3.20	.54
18 - 20	Unb.	1-1	6.1	31	485	0.0	0.3	3.80	15.00	2.87	.51
		1-2	6.0	31	535	0.0	0.4	3.80	12.20	3.20	.51
		1-3	6.2	25	555	0.0	0.5	4.30	13.80	3.61	.51
		2-1	--	48	955	0.0	--	4.00	11.40	3.03	.54
		2-2	6.1	25	675	0.0	0.5	5.90	15.40	3.48	.48

Appendix Table 6. Soil chemical properties of the unburned and burned blocks following burning, site 2, at the 0-2 cm, 8-10 cm and 18-20 cm depths (three replicates at each depth).

Depth in cm		No. of Samples	pH	PPM P	PPM K	PPM NO_3-N	milli-mohs Salts	% O.M.	Millequivalent/100g Ca	Millequivalent/100g Mg	Millequivalent/100g Na
0 - 2	Unb.	1-1	6.1	73	1012	1.0	1.0	5.90	33.80	6.97	.54
		1-2	6.2	63	815	2.5	0.7	5.90	21.00	3.61	.51
		1-3	6.2	63	915	1.5	0.7	5.80	20.60	3.48	.59
	B	2-1	6.3	89	975	2.5	0.8	5.80	17.40	3.03	.59
		2-2	6.4	89	1000	2.0	0.6	5.80	18.20	3.20	.59
		2-3	6.3	89	965	2.0	0.7	5.90	21.00	3.48	.72
8 - 10	Unb.	1-1	6.0	48	595	1.0	0.4	5.30	14.60	2.46	.44
		1-2	6.0	31	665	1.5	0.4	5.70	14.60	2.46	.51
		1-3	6.0	34	785	1.5	0.4	5.80	16.20	2.71	.51
	B	2-1	6.0	60	975	1.0	0.7	5.20	15.80	2.71	.76
		2-2	6.1	51	855	0.5	0.4	5.20	15.00	2.46	.76
		2-3	6.1	51	965	2.5	0.5	5.70	15.00	2.46	.54
18 - 20	Unb.	1-1	6.1	40	445	2.0	0.3	3.60	12.60	2.30	.51
		1-2	6.0	37	475	1.5	0.3	3.70	10.20	1.80	.44
		1-3	5.9	34	605	2.0	0.4	3.80	12.60	2.46	.54
	B	2-1	5.9	57	815	0.5	0.4	3.10	14.20	2.13	.80
		2-2	6.0	66	895	1.0	0.4	4.40	13.00	2.13	.87
		2-3	5.9	51	845	1.0	0.4	4.40	12.60	2.13	.59

Appendix Table 7. Statistical analyses of the soil chemical properties.

Elements	Sites	Treat- ment	Time[1/]	Depth[2/]	Site X Treat	Site X Time	Site X Depth	Treat X Time	Treat X Depth	Time X Depth
Acidity "pH"	**	**	**	n.s.	n.s.	n.s.	**	n.s.	*	n.s.
Phosphorus	**	n.s.	**	**	**	**	n.s.	n.s.	*	n.s.
Potassium	**	**	n.s.	**	*	n.s.	n.s.	n.s.	*	n.s.
Salts	**	n.s.	**	**	n.s.	**	**	n.s.	n.s.	**
Organic Matter	**	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	*	**
Calcium	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Magnesium	n.s.	**	*	**	**	**	**	n.s.	*	n.s.
Sodium	**	n.s.	n.s.	n.s.	n.s.	**	n.s.	**	n.s.	*
Nitrates	n.s.	n.s.	*	**	n.s.	**	**	n.s.	*	n.s.

1/ Time - before and after burning
2/ Depth - 0-2 cm, 8-10 cm, and 18-20 cm.
* Significant differences at the 0.05 probability level
** Significant differences at the 0.01 probability level.

Appendix Table 8 . Weekly averages of basal cover measurements of unburned and burned blocks following burning, site 1 (Values are averages of 20 - 4X5 dm plots).

