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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Date 8. 20. 1974

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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

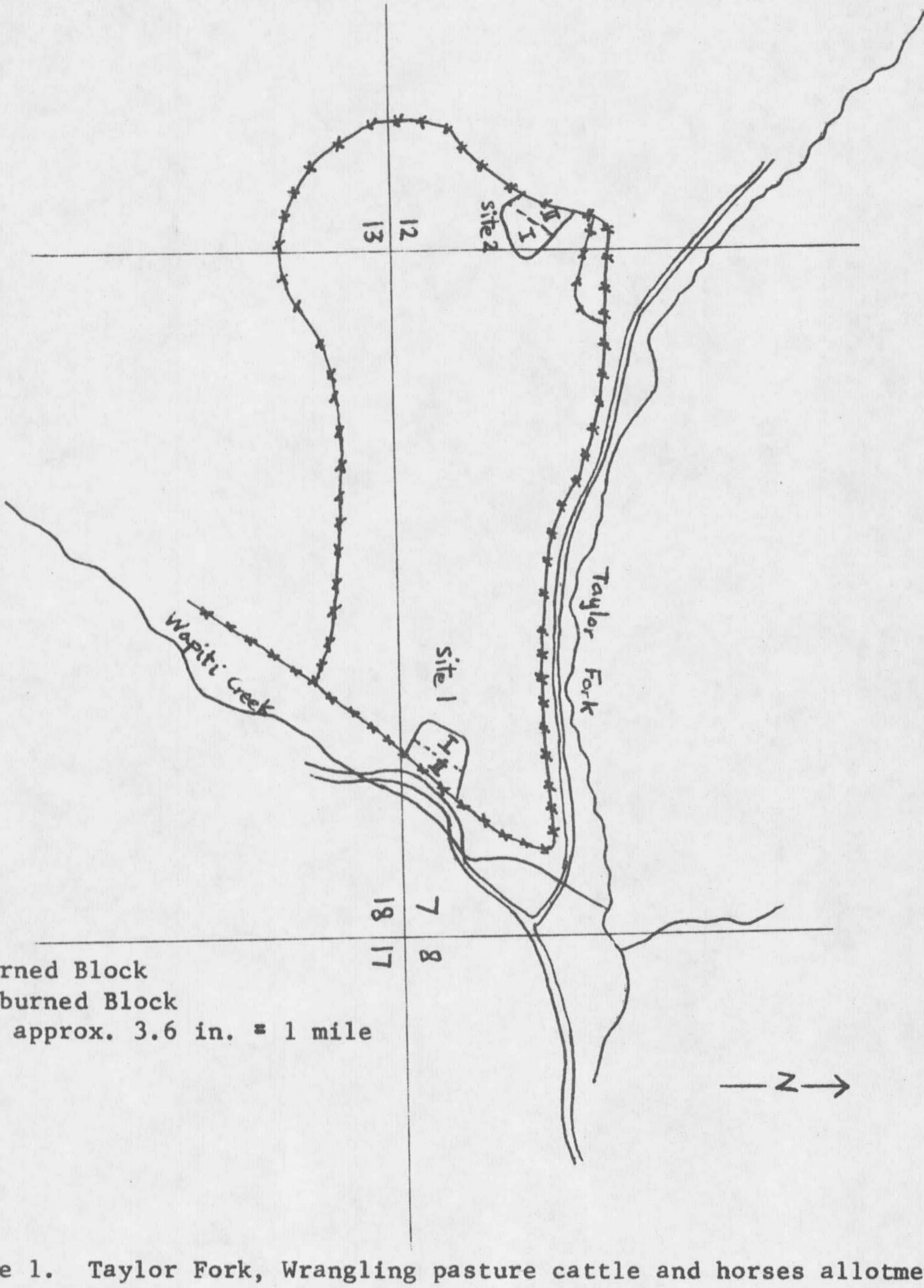
The area under study is a part of Taylor Fork cattle and horses allotment, Gallatin National Forest. It is located on Taylor Fork of the Gallatin River, immediately southwest of the Taylor Fork and Wapiti Creek junction (Figure 1).

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.