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Effects of Prescribed Burning at Different Fuel Moisture Levels on Vegetation and Soils of Grasslands in Wind Cave National Park

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EFFECTS OF PRESCRIBED BURNING AT DIFFERENT FUEL MOISTURE LEVELS ON VEGETATION AND SOILS OF GRASSLANDS IN WIND CAVE NATIONAL PARK

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BY

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EFFECTS OF PRESCRIBED BURNING AT DIFFERENT FUEL MOISTURE LEVELS ON VEGETATION AND SOILS OF GRASSLANDS IN WIND CAVE NATIONAL PARK

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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INTRODUCTION

Prescribed burning has had a short history of use as a management tool for grassland ecosystems. A paucity of information is available concerning the effects of burning grassland vegetation at different fuel moisture levels.

There is ample documentation of the varied effects of burning on the grassland vegetation of humid regions as affected by season of occurrence, successional stage of the ecosystem, kind and density of vegetation, and phenological stage of the dominant vegetation. There is also abundant information on the effect of fire on forest ecosystems and on some grasslands invaded by woody plants, especially in the southwestern United States. In forest-prairie transition zones, forests tend to occupy rough topography and grasslands more gently rolling topography. Soil and climate are determinants in the occurrence of grasslands, but fires have maintained the spatial distribution and extent of grasslands for milleniums. Recent control of fires by man has permitted forest encroachment into many grassland ecosystems (Gartner and Thompson, 1973; Lovass, 1976). Relatively little information is available on the effects of burning on grassland vegetation in semi-arid and arid regions.

Researchers have determined that season of prescribed burning has a marked effect on community composition. Yield and vigor have been found to be affected; the extent and severity of these effects are determined by stage of phenological maturity for the individual components of the community at the time of ignition. Fuel moisture and soil moisture appear to be critical factors in the response of vegetative communities to prescribed burning. Information specific to South Dakota climatic regimes and plant communities is needed for proper resource management.

The objectives of this study were to examine the effects of prescribed burning at varied fuel and surface soil moisture levels on selected plant communities. Vegetative composition, yield and changes in soil chemistry were selected as criteria to evaluate the influence of the variables in the experimental design. Quantification of these aforementioned variables is needed for the formulation of realistic, ecologically effective burning procedures.

LOCATION AND DESCRIPTION OF STUDY AREA

The research was conducted at Wind Cave National Park (WCNP) in the southeastern portion of the Black Hills. WCNP is located approximately 50 air miles south of Rapid City, and midway between Custer and Hot Springs, South Dakota. The main study area was located on the west facing slope of Gobbler's Ridge (Figure 1). A second study area was established at Windy Point in the spring of 1979, which is also shown in Figure 1.

Gobbler's Ridge is in the NW ¼ Sec 24, T 6 S, R 6 E, and Windy Point is in the SE ¼ Sec 3, T 6 S, R 5 E, Custer County, South Dakota. The slope on Gobbler's Ridge had 114.5 m of relief, while the Windy Point study area was nearly level. The Gobbler's Ridge study area was surveyed with a K&E[1/] transit to facilitate accurate topographic representation and plot location (Figure 2). Soil profile descriptions were prepared to record soil characteristics and genesis (Appendix B). Average annual precipitation at WCNP is approximately 46 cm (18 in), 70 percent falling between May 1 and September 30. Snow cover is usually sparse with frost free periods averaging 120 days (N.O.A.A., 1973).

The study areas selected encompassed two plant communities. The major community was dominated by little bluestem (*Schizachyrium scoparium*) and big bluestem (*Andropogon gerardi*)[2/] and is hereafter

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[1/] Use of any trade name is not intended as an endorsement by the author, South Dakota State University or the National Park Service.

[2/] Nomenclature follows Beetle (1970).

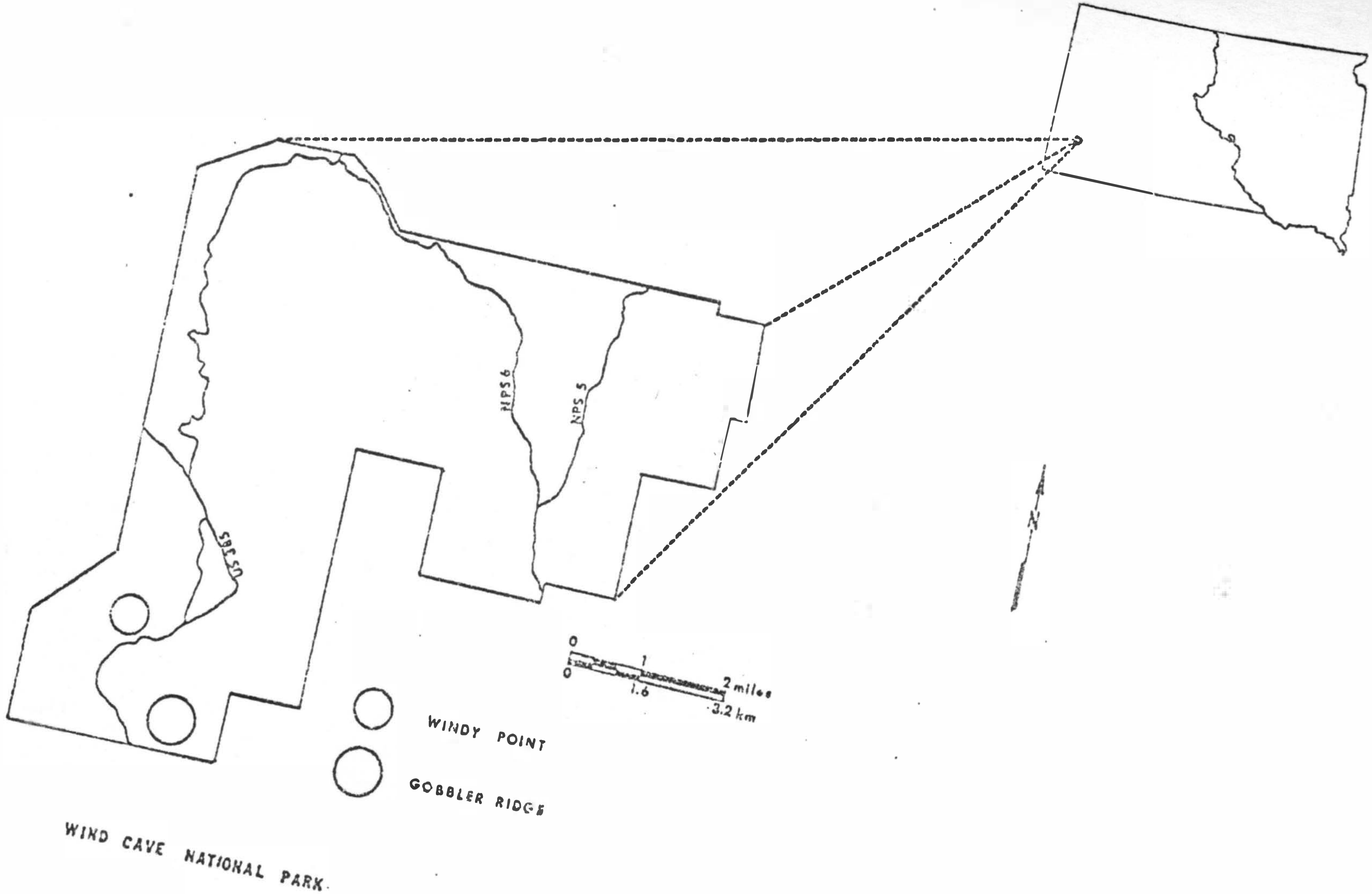
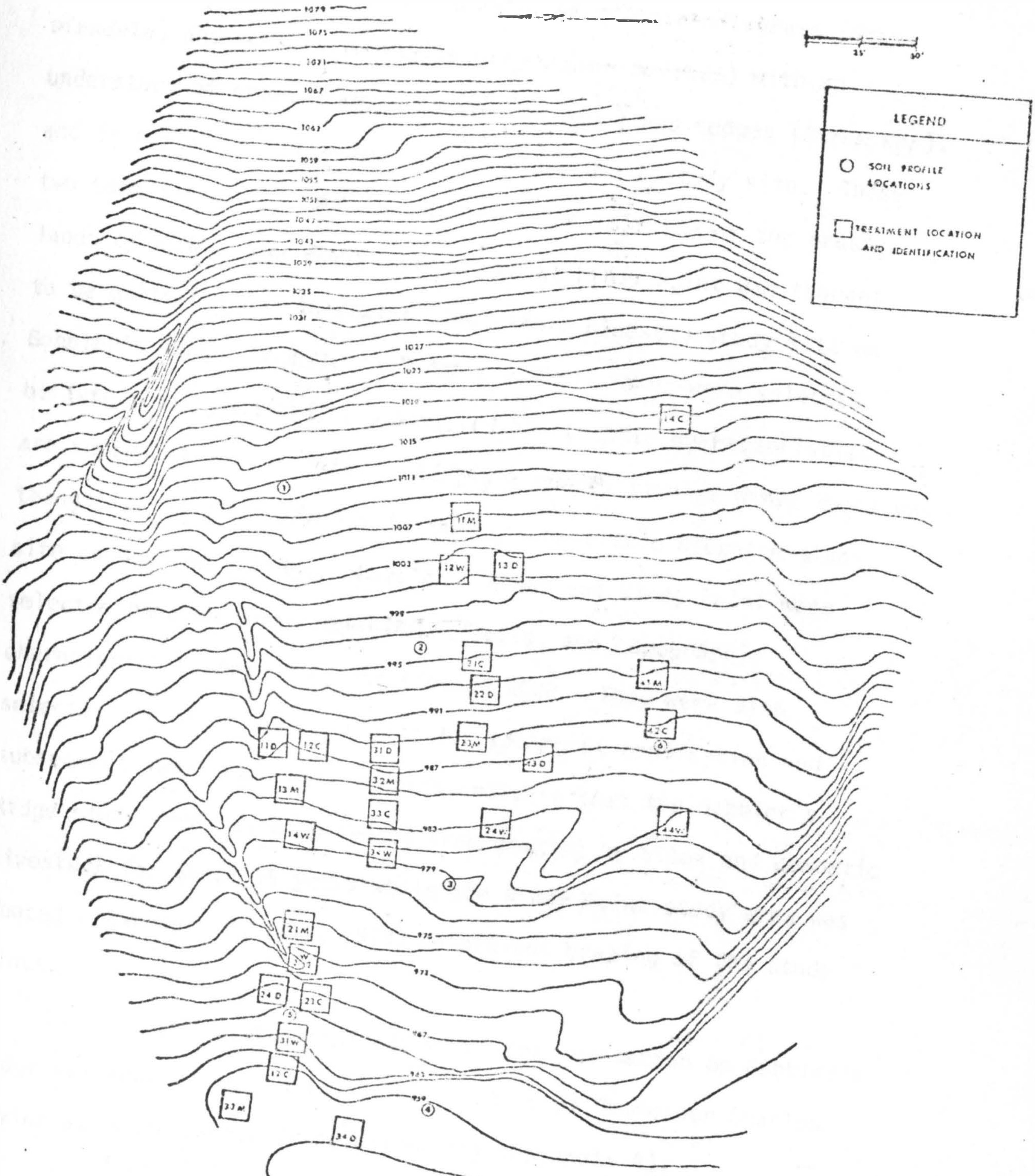


Figure 1. Location of study areas.