Species		Dates of Observations												Average[2/]
		6/19	6/26	7/4	7/11	7/19	7/27	8/3	8/9	8/16	8/22	8/30	9/7	
		Sq dm per 20 sq dm plot												
Agropyron trachycaulum	Unb[1/]	0.0	0.0	0.0	0.0	0.10	0.33	0.13	0.10	0.60	0.33	0.10	0.10	0.15
	B	0.0	0.0	0.0	0.0	0.28	0.75	0.16	0.68	0.60	0.61	0.23	0.26	0.25
Carex Spp.	Unb.	0.05	0.0	0.13	0.20	0.0	0.88	0.50	0.85	1.00	0.75	0.70	0.78	0.49
	B	0.0	0.0	0.08	0.03	0.10	0.30	1.00	0.81	0.48	0.51	0.70	0.36	0.31
Danthonia unispicata	Unb.	3.48	1.85	2.10	2.80	1.53	2.83	2.85	2.78	2.68	3.48	1.78	1.80	2.49
	B	2.28	1.60	3.38	2.95	2.08	2.25	3.53	3.03	2.93	3.10	2.20	3.10	2.70
Festuca idahoensis	Unb.	0.10	0.48	0.38	0.25	0.75	0.28	0.23	0.05	0.28	0.23	0.23	0.0	0.27
	B	0.18	0.18	0.20	0.03	0.38	0.13	0.08	0.13	0.10	0.0	0.05	0.10	0.13
Poa alpina	Unb.	1.53	1.33	0.60	0.38	0.73	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.40
	B	0.28	0.30	0.28	0.18	0.20	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.10
Stipa viridula	Unb.	0.20	0.20	0.25	0.15	0.30	0.05	0.15	0.20	0.28	0.15	0.0	0.08	0.16
	B	0.02	0.43	0.20	0.18	0.48	0.0	0.0	0.10	0.10	0.05	0.0	0.0	0.15
Total grasses and sedges	Unb.	5.53	3.85	3.45	3.78	3.45	4.39	3.93	3.98	4.89	4.26	2.88	2.79	3.95
	B	2.74	2.50	4.09	3.27	3.50	3.22	4.80	4.71	4.20	4.26	3.11	3.77	3.65

1/ Unb. - Unburned block; B - Burned block.

2/ The averages of the weekly observations for each species are calculated from the original data and rounded to the second decimal.

Appendix Table 8 (continued)

Species		Dates of Observations												Average[2/]
		6/19	6/26	7/4	7/11	7/19	7/27	8/3	8/9	8/16	8/22	8/30	9/7	
		Sq dm per 20 sq dm plot												
Achillea	Unb.	0.05	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
millefolium	B	0.0	0.0	0.03	0.0	0.0	0.03	0.03	0.05	0.0	0.0	0.05	0.0	0.01
Agoseris	Unb.	0.70	0.25	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.09
glauca	B	0.50	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.04
Antennaria	Unb.	0.0	0.0	0.0	0.0	0.0	0.43	1.10	0.45	0.25	0.50	0.43	1.20	0.37
rosea	B	0.0	0.0	0.0	0.0	0.0	0.60	0.23	0.45	0.65	0.38	0.63	0.45	0.30
Dodecatheon	Unb.	0.23	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.02
pauciflorum	B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fragaria	Unb.	0.0	0.20	0.40	0.13	0.25	0.18	0.10	0.0	0.0	0.15	0.20	0.05	0.13
virginiana	B	0.0	0.0	0.50	0.23	0.25	0.35	0.30	0.0	0.0	0.50	0.10	0.18	0.20
Geum	Unb.	1.98	1.60	1.25	1.48	1.88	1.50	2.10	1.78	2.40	0.88	1.68	1.68	1.70
triflorum	B	0.48	0.38	0.63	0.48	0.23	0.65	2.03	1.30	1.70	1.0	0.80	1.03	0.90
Lupinus	Unb.	0.35	0.23	0.25	0.43	0.03	0.0	0.0	0.13	0.13	0.05	0.08	0.05	0.14
leucophyllus	B	0.43	0.10	0.48	0.53	0.33	0.0	0.0	0.0	0.13	0.0	0.0	0.0	0.17

Appendix Table 8 (continued)