LEGEND
SOIL PROFILE LOCATIONS
TREATMENT LOCATION AND IDENTIFICATION
25'
50'
1079
1075
1071
1067
1063
1059
1055
1051
1047
1043
1039
1035
1031
1027
1023
1019
1015
1011
1007
1003
999
995
991
987
983
979
975
971
967
963
959
955
14C
11M
12W
13D
21C
22D
41M
42C
11D
12C
31D
23M
43D
32M
13M
33C
24W
44W
14W
34W
21M
24D
23C
31W
32C
33M
34D

designated as the Little Bluestem study site. The minor community was a mixed grass community dominated by green needlegrass (*Stipa virudula*) and western wheatgrass (*Agropyron smithii*) with an understory of grama grasses (*Bouteloua spp.*) and sedges (*Carex spp*), and is hereafter designated as the Mixed Grass study site. These two communities are representative of the majority of the grasslands of WCNP. The plant composition at Windy Point was thought to be quite similar to that of the Little Bluestem study site on Gobbler's Ridge. Gobbler's Ridge and Windy Point were selected because their vegetation, soils, and topographic characteristics are representative of WCNP. The plant composition at Windy Point was thought to be quite similar to that of the Little Bluestem study site on Gobbler's Ridge. Gobbler's Ridge and Windy Point were selected because their vegetation, soils, and topographic characteristics are representative of WCNP. They were also selected for their accessibility for treatment application and subsequent sampling. Park records indicate that the Gobbler's Ridge study area has been fenced from grazing by bison and domestic livestock for about 15 years while the Windy Point study area was fenced after burning (May, 1979) to prevent grazing of the study plots.

Identification and verification of the vegetation on Gobbler's Ridge was accomplished with the cooperation of Professor Charles Taylor at South Dakota State University (Appendix A).

REVIEW OF LITERATURE

Historical Use of Fire

Burning of vegetation by primitive cultures, either purposely or accidentally, is supported by archeological evidence (Hough, 1926). Nomadic pastoralists in lesser developed countries throughout the world continue to use fire as a means or providing more desirable grazing conditions.

Fires have been part of the environment in any area where there is enough organic material to burn and where conditions render the material easily combustible (Philips, 1962). It has been suggested that fires have been influential in shaping present-day patterns of vegetation (Philips, 1962). It is logical, historically, to use fire to manipulate ecosystems to man's benefit. A deterrent to this use has been that man has seen only the immediate and visual damage done by fires, whereas the beneficial effects have not been readily apparent and materialized only in subsequent growing seasons. However, man has been going through the slow process of changing his philosophy about fire from one of "totally harmful" to that of a "management tool".

Consideration of fire as an ecological factor capable of being manipulated has led to prescribed burning of vegetation in various ecosystems. Thomas Lotti (1971), of the Southeastern Forest Experimental Station defined prescribed burning as:

> "...the skillful application of fire to natural fuels under conditions of weather, fuel moisture, and soil moisture that will allow confinement of fire to a predetermined area and

> at the same time will produce the intensity of heat and rate of spread required to accomplish certain planned benefits to one or more objectives of silviculture, wildlife management, or grazing or hazard reduction."

Changing man's philosophy about fire has been difficult. However, more and more research evidence is becoming available in support of fire being ecologically beneficial. One of the early proponents of prescribed burning, Komarek (1962), made many far sighted observations. "Water content of fuel itself appears to contribute to the nature and characteristics of fire, with fires occurring whenever the fuel is dry enough to be combustible." Komarek felt that one of the most challenging areas of fire ecology was to define and devise measurements of fire in nature.

Vegetation Responses to Fire

Yields

Grasslands occur in regions which are climatically conducive to periodic widespread wildfires, most of which have been controlled by man in recent years. The control of wildfires has produced varied responses: stagnation of vegetative communities, heavy accumulations of mulch, a decrease in flower production of some grass species, invasion of woody species into grasslands together with an overall reduction in herbage yields.

In man's attempt to manipulate the environment for his benefit, prescribed burning of these unique grassland ecosystems has been observed to produce varied effects on vegetation, soil moisture and soil chemistry. Timing of prescribed burning has also proven to be of great importance in relation to effects produced in each unique climatic regime and grassland community.

The effects of prescribed burning on herbage yields are of major import, but they are controversial. An example of some of these effects has been reported in a study of two wildfires on short-grass and mixed grass prairies in western Kansas (McMurphy and Anderson, 1964). The authors noted that a spring wildfire during a long drought period was much more harmful to vegetation than a fall wildfire under the same conditions. Compared to unburned areas, burning at either time reduced basal cover and yields of desirable species while yields of broadleaf plants increased.

It was reported for bluestem prairies in the Kansas Flint Hills, that burning may cause severe reductions in yields in areas with precipitation less than 635 mm annually (Anderson, 1965). Herbage yields were lower on burned pastures than on unburned control areas, except in the case of late spring burns. Even though early and mid-spring burned areas showed a reduction in vegetation yields, yields on areas burned late in the spring were not significantly different from unburned control areas (Anderson, Smith and Owensby, 1970).

Botanical Composition

In addition to the effect on herbage yields, date of burning in relation to phenological stage of growth, may determine changes in species composition. Late-spring burning was found to reduce cool-season species and favor warm-season species on bluestem ranges (Anderson, Smith and Owensby, 1970). Percentage basal cover of big bluestem increased 1.5 to 2.5% with late-spring burning. Percent basal cover of little bluestem decreased with early and mid-spring burning. Indiangrass (*Sorghastrum nutans*) increased regardless of date of burning as did sideoats grama (*Bouteloua curtipendula*) and hairy grama (*Bouteloua hirsuta*). Buffalograss (*Buchloe dactyloides*) was reduced by early and late spring burns, but remained stable under mid-spring burning. Kentucky bluegrass (*Poa pratensis*) was markedly reduced by burning at any time. Sedges (*Carex spp.*) were highly susceptible to mid- and late-spring burns. Perennial forb yields were greatest in early spring and unburned areas. Shrubs, smooth sumac (*Rhus glabra*) and leadplant (*Amorpha canescens*), increased with mid- and late-spring burns. Little bluestem was reported to be more susceptible to injury when burned under dry conditions (Anderson, Smith and Owensby, 1970). In general, grasses characterized as increasers became more abundant on early and mid-spring burns, but remained the same under late-spring burning. Annual grasses were most prevalant in unburned pastures. First-season yields for a buffalograss - blue grama community were reduced 65% following an early-spring fire (Launchbaugh, 1964). Western wheatgrass was reduced 82% while various shortgrass species were reduced 48%. Second-season yields were reduced only 39%, 73% and 19% for the buffalo-blue grama mixture, western wheatgrass and shortgrasses. Herbage yields third-season after burning were not significantly different from the unburned areas.

Prescribed burning of mixed prairie in western South Dakota in late winter and early spring reduced Japanese brome *(Bromus japonicus)* both in yield and density. Yield and density of Western wheatgrass was generally increased by burning in late winter or early spring (Gartner et al, 1978).

Height and Reproduction

Factors affecting height increases and greater flowering have been speculated to be earlier growth due to warmer soil temperatures, less shading by mulch and greater nutrient availability (Dix and Butler, 1954). Big bluestem, little bluestem and Indiangrass showed a sharp increase in plant heights the first growing season following a fire with a return to normalcy the end of the second growing season in the prairies of Missouri (Kucera and Ehrenreich, 1962). Flowering was found to be two weeks earlier on burned areas than on unburned areas in Iowa (Aikman, 1955). Plants also developed faster and matured earlier on burned areas compared to the unburned areas (Ehrenreich and Aikman, 1963). Plants in the unburned areas of Iowa prairie grew faster, later in the growing season, and results showed no significant difference in total vegetation yield between burned and unburned areas. Part of the reason for these differences may be due to the removal of old litter cover from the plant crowns. Removal of crown litter may permit an early carbohydrate reserve buildup, thus permitting more flower production (Curtis and Patch, 1950).

Plant height was not affected by the addition of fertilizer in the ash following burning of grasslands in Wisconsin (Curtis and Patch, 1950). However, added fertilizer did result in stimulation of flower stalk production during the first growing season in prairie dropseed (*Sporobolus heterolepsis*) (25x), big bluestem (6x) and little bluestem (3x) (Dix and Butler, 1954).

Grass fires appeared to have little effect on seed survival when seeds were at or in the mineral soil surface (Bentley and Fenner, 1958). However, those located on seed stalks and in the litter were destroyed. Dry seeds were killed by exposure to 121 to 149^{0} C for five minutes. A temperature of 60^{0} C has been found to be lethal depending on duration of temperature (Byram, 1958). Living vegetation is reported to be able to tolerate a hotter fire on a cool day than on a hot day (Byram, 1958).

Mulch

Quantity and depth of mulch effects vegetation and is altered by fires, whether prescribed or wild in nature. Mulch has been defined as:

> "any dead vegetation lying on the surface
> free of the parent plant and easily
> distinguished from inorganic origin."
> (Hopkins, 1959)

Historically, observations have shown a fluctuation of mulch quantity due to grazing pressure. The degree of vegetative utilization was determined by comparisons of amounts of mulch under various grazing pressures. Many researchers have found that mulch reduced soil temperature, retarded evaporation, and increased water infiltration rates into the soil. Heat penetration under grass was relatively low, according to Bentley and Fenner (1958). Under thin mulch, temperatures at the soil surface ranged from 92 to 121^{0} C. Where mulch was greater than 0.01 mm thick, temperatures reached 93^{0} C only in the upper portion of the mulch and the soil temperature was relatively uneffected. Maximum temperatures measured were maintained less than five minutes.