Species		Dates of Observations												Average
		6/19	/26	7/4	7/11	7/19	7/27	8/3	8/9	8/16	8/22	8/30	9/7	
		Sq dm per 20 sq dm plot												
Phlox caespitosa	Unb.	0.35	1.25	0.40	0.68	0.60	0.35	0.88	0.08	0.18	0.08	0.0	0.20	0.21
	B.	0.25	0.13	0.78	0.28	0.30	0.35	0.30	0.10	0.0	0.0	0.05	0.0	0.42
Potentilla gracilis	Unb.	0.08	0.05	0.23	0.25	0.08	0.15	0.25	0.15	0.28	0.15	0.13	0.05	0.15
	B	0.08	0.10	0.20	0.20	0.25	0.13	0.05	0.25	0.60	0.10	0.30	0.0	0.19
Taraxicum officinale	Unb.	0.20	0.10	0.05	0.03	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.0	0.03
	B	0.25	0.43	1.25	0.70	0.0	0.18	0.03	0.0	0.0	0.0	0.0	0.0	0.21
Miscellaneous forbs	Unb.	1.60	1.97	1.18	0.73	1.16	0.88	0.59	0.28	0.47	0.46	0.37	0.48	0.84
	B	0.80	0.93	1.05	0.45	0.85	0.80	0.25	0.23	0.35	0.20	0.38	0.20	0.54
Total forbs	Unb.	5.53	5.68	3.73	3.70	3.95	3.45	4.98	2.85	3.65	2.20	2.95	3.68	3.90
	B	2.78	2.08	4.90	2.90	2.20	3.08	3.20	2.38	3.43	2.18	2.35	1.85	2.78
Artemisia tridentata	Unb.	2.58	2.15	1.68	1.55	2.43	1.10	2.45	2.88	2.98	1.60	1.90	1.90	2.05
	B	0.0	0.0	0.08	3.35	0.05	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.29
Potentilla fruticosa	Unb.	0.49	0.14	0.32	1.82	0.42	0.70	0.30	0.39	0.91	0.50	0.55	1.22	0.65
	B	0.0	0.0	0.13	0.13	0.08	0.13	0.90	0.20	0.05	0.0	0.0	0.15	0.15

Appendix Table 8 (continued)

Species		Dates of Observations												Average
		6/19	6/26	7/4	7/11	7/19	7/27	8/3	8/9	8/16	8/22	8/30	9/7	
		Sq dm per 20 sq dm plot												
Dead *Artemisia tridentata*	Unb.	0.75	1.18	0.70	0.60	0.95	1.00	1.85	1.85	2.10	1.28	1.58	1.53	1.28
	B	2.05	1.83	1.83	1.40	3.75	1.93	2.30	1.78	2.10	1.93	1.45	0.75	1.94
Dead *Potentilla fruticosa*	Unb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.13	0.0	0.0	0.01
	B	0.0	0.0	0.0	0.13	0.20	0.10	0.0	0.25	0.15	0.0	0.0	0.0	0.07
Ash	Unb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	B	2.71	3.45	2.67	4.28	0.69	1.98	2.45	3.13	2.69	2.45	1.38	1.40	2.46
Bare soil	Unb.	0.50	0.90	0.05	0.83	0.95	0.53	0.58	0.18	0.68	0.55	0.63	1.08	0.62
	B	0.43	0.30	0.08	0.15	0.20	0.83	0.83	0.60	0.70	0.78	0.65	0.30	0.49
Lichen	Unb.	0.20	0.20	0.86	0.0	0.0	0.39	1.50	0.56	0.20	0.71	0.55	0.30	0.44
	B	1.33	2.23	3.15	0.0	0.0	1.15	1.00	0.43	1.08	0.85	0.90	0.83	1.06
Litter	Unb.	7.60	9.18	10.70	11.58	11.55	11.33	9.80	12.40	11.15	11.70	13.10	12.13	10.99
	B	10.46	9.33	6.41	8.86	13.31	9.81	7.66	8.86	7.70	8.84	11.46	11.81	9.54
Rock	Unb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	B	0.08	0.0	0.05	0.48	0.15	0.20	0.13	0.08	0.20	0.05	0.03	0.0	0.12

Appendix Table 9. Weekly averages of basal cover measurements of unburned and burned blocks following burning, site 2 (Values are averages of 20 - 4X5 dm plots).