Accumulations of excessive amounts of mulch under light or no grazing can cause degeneration and lower vegetation yields even in a shortgrass community in western Kansas (Tomanek, 1948). It is very difficult to specify optimum mulch conditions. Complete decomposition of mulch required 3 to 4 years with approximately half the initial weight lost in the first year (Hopkins, 1954). Mulch reduced the temperature of soil thereby delaying the initiation of vegetative growth in the spring. Mulch also retarded surface evaporation and thereby improves the microbial habitat. This is important in the mineralization of plant nutrients from the mulch itself as well as from soil organic matter. Evaporation losses were not in direct proportion to the thickness of mulch. Infiltration rates and soil moisture contents were reported greater on soils with mulch than those without mulch (Dix, 1960).

Litter buildup after a burn in the Texas High Plains was relatively fast the first growing season then leveled off according to Wright (1972). Mulch structure completely recovered by the end of the fourth growing season after burning. Based on the recovery of 1,814 kg of mulch per hectare, Wright (1972) suggested reburning every five years. However, Launchbaugh (1964) noted that mulch accumulation increased yearly, but did not equal amounts present in unburned areas by the end of the third growing season in western Kansas.

Dix (1960) suggested that there is a lag in adjustment of perennial species due to modifications by fire. Recovery of perennial vegetation from burning, regardless of season or time of burning, was due jointly to an increase of ground cover and an accumulation of protective mulch which increases infiltration of moisture into the soil profile (Launchbaugh, 1973).

Soil Responses

Vegetation responses are well documented and readily apparent despite controversial results. The impact of prescribed burning on soils is not as well documented, much less apparent and more subtle.

Reduction in water intake, regardless of timing of burning, was associated with the destruction of mulch (Hanks and Anderson, 1957). Removal of mulch on silty clay loam soils near Hays, Kansas resulted in less moisture infiltration, greater evaporation rates, the net result being less moisture for plant growth (Launchbaugh, 1973). Burning can improve herbage yields by reducing excessive mulch accumulations. However, burning may reduce yields by reducing the mulch layer, thus creating unfavorable soil moisture relationships, by removal of growing points, or by killing of plants by extreme temperatures. Launchbaugh (1964) used plant heights to indicate stunting of growth in burned areas. He attributed reduced plant growth to fire damage to the plant itself or to a reduction in amount of moisture entering the soil.

Timing of prescribed burning was found to affect soil moisture as well as herbage yields (Anderson, 1965). Earliest burning in the spring in the Flint Hills caused the greatest reduction in soil moisture. It was found that the upper 91 cm of the soil profile on the burned area was drier than the unburned area. Unburned areas had the highest soil moisture levels. Winter burns had lowest soil moisture levels, while late-spring burns had higher levels of soil moisture although still less than unburned areas. Late-spring burning facilitated the accumulation of soil moisture and reduced the time of exposure of soil to erosion forces prior to regrowth (Anderson, 1965). Late-spring burning effects on soil moisture were not significantly different from an unburned area. The advantages of late-spring burning over not burning were an increase in big bluestem, control of kentucky bluegrass, Japanese brome and western snowberry (*Symphoricarpos occidentalis*) and a more rapid weight gain of herbivores (Anderson, 1965). Disadvantages of late-spring burns include reduced infiltration rates and reduced forage yields (McMurphy and Anderson, 1965). Launchbaugh (1964) found that first year vegetation yields were reduced 50%, probably due to reduced moisture in the top foot of the soil profile.

Soil temperatures were increased -16.5 to -15.6^{0} C on burned areas, an amount insufficient by itself to explain decreased soil moisture content (Anderson, 1965). However, increased soil temperature probably induced early plant growth and use of soil moisture, thus influencing moisture levels later in the growing season (Anderson, 1965).

Infiltration rates of soils were not altered by ash from burned vegetation under "normal" conditions. However, high temperatures caused by heavy fuel loads of brush on very wet soils caused a reduction in infiltration (Burgy and Scott, 1952). High temperatures tend to influence aggregation of soil particles and increase magnesium and potassium content (Burgy and Scott, 1952).

Researchers have tried to explain increases or decreases in vegetation response by soil chemical changes caused by burning. Heating of soils via prescribed burns or wild fires increased exchangeable soil ammonium only slightly (Sharrow and Wright, 1977). Fires consume mulch, resulting in volatilization of nitrogen and concentration of other nutrients in the ash which are readily leached if not taken up by plants or microorganisms. Despite the volatilization of nitrogen via fire, total and available soil nitrogen increased. This was explained by a stimulation of native legumes and nitrifying and nitrogen-fixing microroganisms by the nutrient rich ash.

White and Gartner (1975) found that prairie soils from 0-2 cm in depth had more NH_4^+-N when the prairie had been burned than when it had not been burned. They also found that NO_3^--N was not reduced to NH_4^+-N during burning. Total N increased due to incompletely burned plant fragments. Available $PO_4^{\equiv}$-P was also found to be greater on burned prairie. The authors theorized that NH_4^--N and $PO_4^{\equiv}$-P increased due to heating of the soil by the prescribed burn. The more moist the soil at the time of burning the lower the temperature of the soil resulting in less NH_4^+-N and available $PO_4^{\equiv}$-P for plant use. These chemical changes, brought about by heating the soil, may result in vigorous growth of vegetation due to the increased soil fertility.

Weather Effects

Obviously, an important consideration in preparing prescriptions for a prescribed burn is weather and its effects. Weather has been observed to have a major influence on fuel moisture content (Britton and Wright, 1971). Moisture content of hygroscopic fine fuels, 3 mm in diameter, was positively correlated with relative humidity. The preferred range of fine fuel moisture was from 5 to 10% (Mobley, 1967). With fuel moisture less than 5%, fire intensity may cause damage to soil and overstory. Fires tend to be slower moving and leave irregular burn patterns when fuel moisture is greater than 10%. Although these results were from research on forest floor fine fuels, they most likely have application to grassland situations as well. The rate of fire spread decreases with an increase in relative humidity (Mobley, 1967). Flame height and fire intensity have been found to be directly proportional to fuel quantity as modified by various weather factors. In addition to relative humidity, it has been found that fuel moisture depends on the degree of exposure of fuels, reduced exposure to the direct rays of the sun and wind, leading to higher moisture contents (Jemison, 1935). Factors considered in determining fuel moisture include solar radiation, evaporation rate, soil moisture, air temperature, precipitation, dew point and relative humidity. Of these, air temperature and relative humidity seem to be most important. After a fire has been ignited, it can influence the occurrence, amount and behavior of winds (Mobley, 1967). Fanning of wind has been found to increase temperature of a fire 1.8 times that of a fire with no wind influence.

Prescribed burning conditions best suited to the Black Hills region have been described as: air temperature 21° C or less, relative humidity 30% or more, steady winds of 24 kph or less (Schripsema, 1977). Since soil transmits heat slowly when moist, adequate soil moisture levels to protect vegetative roots and soil organic material are essential in prescription writing.

National Park Service Policy

National Park Service nationwide policy was first changed in 1968 to allow management areas to burn if naturally ignited fires or prescribed burns were used to reduce fuel loads and to create fire breaks. Until 1973, National Park Service personnel at Wind Cave National Park did not adhere to the use of prescribed burning as a management method. Prior to the use of prescribed burning, fire suppression resulted in the thickening of pine stands, pine invasion in grasslands, and secondary stages of plant succession beneficial to wildlife habitat (Lovass, 1976). Subsequently, prescribed burning in Wind Cave National Park has reduced pine encroachment onto grasslands, thinned thickets of pines, reduced exotic species, invigorated stagnant grasslands, controlled forest insect epidemics, increased the diversity of vegetation, created seral vegetation stages, improved wildlife distribution, reestablished stream flow, controlled prairie dogs to a degree, and reduced fuel loads (Lovass, 1976).

Early Burning Studies in Black Hills Area

Pine encroachment into grasslands in the Black Hills was most evident on areas occupied by warm-season grasses, dominated by little bluestem (Gartner and Thompson, 1972). This plant community occurred where there were shallow, coarse-textured, less fertile soils. No encroachment was observed on the fine-textured soils occupied by cool-season western wheatgrass associations. Differences in grass density, season of growth, and soil texture were cited to explain the presence or absence of pine encroachment.

One of the first controlled burns, if not the first, conducted in the foothills of the eastern Black Hills was done on the Murphy Ranch on April 24, 1971, resulting in these benefits (Gartner and Thompson, 1972):

1) more productive grasslands with greater diversity (where postburn grazing was controlled);
2) more productive forests with botanically diverse understory;
3) better wildlife habitat;
4) increased water production;
5) decreased costs of wildfire protection;
6) aesthetic enhancement; and
7) reduction of pine needle consumption by cattle.

No forage reduction occurred as a result of the prescribed burn. However, pine seedling encroachment was reduced.

Research Objectives

Prescribed burning at varied fuel moisture contents has been alluded to concerning chaparral, but not investigated with respect to grassland ecosystems to ascertain the influence on vegetation yields and soil chemistry (Countryman, 1974).

Fisher (1971) of the U.S. Forest Service stated that:

> "For prescribed burning to be successful, the prescription must be specific to a fuel bed, moisture content, and land management objectives."

This research was conducted to help fill information needs of the various agencies and individuals using prescribed burning to manipulate grassland ecosystems.

METHODS AND PROCEDURES

Treatments

Treatments on the Gobbler's Ridge study area were burned at three different fuel moisture levels, with an unburned control. Four replications of the four treatments were applied to the little bluestem community and three replications of four treatments were applied to the mixed grass community. Treatments were randomly assigned to 4x4 m study plots. This plot size was chosen to enable quantitative data collection and for ease of fire control. Treatments were mnemonically referred to as dry, medium and wet burns.

The dry and medium burns took place under naturally occurring moisture conditions, while the surface soil and mulch was artificially moistened for the wet burn. The dry burn treatment was imposed on May 26, 1978. The medium burn was achieved on June 1, 1978 after a rain of 6.25 mm had occurred the previous night. There was also a heavy dew the morning of ignition. To insure a wider range of fuel moisture levels, approximately 6.25 mm of water was sprayed on the wet treatment study plots with a gas powered backpack sprayer just prior to ignition. The wet burn was accomplished on June 1, 1978. Fuel moisture determinations showed the dry, medium, and wet treatments had 30.2, 37.6, and 45.6 percent moisture, respectively, at time of ignition.

The Windy Point study area was established in the spring of 1979 to replicate the Little Bluestem study site at Gobbler's Ridge. The purpose was to try to obtain a wider range of preignition fuel moisture conditions. Four replications of the wet and dry treatments and unburned controls were allotted randomly to the 4x4 m study plots. The wet treatment was simulated by applying 98 liters of water under pressure (200 psi) for a three minute period. Each wet treatment study plot received 6.25 mm of artificial precipitation late the afternoon of May 23, 1979 with ignition taking place the following morning. The dry treatment study plots were burned on May 24, 1979 with no artificial rainfall. Both the dry treatments and the unburned control study plots received 6.25 mm of artificial precipitation postburn to preclude variability of vegetation response due to differential water application. The fuel moisture determinations showed the dry and wet treatments were 26.8 and 54.0 percent moisture at time of ignition.

Burning Techniques

All burning and fire control was done under the supervision of Mr. D. Shilts, Chief, Visitor Protection and Resource Management. Fire barriers around each 4x4 m study plot were devised by mowing a 61 cm wide swath with a handheld electric mower and by spraying perimeters with water using power backpack applicators. Fires were ignited with diesel-gas drip torches applying flames to a 10 cm sacrifice perimeter in each 4x4 m study plot. The 10 cm sacrifice perimeter was deleted from all postburn vegetation sampling.

Sampling Techniques

Fire Temperatures

Maximum fire temperatures were recorded with pyrometers made of Tempilaq fusible chemicals painted on thin sheet mica. Temperature ranges were 38 to 371^{0} C in 50^{0} increments, and 371 to 538^{0} C in 100^{0} increments (Table 1).

Table 1. Mean burn temperatures (^{0}C) at the Gobbler's Ridge study area.

Treatment	Little Bluestem Site	Mixed Grass Site
Dry	538	208
Medium	517	186
Wet	485	143

Soils

Soil samples, two per plot-treatment combination, were collected immediately pre- and postburn. Paired samples at 0-1 cm and 1-3 cm depths were placed in plastic bags and kept cool until laboratory analyses could be performed. Postburn samples were collected as soon as the smoke cleared and the ash was cool enough to handle. Soil samples were collected for determination of soil moisture, ammonium and nitrate nitrogen content (Microkjeldahl analysis), total nitrogen (Macrokjeldahl analysis), organic matter (Walkley-Black procedure), and available phosphorus (NaCl and $HCl\text{-}NH_4F$ procedures). Standard laboratory analysis procedures were used (Jackson, 1958; Olsen and Dean, 1965).

Periodic monthly soil moisture readings were taken at Gobbler's Ridge study area with a Troxler neutron proble throughout 1978 and 1979 growing seasons. Readings were taken at 31, 46, and 61 cm depths on the Little Bluestem study sites and at 31 and 46 cm depths on the Mixed Grass study sites. No soil moisture measurements were taken at the Windy Point study area.

Soil moisture availability and utilization varies throughout the growing season and influences vegetation yields. These measurements were taken to enable analysis of the effect of available soil moisture on plant yields.

Vegetation

Vegetation measurements taken prior to burning included basal cover of little bluestem, length of previous year's little bluestem flower culms, weight of dead and green fuels, and fuel moisture.

Basal cover was determined by the standard method of point quadrat sampling (Brown, 1954). Each study plot was divided into six, 50 cm-wide line transects within the central 3x3 m area. Three line transects were located at random and basal hits on 10 pins were recorded at 50 cm intervals. Percentage basal cover was used to characterize vegetation and determine similarity or differences between study plots at the Little Bluestem study site. This method was not imposed on the Mixed Grass sites because the frequency of little bluestem was low and data comparisons were not expected to be meaningful.

Length measurements of flower culms from soil surface to tip of flowers were taken randomly within the 4x4 m study plots to determine vigor of growth and to establish a reference point with which to compare regrowth after burning.

Fuel weight samples were clipped from within the 50 cm perimeter in an attempt to insure similarity to the inner 3x3 m sampling area and so as not to reduce the inner area for subsequent data collection. Samples 20x100 cm were clipped to ground level, bagged, weighed, and oven-dried at 70^0 C for 24 hours and reweighed.

Postburn fuel weight samples were taken within a 20x100 cm frame within the 50 cm sacrifice area. The fuel residue was clipped to ground level and the ash within the frame collected as soon as the material was cool enough to handle. These samples were weighed and the data was used in computation of fuel consumption (Table 2).

Periodic postburn measurements of little bluestem bunch heights were taken during the 1978 and 1979 growing seasons on both Gobbler's Ridge and Windy Point study areas. Bunch height measurements were made on both the Mixed and Little Bluestem study sites, measuring from ground surface to the uppermost point.

Yield samples were harvested in 40x100 cm frames during and after peak flower production of little bluestem had occurred. Four samples were clipped to ground level in each study plot. Diagrams of the plots were made to facilitate systematic random selection of sample location and to prevent resampling the same area during second year data collection (Figure 3). Samples were sorted in the field into eight categories: little bluestem, grama grasses, sedges, cool-season

Table 2. Fuel consumption (%)* on Little Bluestem sites at Gobbler's Ridge under three fuel moisture burn treatments.

Rep.		Mean
	Dry Burn	
1	31.2	
2	60.1	47.2
3	46.6	
4	50.7	
	Medium Burn	
1	***	
2	22.0	30.2
3	***	
4	38.5	
	Wet Burn	
1	27.0	
2	31.9	31.4
3	37.6	
4	29.3	

* Fuel consumption calculated as $\frac{\text{wt of fuel preburn}}{\text{wt of fuel postburn}} \times 100$

*** Missing data

grasses, big bluestem, forbs, shrubs, and scurfpeas (*Psoralea spp.*). Each sample was oven-dried at 70° C for 24 hours and weighed.

Vegetation samples were taken in the same manner at both the primary and secondary study areas and all samples were handled and analyzed by the same procedures.

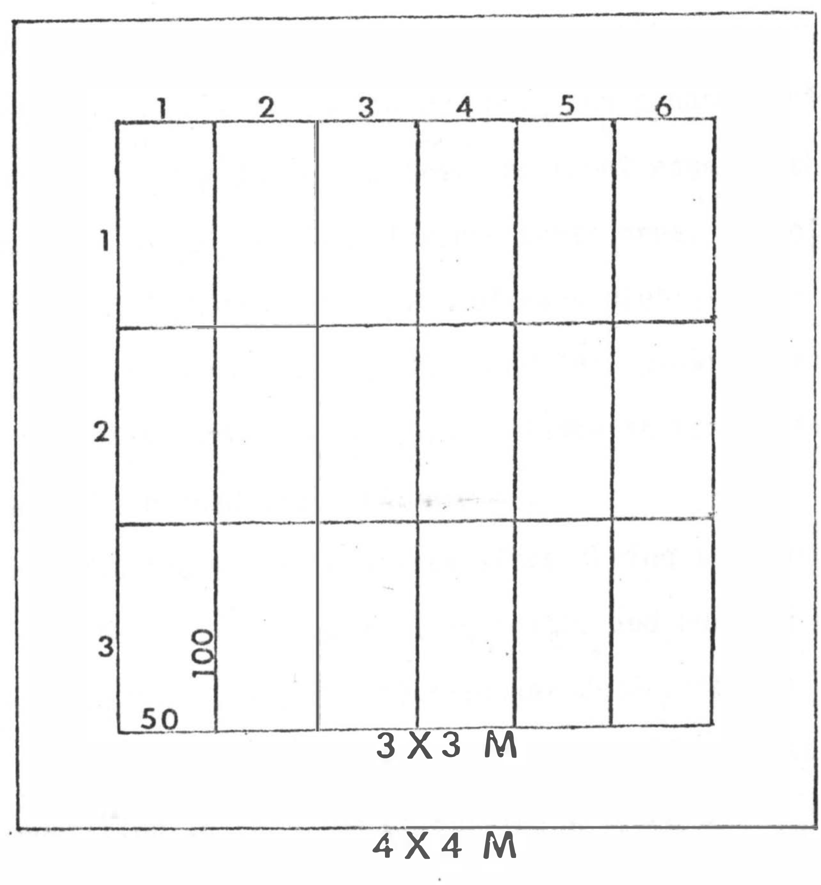


Figure 3. Schmatic of Study Plot.

Photographic Records

Permanent photopoints were established within the 3x3 m central area of each plot on Gobbler's Ridge, and three representative study plots were chosen for establishment of photopoints at Windy Point. Photographs were taken prior to ignition and immediately after the burns were completed to record fuel consumption. All photographs were taken with a 50 mm focal length lens on a 35 mm Nikon camera pack. Vertical photographs were taken 110 cm above the ground surface. Oblique photographs were taken 1 m from the front edge of the 1 meter square frame used to define the reference photo area. A set of vertical and oblique photos were taken of each plot at representative phenological stages throughout the 1978 and 1979 growing seasons. An immediate postburn telephoto of Gobbler's Ridge shows location of the study area and the burned plots (Figure 4).

General photographs of the study sites during the burning procedures were taken to document flame height and burning characteristics. Infrared photographs enabled easier determination of flame height than Ektachrome film, and also aided in differentiating dormant from live vegetation at the time of burning (Figure 5).

Climatological Data

The climatic variables of wind speed, air temperature, and relative humidity were recorded with a sling psychrometer and a hand-held anemometer at the time of burning (Table 3). Montly precipitation and temperature totals for Custer and Hot Springs were obtained from reports published by the National Weather Service. Precipitation records for WCNP, monitored by recording rain gauges at Park

Figure 4. View of dry burned study plots on Gobbler's Ridge taken immediately after burns were completed.

Figure 5. Infrared photo of little bluestem, before burning, May 31, 1978.

Table 3. Climatic and microclimatic conditions on study areas at time of burning

Treatment	Date	Mulch Moisture (%)	Soil 0-1 cm (%) Moisture	Air Temp. ($^{\circ}C$)	Rel. Hum. (%)	Wind Speed (km/hr)
		GOBBLER'S RIDGE STUDY AREA				
Dry	5/27/78	30.0	33.0	21.1	37	4.8
Medium	6/1/78	38.0	41.0	10.6	61	4.2
Wet	6/2/78	46.0	46.0	12.8	50	4.2
		WINDY POINT STUDY AREA				
Dry	5/24/79	27.0	37.0	16.7	68	3.0
Wet	5/23/79	54.0	37.0	16.7	68	5.0

headquarters, for 1977, 1978, and 1979 indicate monthly totals and deviations from normal during the growing seasons (Appendix C).