Species		Dates of Observations												Average[2/]
		6/21	6/27	7/4	7/13	7/19	7/28	8/3	8/8	8/17	8/22	8/29	9/7	
		Sq dm per 20 sq dm plot												
Agropyron trachycaulum	Unb[1/]	0.0	0.0	0.0	0.0	0.08	0.38	0.08	0.20	0.10	0.08	0.10	0.15	0.11
	B	0.0	0.0	0.0	0.0	0.08	0.43	0.23	0.50	0.18	0.48	0.25	0.18	0.19
Agrostis alba	Unb.	0.0	0.0	0.0	0.0	0.0	0.63	0.18	0.30	0.46	0.33	0.20	0.0	0.18
	B	0.0	0.0	0.0	0.0	0.0	0.08	0.20	0.23	0.25	0.20	0.0	0.0	0.08
Bromus marginatus	Unb.	0.45	0.79	0.65	1.10	0.66	0.68	0.50	0.94	0.99	0.55	0.74	0.45	0.72
	B	0.15	0.28	0.50	0.80	0.53	0.80	0.43	0.65	0.65	0.43	0.43	0.98	0.55
Carex spp.	Unb.	0.05	0.10	0.15	0.0	0.05	0.33	0.14	0.70	1.17	1.03	0.89	0.86	0.44
	B	0.05	0.05	0.05	0.08	0.03	0.10	0.33	0.73	0.43	0.65	0.80	1.75	0.42
Danthonia unispicata	Unb.	0.0	0.0	0.0	0.0	0.0	0.0	0.08	0.0	0.10	0.0	0.08	0.03	0.03
	B	0.03	0.0	0.03	0.0	0.0	0.20	0.0	0.0	0.15	0.0	0.08	0.13	0.05
Festuca idahoensis	Unb.	1.33	0.63	0.63	0.80	0.90	0.40	0.63	0.55	0.53	0.43	0.88	0.55	0.69
	B	0.60	0.53	0.70	0.58	0.70	0.88	0.63	0.73	0.63	0.73	0.98	0.40	0.66
Poa alpina	Unb.	0.40	0.10	0.25	0.20	0.43	0.0	0.03	0.0	0.0	0.0	0.0	0.0	0.12
	B	0.33	0.10	0.10	0.10	0.55	0.0	0.18	0.0	0.0	0.20	0.0	0.0	0.12

1/ Unb. - Unburned block; B - Burned block.

2/ The averages of the weekly observations for each species are calculated from the original data and rounded to the second decimal.

Appendix Table 9 (Continued)

Species		6/21	6/27	7/4	7/13	7/19	7/28	8/3	8/8	8/17	8/22	8/29	9/7	Average[2/]
		Dates of Observations												
		Sq dm per 20 sq dm plot												
Stipa viridula	Unb.	0.44	0.44	0.14	0.24	0.28	0.06	0.54	0.19	0.34	0.49	0.28	0.05	0.30
	B	0.50	0.55	0.25	0.20	0.15	0.28	0.33	0.25	0.24	0.38	0.20	0.23	0.30
Total grasses and sedges	Unb.	2.64	1.93	1.79	2.19	2.48	2.90	2.15	3.00	3.16	2.79	2.96	2.14	2.52
	B	1.65	1.40	1.63	1.78	2.03	2.78	2.30	3.08	2.53	3.05	2.73	3.65	2.38
Achillea millefolium	Unb.	0.15	0.13	0.23	0.10	0.05	0.05	0.08	0.43	0.03	0.15	0.10	0.03	0.14
	B	0.0	0.40	0.55	0.40	0.18	0.45	0.30	0.55	0.98	0.18	0.25	0.05	0.37
Agoseris glauca	Unb.	0.93	0.83	0.45	0.53	0.53	0.0	0.0	0.13	0.0	0.0	0.25	0.13	0.32
	B	0.98	0.68	0.55	0.75	0.53	0.38	0.15	0.0	0.0	0.0	0.13	0.0	0.34
Antennaria rosea	Unb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.20	0.68	0.07
	B	0.0	0.0	0.0	0.0	0.0	0.0	0.23	0.40	0.0	0.30	0.25	0.60	0.15
Aster scopulorum	Unb.	0.0	0.0	0.0	0.0	0.0	0.90	0.95	0.21	0.45	0.13	0.25	0.10	0.24
	B	0.0	0.0	0.0	0.0	0.0	0.63	0.63	1.25	1.10	0.53	0.53	0.48	0.43
Fragaria virginiana	Unb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.05	0.05	0.03	0.01
	B	0.0	0.0	0.0	0.13	0.25	0.0	0.0	0.0	0.0	0.0	0.05	0.0	0.04