Statistical Methods

The experimental design was a randomized block, mixed model, with subsampling. The treatments were fixed; dry, medium, and wet burns, and replications were random.

The linear model was $X_{ijk} = u + \beta_j + \varepsilon_{ij} + \delta_{ijk}$; u represents the population mean, β_j represents the block effect, ε_{ij} represents the treatment effects and ε_{ijk} represents the residual effects not accounted for elsewhere in the model. δ_{ijk} was assumed random and its variance was used to test hypotheses regarding β_i and ε_{ij}.

Standard one way analyses of variance were used to analyze vegetation yeild response, soil chemical changes and soil water content following burn treatments using the Statistical Analysis System (Barr and Goodnight, 1979). Data from Gobbler's Ridge and Windy Point were analyzed with the same procedures.

Means were separated using Tukey's honestly significant difference test (Steele and Torrie, 1960).

Mean squares for the analyses of variance are presented in Appendix tables E-1, E-2, E-3, and E-4.

RESULTS AND DISCUSSION

Introduction

Prescribed burning in the southern Black Hills of South Dakota has been used to control pine encroachment into grasslands, control exotic species, improve wildlife habitat, increase water production, enhance aesthetic values, and prepare fire breaks for protection against wildfire. Prescribed burning is an effective and efficient management tool in the manipulation of grassland ecosystems. This research was conducted to increase knowledge of the effects of prescribed burning on plant communities dominated by warm-season grasses.

Preburn Data Analyses

Gobbler's Ridge: Little Bluestem Study Site

Various pretreatment vegetation and soil measurements were made at the study sites. These served as a basis for evaluating the comparability of the sites.

Basal Cover

Basal cover of little bluestem was determined by using the point-quadrat method. These data indicated that within replications percentage basal cover was comparable as indicated by the low standard deviation of the means (Table 4). However, differences existed between replications. Percentage basal cover was similar in reps 1, 3, and 4, but replication 2 was considerably greater.

Table 4. Comparison of preburn basal cover (%) of little bluestem among replications on the Little Bluestem study site at Gobbler's Ridge, May, 1978.

Rep.	Plot	Treat-ment*	No. of Hits (210 possible)	Mean basal cover plot	Standard Deviation Within Plots	Mean basal cover Rep.	Mean Standard Deviation Within Rep.
1	1	D	83	39	15		
1	2	C	81	39	10		
1	3	M	104	49	07		
1	4	W	77	37	21	41	13
2	1	M	149	71	08		
2	2	W	116	55	14		
2	3	C	135	64	18		
2	4	D	106	50	05	60	13
3	1	W	73	35	17		
3	2	C	73	35	11		
3	3	M	74	35	15		
3	4	D	49	23	12	32	13
4	1	M	76	36	10		
4	2	C	98	47	04		
4	3	D	86	41	15		
4	4	W	103	49	08	43	10

*D=Dry; M=Medium; W=Wet; C=Control.

Replication 2 occurred low on the landscape where finer-sized soil particles, eroded from higher locations, were deposited. The accumulation of finer soil particles tends to increase the water holding capacity and depth of soil. An environment more conducive to plant growth probably resulted in greater basal cover. Differences in pretreatment basal cover on treated plots were not significant, likewise, but cover was similar on those plots receiving the same burn treatment as indicated by small standard deviations in the data (Table 5).

Table 5. Basal cover (%) of little bluestem on four fuel moisture treatments on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Treatment	No. of Hits 840 possible	Mean Basal Cover	Standard Deviation
Control	387	46	16
Dry	324	38	15
Medium	403	48	17
Wet	369	44	16

Culm Height

Preburn culm height measurements indicated that all study plots within each replication were similar. Mean and standard deviations of preburn culm height comparisons indicate similarity between replications (Table 6) and treated plots (Table 7). The standard deviation of the plots under similar burn treatment was also small, indicating similarity in preburn culm height.

Table 6. Preburn culm heights (cm) of little bluestem within and between replications on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Replication	Within Rep. Mean Culm Height	Standard Deviation
1	46.1	8.9
2	54.8	3.9
3	47.1	1.8
4	41.0	5.3

Table 7. Preburn culm heights (cm) of little bluestem on four fuel moisture treatments on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Treatment	Within Treatment Mean Culm Height	Standard Deviation	Between Treatment Mean Culm Height	Standard Deviation
Dry	47.4	7.4		
Medium	47.7	9.9		
Wet	46.9	6.3		
Control	45.2	6.8	47.2	1.2

Fuel Weight

Preburn fuel weights were separated into live and dead vegetation. Live and dead fuel weights on replication 1 were much lower than on replications 2, 3 and 4 (Table 8). This may be due to the fact that replication 1 was on a shallower soil because of its higher position on the slope. Perhaps the soil there had a lower water holding capacity due to erosion of finer particles down slope. Replication 2 had the greatest live and dead fuel weights (Table 8). Greater live and dead fuel weights were related to the larger basal cover of replication 2 (Table 4). Preburn fuel weights were similar on treated plots and on plots receiving the same burn treatments as indicated by the small standard deviations (Table 9). A positive correlation of 0.497, significant at the 0.05 level was found between percentage basal cover and dead fuel weight. Combining live and dead fuel weights and relating this to percent basal cover produced a positive correlation of 0.44, significant at the 0.10 level. A negative correlation of

Table 8. Preburn fuel quantities (gm/m^2) among replications on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Rep.	Plot	Treat-ment	Within Plots Mean Dead	Within Plots Mean Live	Fuel Type	Within Rep. Mean	Standard Deviation
1	1	D	225.0	9.2	Dead	217.7	6.2
1	2	C	209.7	7.0			
1	3	M	218.0	5.7	Live	3.2	2.0
1	4	W	218.0	0.7			
2	1	M	483.0	4.7			
2	2	W	548.0	5.2	Dead	513.8	35.5
2	3	C	564.5	5.0	Live	1.9	0.7
2	4	D	542.0	3.7			
3	1	W	479.5	9.5			
3	2	C	352.0	8.0	Dead	375.5	71.5
3	3	M	316.2	32.5	Live	16.0	11.5
3	4	D	354.2	11.5			
4	1	M	394.0	11.5			
4	2	C	279.2	12.5	Dead	336.2	49.7
4	3	D	356.0	16.2	Live	13.7	6.2
4	4	W	315.5	15.2			

Table 9. Comparison of preburn fuel quantities (gm/m^2)* between treatments on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Treatment	Mean Dead	Standard Deviation	Mean Live	Standard Deviation
Control	351.5	143.0	8.0	3.5
Dry	369.0	134.7	10.2	5.2
Medium	353.0	107.0	13.5	12.0
Wet	390.2	176.2	9.7	7.5

* 8.9 x gm/m^2 = lb/acre

live fuel to basal cover of 0.42 indicated that for greater basal cover less growth results early in the growing season. This supports the premise that mulch retards growth in the spring by shading plant crowns and insulating soil (Dix and Butler, 1954; Kucera and Ehrenreich, 1962). No statistically significant relationships were found between live and dead fuel weights. Data used in correlations is presented in Appendix D.

Fuel Moisture

Fuel moisture content on the Little Bluestem study site was relatively uniform within replications as evidenced by the small standard deviations (Table 10). Fuel moisture contents within treatments were also similar (Table 11). The within treatment similarities were expectable since water was applied at predetermined rates immediately preburn.

Soil Chemical Analyses

Preburn soil chemical measurements of NH_4^+-N, NO_3^--N, total N, and organic matter on the Little Bluestem study site on Gobbler's Ridge were very similar (Table 12). It was evident that the variations were a function of depth, however the differences that occurred were not large. The same soil chemical measurements were made on the Mixed Grass study sites. The preburn data showed only small deviations between depths (Table 13). All chemical properties showed a decrease with depth. The small differences shown in Table 22 other than O.M. and Total Nitrogen, can be explained by sampling errors.

Table 10. Fuel moisture content (%) at time of ignition on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Rep	Plot	Treat-ment	Mean Fuel Moisture	Mean Within Rep	Standard Deviation
1	1	D	30.7		
1	2	C	**		
1	3	M	37.5		
1	4	W	55.4	41.2	12.7
2	1	M	36.6		
2	2	W	37.4		
2	3	C	**		
2	4	D	24.5	32.8	7.2
3	1	W	48.3		
3	2	C	**		
3	3	M	31.7		
3	4	D	36.3	38.8	8.5
4	1	M	44.5		
4	2	C	**		
4	3	D	29.1		
4	4	W	41.2	38.3	8.1

* D=Dry, M=Medium, W=Wet, C=Control
** Samples not collected

Table 11. Fuel moisture comparisons between treatments on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Rep	Plot	Treat-ment	Mean Fuel Moisture (%)	Mean Within Trt.	Standard Deviation
1	1	D	30.7		
2	4	D	24.5		
3	4	D	36.3		
4	3	D	29.1	30.1	4.9
1	3	M	37.5		
2	1	M	36.6		
3	3	M	31.7		
4	1	M	44.5	37.6	5.3
1	4	W	55.4		
2	2	W	37.4		
3	1	W	48.3		
4	4	W	41.2	45.6	7.9

* Relative humidity at ignition: dry burn=37%; medium burn=60%; wet burn=50%.

Table 12. Preburn soil chemical properties** at depths of 0-1 and 1-3 cm on the Little Bluestem study site at Gobbler's Ridge, May, 1978.

	H_2O		NH_4-N		NH_3-N		N		OM	
Depth	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
0-1	37.2	8.3	13.9	2.4	6.6	2.5	0.51	.05	11.5	0.9
1-3	33.0	5.8	13.4	2.1	6.2	2.2	0.43	.02	8.5	0.5

* gravimetrically determined
** H_2O=gravimetric water content, NH_4-N=ammonium nitrogen, ppm; NO_3-N=Nitrate nitrogen, ppm; N=Total nitrogen (%); organic matter (%).

Table 13. Preburn soil chemical properties** at depths of 0-1 and 1-3 cm on the Mixed Grass study site at Gobbler's Ridge, May, 1978.

	H_2O*		NH_4-N		NH_3-N		N		OM	
Depth	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD	$\overline{X}$	SD
0-1	33.5	9.4	10.6	3.1	9.1	4.1	.57	.02	13.7	1.4
1-3	33.1	6.9	10.4	1.7	8.3	2.6	.44	.03	10.0	1.2

* gravimetrically determined.
** H_2O=gravimetric water content, NH_4-N=Ammonium nitrogen, ppm; NO_3-N=Nitrate nitrogen, ppm; N=total nitrogen (%); organic matter (%).

The within-treatment preburn data for both Little Bluestem and Mixed Grass study sites are presented in Appendix D.

Windy Point soils were not analyzed for chemical properties. Surface soil moisture was measured gravimetrically.

The preburn data indicated some variation in vegetation and soils within the Little Bluestem study site and within the Mixed Grass study site, respectively. The random assignment of treatments to plots overcame any variation between replications. It can be concluded that variations in vegetation and soils were minimal and results can be based on treatment effects.

Gobbler's Ridge: Mixed Grass Study Site

Preburn data collection for the Mixed Grass study site was minimal. Culm height and basal cover of little bluestem on the Mixed Grass site was not collected due to the low frequency of occurrence of that species.

Fuel Weight

Preburn fuel weights were separated into live and dead vegetation. Within replications, preburn live and dead fuel weights varied little as indicated by the low standard deviations of the means (Table 14). Plots under similar burn treatments also had similar preburn fuel weights (Table 15).

Fuel Moisture

Fuel moisture content within replications on the Mixed Grass study site was similar as evidenced by the low standard deviations of the means (Table 16). Fuel moisture content within treatments was also comparable (Table 17). The fuel moisture content of the medium treatment was higher than the wet treatment due to a heavy dew received the night prior to the burn and greater realtive humidity at the time of ignition. Since fuel moisture content was determined gravimetrically in the laboratory, immediate knowledge of fuel moisture content was not available at time of ignition. A

Table 14. Preburn fuel quantities (gm/m^2) on Mixed Grass study site at Gobbler's Ridge, May, 1978.

Rep	Plot	Treat-ment*	Within Plots Mean Dead	Within Plots Mean Live	Fuel Type	Within Rep. Mean	Standard Deviation
1	1	M	155.0	15.0			
1	2	W	84.7	28.5	Dead	103.5	45.5
1	3	D	70.0	16.0	Live	19.7	7.5
1	4	C	**	**			
2	1	C	77.0	15.7			
2	1	D	202.7	12.2	Dead	130.2	53.2
2	2	M	131.5	17.7	Live	16.5	3.2
2	3	W	109.7	19.7			
3	1	D	115.5	19.0			
3	2	M	87.0	21.5	Dead	122.7	39.7
3	3	C	177.7	15.5	Live	17.2	4.0
3	4	W	109.4	12.5			

* C=Control; W=Wet; M=Medium; D=Dry
** Missing data.

Table 15. Comparison of preburn fuel quantities (gm/m^2) between treatments on Mixed Grass study site at Gobbler's Ridge, May, 1978.

Treatment*	Mean Dead	Standard Deviation	Mean Live	Standard Deviation
Control	128.2	72.2	15.5	0.2
Dry	129.5	67.5	15.7	3.2
Medium	124.5	34.5	18.2	3.2
Wet	101.2	14.2	20.2	8.0

* C=Control; W=Wet; M=Medium; D=Dry

Table 16. Fuel moisture content within replications at time of ignition on the Mixed Grass study site at Gobbler's Ridge, May, 1978.

Rep.	Plot	Treat-ment*	Mean Fuel Moisture (%)	Mean Within Rep.	Standard Deviation
1	1	M	48.9		
1	2	W	37.2		
1	3	D	37.0		
1	4	C	***	41.0	6.8
2	1	C	***		
2	2	D	31.1		
2	3	M	43.9		
2	4	W	43.0	39.3	7.1
3	1	D	27.9		
3	2	M	49.7		
3	3	C	***		
3	4	W	40.0	39.2	10.9

* C=Control; W=Wet; M=Medium; D=Dry
*** Samples not collected

Table 17. Fuel moisture (%) comparisons between treatments on the Mixed Grass study site at Gobbler's Ridge, May, 1978.

Rep.	Treat-ment*	Mean Fuel Moisture (%)	Mean Within Treatment	Standard Deviation
1	Dry	37.0		
2	Dry	31.1		
3	Dry	27.9	32.0	4.6
1	Medium	48.9		
2	Medium	43.9		
3	Medium	49.7	47.5	3.1
1	Wet	37.2		
2	Wet	43.0		
3	Wet	40.0	40.1	2.9

* Relative humidity at ignition of dry burn=37%, Medium burn 61%, Wet burn 50%.

method of rapidly and accurately determining fuel moisture content in the field would be beneficial. Fuel moisture content differences between treatments were not as large as desired for either the Little Bluestem or the Mixed Grass study sites.

Photographic documentation on the Mixed Grass study sites was used to indicate similarity and differences between replications (Figure 6-11).

Windy Point Study Area

Fuel Moisture

Fuel moisture differences between wet and dry burn treatments at Windy Point (Table 18) were larger than at the Gobbler's Ridge

Table 18. Fuel moisture comparisons between treatments at Windy Point study area, May, 1979.

Treatment	Mean Fuel Moisture (%)	Mean Within Treatment	Standard Deviation
Dry	36.1		
Dry	26.5		
Dry	20.8		
Dry	23.7	26.8	6.6
Wet	53.1		
Wet	58.3		
Wet	54.8		
Wet	49.3	53.9	3.7

Little Bluestem study site (Table 11). Fuel moisture contents within replications of the dry and wet treatments had low standard deviations of means. Presumably a wider range in fuel moisture

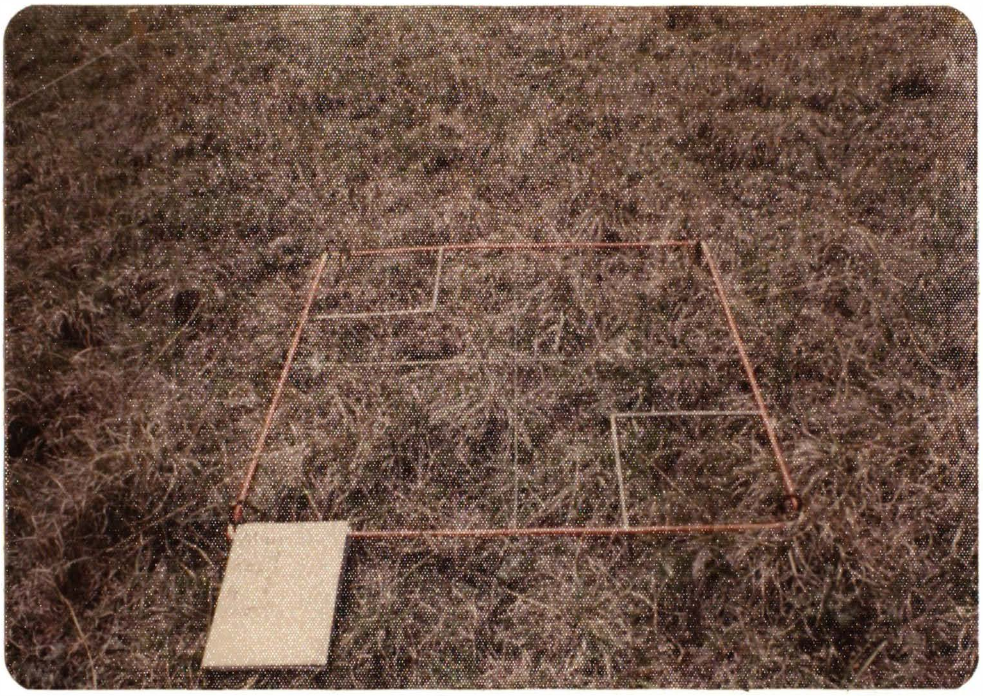


Figure 6. Preburn, Mixed Grass study site on Gobbler's Ridge, medium burn treatment, May 25, 1978.

Figure 7. Postburn, Mixed Grass study site on Gobbler's Ridge, medium burn treatment, June 6, 1978.

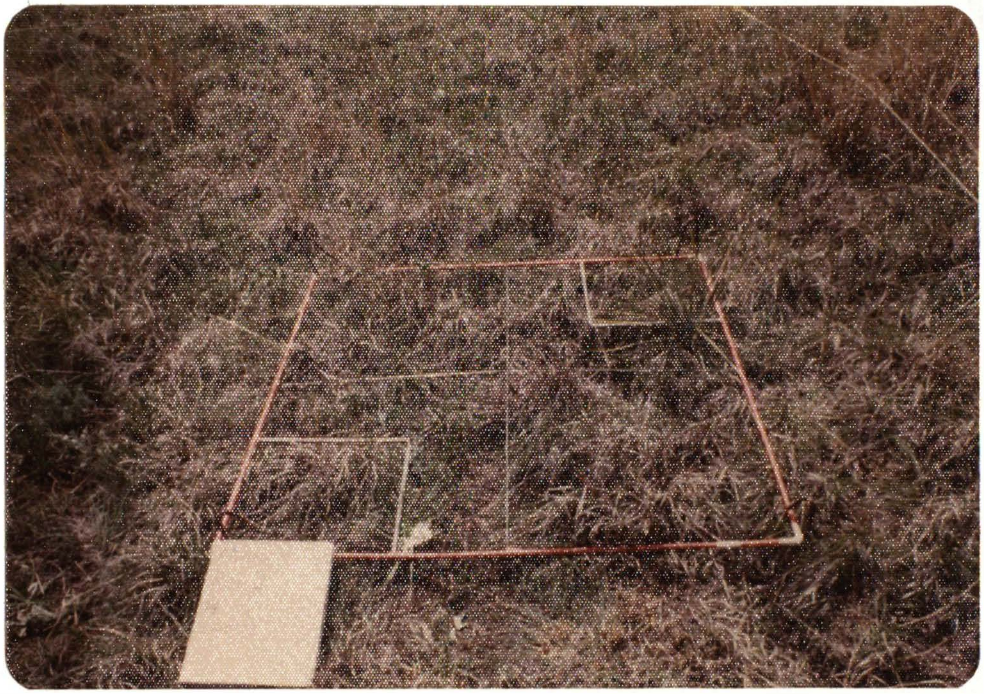


Figure 8. Preburn, Mixed Grass study site on Gobbler's Ridge, wet burn treatment, May 25, 1978.