Appendix Table 9 (Continued)

Species		6/21	6/27	7/4	7/13	7/19	7/28	8/3	8/8	8/17	8/22	8/29	9/7	Average
		Dates of Observations												
		Sq dm per 20 sq dm plot												
Geranium viscississimum	Unb.	0.0	2.05	1.48	1.03	0.85	0.88	0.18	0.35	0.30	0.18	0.13	0.03	0.62
	B	0.0	1.13	1.03	0.55	0.98	0.50	0.75	0.45	0.15	0.20	0.20	0.10	0.49
Geum triflorum	Unb.	0.13	0.33	0.23	0.63	0.25	0.25	0.33	0.33	0.25	0.18	0.35	0.33	0.29
	B.	0.05	0.13	0.30	0.30	0.02	0.45	0.30	0.0	0.13	0.33	0.15	0.28	0.20
Lupinus leucophyllus	Unb.	0.18	0.15	0.23	0.13	0.18	0.10	0.60	0.30	0.33	0.75	0.38	0.33	0.32
	B	0.0	0.15	0.45	0.38	0.65	0.25	0.33	0.50	0.48	0.38	0.25	0.33	0.34
Myosotis sylvatica	Unb.	0.18	1.05	0.15	0.25	0.13	0.0	0.30	0.43	0.20	0.08	0.38	0.20	0.28
	B	0.05	0.20	0.03	0.25	0.20	0.53	0.33	0.40	0.25	0.43	0.45	0.15	0.26
Potentilla gracilis	Unb.	1.25	0.0	0.85	1.28	1.45	1.48	1.38	1.23	2.15	1.08	0.93	0.83	1.16
	B	0.70	1.50	1.30	1.53	1.23	1.60	1.80	1.40	1.48	1.50	1.60	1.43	1.41
Taraxicum officinale	Unb.	0.48	0.93	0.95	0.45	0.68	1.28	1.00	1.05	0.50	0.50	0.60	0.38	0.73
	B	0.67	0.87	0.65	0.48	1.04	0.76	0.76	0.38	0.38	0.50	0.37	0.20	0.56
Miscellaneous forbs	Unb.	1.60	1.73	1.15	1.03	0.70	0.35	0.71	1.08	0.55	0.33	0.30	0.68	0.84
	B	1.58	1.08	0.90	0.78	1.25	0.20	0.70	0.55	0.63	0.58	0.40	0.28	0.74

Appendix Table 9 (Continued)

Species		Dates of Observations												Average
		6/21	6/27	7/4	7/13	7/19	7/28	8/3	8/8	8/17	8/22	8/29	9/7	
		Sq dm per 20 sq dm plot												
Total forbs	Unb.	4.88	7.65	5.70	5.05	5.28	5.20	5.63	5.63	4.78	3.55	3.85	3.70	5.06
	B	3.50	6.15	5.73	5.58	6.34	5.68	6.33	5.78	5.80	4.95	4.68	3.90	5.36
Artemisia tridentata	Unb.	1.70	0.98	1.03	1.08	2.33	0.40	1.25	1.85	1.68	2.10	1.20	1.88	1.46
	B	0.13	0.0	0.0	0.03	0.10	0.03	0.0	0.0	0.0	0.35	0.08	0.13	0.08
Dead *Artemisia tridentata*	Unb.	0.80	0.85	1.18	2.68	1.70	1.25	0.63	1.65	3.10	0.95	2.08	1.05	1.49
	B	2.35	0.83	0.23	1.13	1.80	1.45	2.38	1.73	1.10	2.30	1.68	1.58	1.54
Litter	Unb.	8.45	8.65	11.05	11.80	11.10	11.50	10.25	9.50	9.28	11.13	12.18	12.73	10.63
	B	8.15	8.15	9.75	9.05	8.83	9.13	8.60	7.55	7.88	8.40	8.33	9.38	8.61
Lichen	Unb.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.15	0.08	0.02
	B	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bare soil	Unb.	3.68	1.58	0.95	0.88	1.15	0.10	1.53	1.83	2.13	2.85	0.88	0.83	1.54
	B	6.35	4.33	2.88	3.68	2.25	2.48	2.78	3.50	3.95	3.15	4.10	2.88	3.56
Rock	Unb.	0.03	0.15	0.0	0.0	0.20	0.0	0.50	0.0	0.0	0.0	0.03	0.0	0.08
	B	0.0	0.0	0.13	0.0	0.0	0.0	0.0	0.0	0.10	0.0	0.0	0.08	0.03