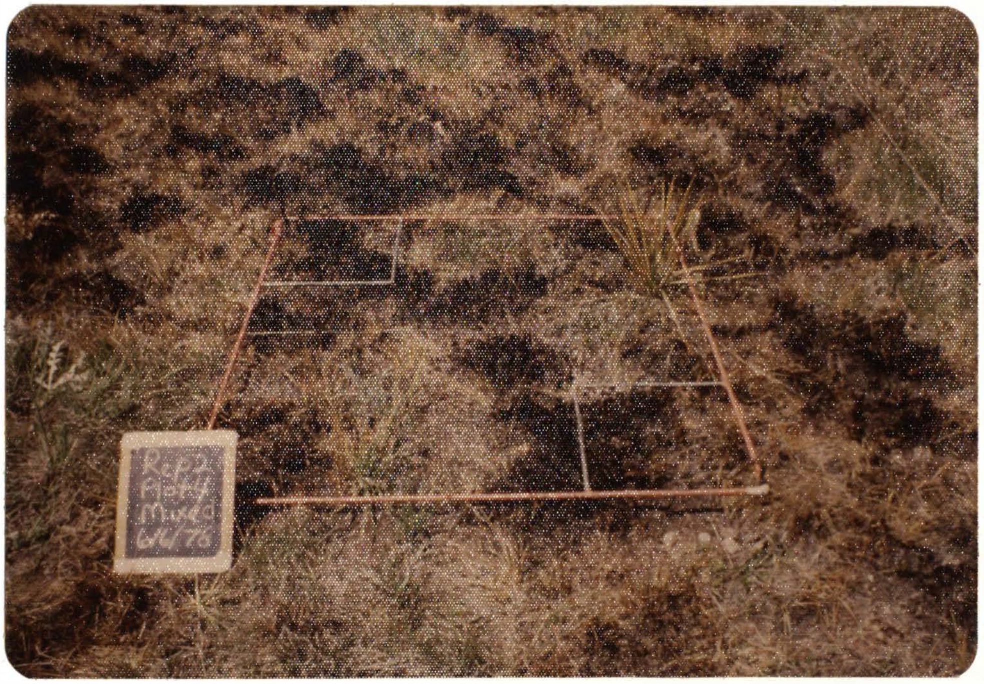


Figure 9. Postburn, Mixed Grass study site on Gobbler's Ridge, wet burn treatment, June 6, 1978.

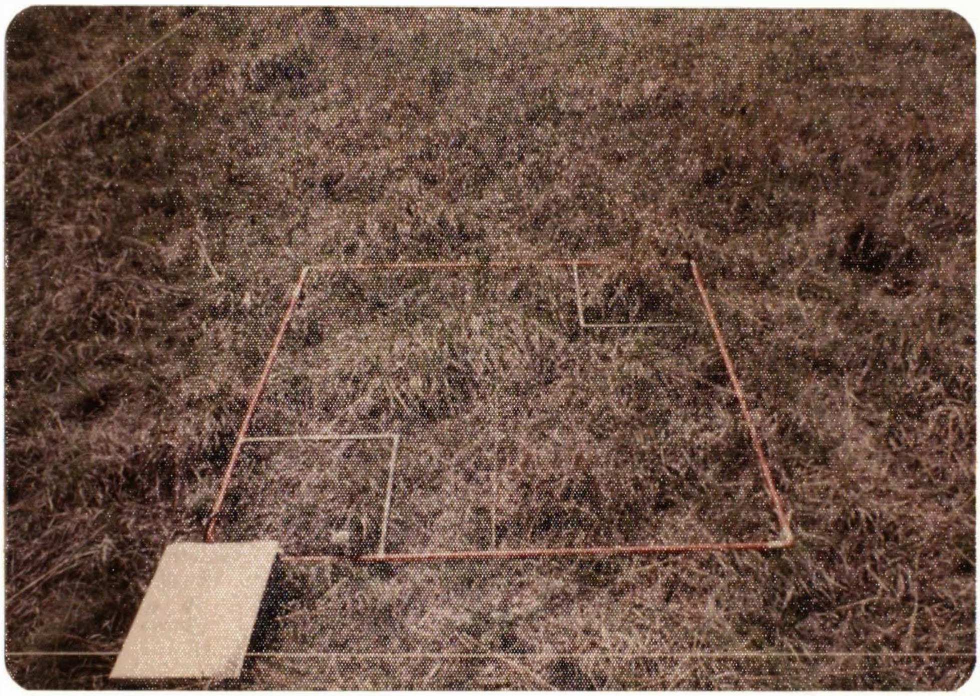


Figure 10. Preburn, Mixed Grass study site on Gobbler's Ridge, wet burn treatment, May 25, 1978.

Figure 11. Postburn, Mixed Grass study site on Gobbler's Ridge, wet burn treatment, June 6, 1978.

content at ignition would aid in the detection of any major differences in postburn vegetative production or composition changes.

Fuel Weight

Fuel weight comparisons within treatments showed a large degree of variation between plots (Table 19). This could be attributed to differences in percent basal cover which were not measured on this study site. Variable grazing use by bison may also have influenced preburn fuel quantities.

Table 19. Comparison of fuel weights at the Windy Point study area, May, 1979.

Treatment	Mean Fuel Weight gm/m^2	Mean Within Treatment	Standard Deviation
Dry	102.7		
Dry	203.5		
Dry	120.2		
Dry	246.0	168.0	68.0
Wet	297.2		
Wet	239.2		
Wet	299.7		
Wet	315.0	287.7	33.2

Culm Height

Preburn culm height within plots, within replications, and between replications had very low standard deviations of means indicating preburn conditions were comparable (Table 20 and 21).

Table 20. Comparison of preburn culm heights (cm) of little bluestem at the Windy Point study area, May, 1979.

			Within Plots		Within Treatment		Between Rep.	
Rep.	Plot	Treatment*	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
1	1	C	21.3	3.3				
1	7	W	16.1	2.8				
1	8	D	13.7	2.1	17.9	3.9		
2	3	C	23.4	3.9				
2	4	W	16.4	3.7				
2	2	D	15.7	2.1	18.5	4.2		
3	9	C	21.3	3.4				
3	5	W	16.0	3.1			17.4	0.72
3	6	D	14.2	2.4	17.2	3.7		
4	10	C	27.2	5.9				
4	11	W	12.6	2.8				
4	12	D	11.1	3.2	17.0	8.0		

* C=Control; D=Dry; W=Wet

Table 21. Comparison between treatments of preburn culm heights (cm) of ittle luestem at the Windy Point study area, May, 1979.

Treatment	Mean	Standard Deviation
Control	23.3	4.8
Wet	15.3	3.4
Dry	13.8	2.9

Surface Soil Moisture

Comparison of surface soil moisture at time of ignition indicated similarity between treatments as evidenced by the small deviation of the means (Table 22). There were more variations in surface soil moisture between plots under the dry burn treatment than under the wet burn treatment (Table 22). This was predictable due to the application of water prior to ignition to the wet burn treatments.

Table 22. Surface (0-3 cm) soil moisture (%) on the Windy Point study area, May, 1979.

Rep.	Plot	Treat-ment	Mean Soil Moisture	Within Treatment	Standard Deviation
1	8	Dry	32.2		
2	2	Dry	21.7		
3	6	Dry	28.3		
4	12	Dry	54.6	36.7	12.0
1	7	Wet	36.7		
2	4	Wet	43.1		
3	5	Wet	42.1		
4	11	Wet	42.6	41.1	3.0

General Burn Characteristics

Dry, medium and wet burn treatment applications on the Little Bluestem and Mixed Grass study sites occurred on May 26, June 1, and June 2, 1978, respectively. The dry burns on Little Bluestem study sites were rapid and produced intense heat, but very little smoke (Figure 12).

Figure 12. Dry burn treatment on Little Bluestem study sites at Gobbler's Ridge, May, 1978.

Consumption of vegetation in the 4x4 m plots took three minutes from ignition. Flame height was approximately 100 to 174 cm above ground level.

Flames appeared dense and covered the entire plot very rapidly. The fire characteristics of the medium burn treatment did not vary in general appearance from the dry burn treatments on Little Bluestem study sites.

The wet burns were much slower to ignite, left a mosaic pattern, and produced large quantities of white smoke (Figure 13).

The amount of smoke produced was surmised to be related to fuel moisture content. Estimation of flame height was difficult

Figure 13. Wet burn treatment on Little Bluestem study site at Gobbler's Ridge, June, 1978.

on wet burns due to smoke. It was noted that infrared film does not record the presence of smoke and makes flame height estimations more practical (Figure 14).

The dry burns on the Mixed Grass study sites were not as rapid or as intense as the dry burns on Little Bluestem study sites because cool-season species were green, actively growing, and high in moisture. Vegetation consumption was variable and flames usually crept from the edges of the plots toward the center. The medium burn treatments were similar to dry burn treatments in appearance (Figure 15).

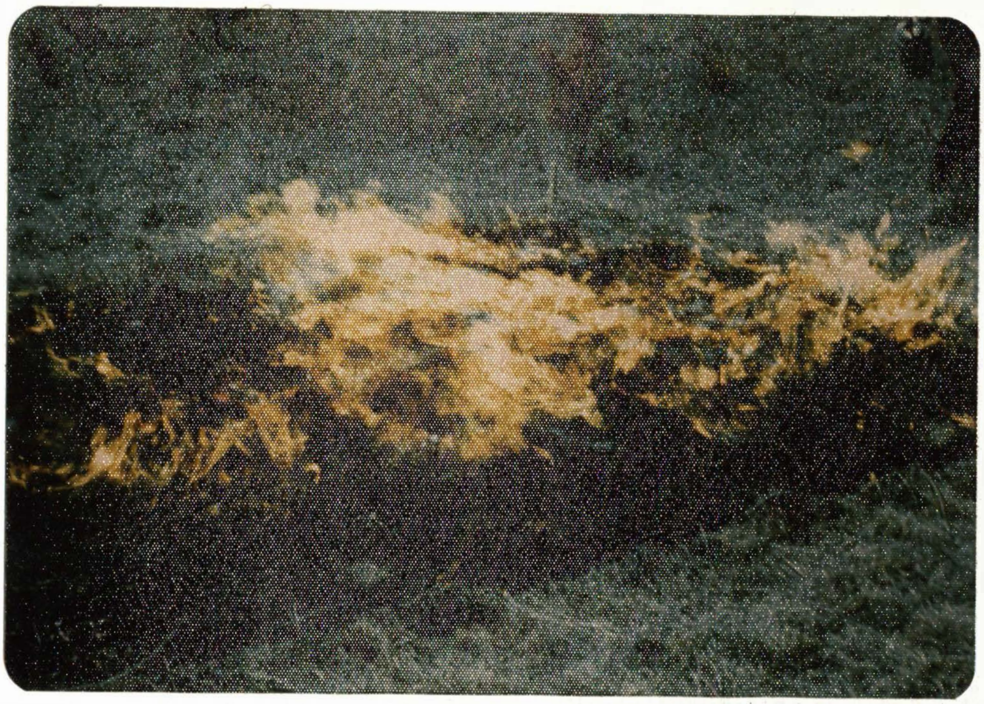


Figure 14. Infrared photo of flames on Little Bluestem study site at Gobbler's Ridge, May, 1978.