Appendix A . Theoretical calculations of the different elements expected to be added to the soil as a result of burning on the study area.

Site 1:

Average wt. of mulch = 2.8 g/sq. dm/one acre = 4200 sq. meter
= 4200 X 10 X 10 sq dm

.:Mulch in one acre = 2.8 X 4200 X 10 X 10 g/acre

Area burnt in site 1 = 48%

Mulch actually burnt in site 1 is not 100% burnt (Look at measurement of burn classes).

.:Mulch actually burnt = 42% (class 1) + ½ X 24% (Class 2) –

$$= \frac{52}{100} \times 48 = 25\%$$

.:Amount of mulch actually burnt

$$= \frac{25 \times 4200 \times 10 \times 10 \times 2.8}{100} = 2940\ 00 \text{g/acre}$$

$$\frac{294000}{1000} = 294 \text{ Kg/acre}$$

.:Mulch burnt/acre in lb = 294 X 2.2

$$294 \times 2.2 = \underline{646.8} \text{ lb/acre}$$

$$\simeq \underline{650} \text{ lb}$$

Amount of Ca in prairie hay mature & weathered = 0.41%

.:Amount of Ca added to soil as result of burning

$$= \frac{650 \times 0.41}{100} = 2.665 \text{ lb/acre}$$

$$= \frac{2.66}{2{,}000{,}000} \simeq \underline{\underline{2}} \text{ ppm } \underline{1/}$$

1/ Average values in the top 15 cm of the soil.

Amount of phosphorus in mulch - 0.03%

$$= \frac{650 \times 0.03}{100} = 1950$$

$$= .19$$

ppm of P added $\simeq$ .09 ppm

$$K = \frac{650 \times 0.73}{100} = 4.745 \text{ lb/acre}$$

$$= 2.6 \text{ ppm}$$

Amount of Mg. in mulch = 0.26%

.:Amount added to soil due to burning

$$= \frac{650 \times 0.26}{100} = 1.69 \text{ lb.}$$

.:Amount added in ppm $\simeq$ 1 ppm

Site 2:

Average wt. of mulch = 12.4 g/sq dm

.:Mulch in one acre = 12.4 X 4200 X 10 X 10 g/acre

Area in site 2 = = 58%

Class 1 burn = 5%

Class 2 burn = 36%

.:Total %age of mulch turned to ash = $5 + 18 = \frac{23 \times 58}{100} = 13.34\%$

Amount of mulch actually burnt

$= \frac{12.4 \times 4200 \times 10 \times 10 \times 13}{100} = 6728.4000$ g/acre

= 672840 Kg/acre

= 673 X 2.2 = 1480.6 lb/acre

Amount of Ca in mulch = .41%

.:Amount of Ca added to soil due to burning

= 1480 X .41 = 6.0680 lb/acre

.:Ca added - ppm = 3 ppm 1/

Amount of phosphorus in mulch = .03%

Amount of phosphorus added after burning

$= \frac{1480 \times .03}{100} = .4440$ lb/acre

= .2 ppm

Amount of K (potassium - mulch = .73

Amount of K added to the soil after burning

$= \frac{1480 \times .73}{100} = 10.8$ lb/acre = 5 ppm

1/ Average values in the top 15 cm of the soil.

Amount of Mg in mulch = .26%

Amount of Mg added to the soil after burning

$$= \frac{1480 \times .26}{100} = 3.84 \text{ lb/acre}$$

$$= \underline{\underline{2}} \text{ ppm}$$