Figure 15. Dry burn treatment on Mixed Grass study site at Gobbler's Ridge, May, 1978.

The wet burns on the Mixed Grass sites were much slower, produced larger amounts of smoke and left mottled patterns of unburned vegetation (Figure 16).

Figure 16. The wet burn treatment on Mixed Grass study site at Gobbler's Ridge, June, 1978.

Flame heights were much lower for all treatments on Mixed Grass study sites than on Little Bluestem study sites. This was probably due to actively growing cool-season species and less fuel present on the Mixed Grass study sites.

The appearance of mulch and ash layers on the ground immediately after burning showed little variation between plots within study sites. However, treatment did affect the amount of unburned mulch left on the ground surface. The mineral soil was visible on the dry burn treatments at the Little Bluestem study site (Figure 17).

Figure 17. Ground cover and mulch appearance for dry treatment on Little Bluestem study site on Gobbler's Ridge, May, 1978.

As fuel moisture content increased more protective cover remained over the soil after burning. Fine ash particles were removed by wind action within three days of the burns.

The Windy Point dry burns produced similar appearances to the dry burns at Gobbler's Ridge in all respects. The application of water to the dry treatment after burning prevented fine ash particles from being removed by wind action (Figure 18).

Percentage fuel consumption at the Little Bluestem study site showed a highly significant positive correlation of 0.76 to burn

Figure 18. The dry treatment at Windy Point at time of burning, May 24, 1979.

temperature. Fuel moisture content at time of ignition showed a significant negative correlation of 0.995 to burn temperature. There was a highly significant negative correlation, 0.820, of fuel moisture to percent consumption.

Similar measures were not conducted at the Mixed Grass study sites because differential density of vegetation greatly influenced fire characteristics. Flames did not evenly carry over the Mixed Grass study plots. The random placement of quadrats resulted in higher fuel weights after burning than before burning. Another influence could have been the difference in sampling techniques of three individuals used in data collection.

Post Burn Data Analyses

Vegetation Results

Culm Height

Relationships do occur between fuel moisture content, burn temperature and fuel consumption. However, the real criteria for the measure of success for any management practice are the recovery and yield of vegetation. For this reason, culm height and yield were measured in 1978 and 1979.

Vegetative recovery began within two weeks after burning. One month postburn, the plots were green with succulent vegetation. Vegetative recovery was monitored with photographs and culm height measurements. In early recovery stages, visual observations of the wet burn treatments judged it to have slightly taller vegetation, greater biomass and faster growth. The data collected at the end of the 1979 growing season for the Little Bluestem study site on Gobbler's Ridge showed a slight decrease in culm height compared to the 1978 data. This reflects the lack of readily available plant nutrients and supports the premise that burning releases plant nutrients resulting in an invigoration of a stagnant community.

Comparison of preburn and postburn culm heights (August, 1978 and 1979) indicated a trend of taller vegetation following burning (Table 23). However, the unburned controls had consistantly

Table 23. Pre- and postburn culm height comparisons of little bluestem on the Little Bluestem study site at Gobbler's Ridge.

Treat-ment	1978						1979			
	Preburn		July		August		July		August	
	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
Dry	47.4	7.4	19.5	1.1	64.7	2.9	22.5	3.4	56.5	4.5
Med.	47.7	9.9	19.4	1.3	60.7	5.1	19.8	1.3	53.1	7.2
Wet	46.9	6.3	21.5	2.2	62.5	3.9	22.0	2.4	59.1	8.9
Control	45.2	6.8	33.9	5.5	64.2	5.7	24.3	2.7	58.0	10.6

taller vegetation than the burned areas which may have been due to the presence of mulch. Comparison of July, 1978 and 1979 culm heights showed taller vegetation earlier in the season the second year following burning (Table 23). The second year's response could be related to more soil moisture due to better infiltration influenced by the recovery of mulch. The culm heights of little bluestem may have been influenced by unusual amounts of precipitation received in 1978 and 1979.

Examination of available data at the Mixed Grass study sites indicated a similar trend in recovery (Table 24). Windy Point vegetation showed similar trends in recover after burning (Table 25).

Vegetation Weights or Yields

The analyses of variance of 1978 vegetation weights of eight key species or species groups, little bluestem, sedges, cool-season

Table 24. Postburn culm heights (cm) of little bluestem on the Mixed Grass study site on Gobbler's Ridge, 1979.

Treatment	July $\bar{X}$	July SD	August $\bar{X}$	August SD
Dry	13.8	0.3	33.9	1.6
Med.	15.7	1.6	35.8	3.5
Wet	14.3	1.1	33.8	3.4
Control	17.9	2.6	36.1	4.1

Table 25. Postburn culm heights (cm) of little bluestem on the Windy Point study area, 1979.

Treatment	July $\bar{X}$	July SD	August $\bar{X}$	August SD
Dry	13.7	1.9	62.1	13.1
Wet	15.9	3.3	63.6	6.7
Control	23.3	2.8	57.3	10.7

grasses, grama grasses, scurfpeas, forbs, shrubs, and big bluestem for the Little Bluestem study site showed no significant differences due to treatments except in the cool-season grasses category (Table 26 and Appendix Table E-1). Tukey's honestly significant difference test showed a significant decrease in cool-season species due to burning at any moisture content. This was an expected response since ignition occurred well into the growth period of cool-season species (late May to early June, 1978).

Table 26. Mean yields (gm/m^2) of vegetation components on the Little Bluestem study site at Gobbler's Ridge sampled August, 1978.

Treat-ment*	Vegetation Components 1/ Scsc	Sedges	Cool	Grama	Scurfpeas	Forbs	Shrubs	Ange
C	106.5	7.6	13.2**	1.1	2.5	12.1	0.4	0.02
W	117.1	6.0	4.1	1.5	3.6	5.3	0.0	2.70
M	116.9	3.5	1.4	2.4	4.0	4.0	2.7	0.00
D	114.9	2.3	1.8	1.4	10.3	16.0	0.0	0.00

* C=Control; W=Wet; M=Medium; D=Dry

** Tukey's Q value 5.947; C=Control; W=Wet; M=Medium; D=Dry

1/ Scsc=little bluestem; Sedges=Carex spp.; Cool=cool-season grasses; Scurfpeas=Psoralea spp.; Ange=big bluestem.

The analysis of variance of these same eight species or species groups on the Mixed Grass study sites showed no significant difference due to treatments for the cool-season species, grama grasses, scurfpeas, forbs, shrubs or big bluestem (Table 27 and Appendix Table

Table 27. Mean yields (gm/m^2) of vegetation components on the Mixed Grass study site at Gobbler's Ridge sampled, August, 1978.

Treat-ment*	Vegetation Components 1/ Scsc	Sedges	Cool	Grama	Scurfpeas	Forbs	Shrubs	Ange
C	67.8**	5.7***	3.1	1.8	4.4	9.8	1.2	0.3
W	46.5	4.2	1.2	1.8	10.7	9.5	0.6	0.0
M	59.9	2.8	0.7	2.3	18.6	14.0	0.6	0.0
D	59.3	3.0	2.3	0.6	0.5	7.3	2.5	0.0

* C=Control; W=Wet; M=Medium; D=Dry

** Tukey's Q value for Sedges, 3.15

1/ Scsc=little bluestem; Sedges=Carex spp.; Cool=cool-season grasses; Scurfpeas=Psoralea spp.; Ange=big bluestem.

E-1). There were significant differences found for little bluestem and sedge species. There were significant differences, at the 0.01 level, between the control plots and the wet burns, between the medium and wet burns as well as between the dry and wet burns. These differences were determined with the use of Tukey's honestly significant difference test. This reduction in yield due to burning at all three moisture contents on the Mixed Grass study site may be accounted for by differences in frequency of occurrence of little bluestem. Also warm-season vegetation may have emerged earlier due to less shading by mulch. The sedge species showed a significant decrease due to all burning treatments at the 0.01 level.

The analysis of the 1979 yield data shows no significant difference in yields due to treatments on the Little Bluestem or Mixed Grass study sites (Table 28 and Appendix Table E-1). Despite the greater range in fuel moisture content at Windy Point there were no significant differences due to treatment (Table 29 and Appendix Table E-2). However, there may have been differences that were masked by unusual amounts of precipitation or differences that were undetectable due to sample size.

Soil Moisture Determinations

Soil moisture utilization was increased in the upper 30 cm of the soil profile on the Little Bluestem study sites under all three treatments during the month following burning (78173)(Table 30 and Appendix Table E-3).

Table 28. Mean yields (gm/m^2) at the Gobbler's Ridge study area, sampled August, 1979.

Treat-ment*	Vegetation Components[1/]							
	Scsc	Sedges	Cool	Grama	Scurfpeas	Forbs	Shrubs	Ange
				Little Bluestem Study Site				
C	131.2	12.1	4.3	2.0	7.9	4.5	2.1	0.4
W	125.4	7.6	7.6	4.0	9.0	6.5	0.3	0.0
M	117.8	6.1	2.5	2.8	1.2	4.4	5.5	0.1
D	181.1	13.0	5.8	2.4	2.4	2.4	1.7	0.1
				Mixed Grass Study Site				
C	44.5	13.2	2.2	3.9	2.0	3.3	0.05	5.5
W	46.7	11.2	0.9	3.5	4.0	2.1	1.0	0.0
M	50.2	11.5	0.2	2.2	3.5	11.0	0.9	0.0
D	49.3	10.95	1.0	1.7	7.3	6.8	0.9	0.2

* C=Control, W=Wet, M=Medium, D=Dry

1/ Scsc=little bluestem; Sedges=*Carex* spp.; Cool=cool-season grasses; Scurfpeas=*Psoralea* spp.; Ange=big bluestem

Table 29. Mean yields (gm/m^2) on the Windy Point study area, sampled August, 1979.

Treat-ments*	Vegetation Components[1/]							
	Scsc	Sedge	Cool	Grama	Scurfpeas	Forbs	Shrubs	Ange
C	120.8	5.7	5.7	0.8	7.9	1.2	9.8	0.0
W	142.4	3.6	1.8	0.6	1.9	5.9	0.0	0.05
D	93.6	8.9	4.5	0.7	1.1	14.2	0.0	0.0

* C=Control; W=Wet; D=Dry

1/ Scsc=little bluestem; Sedges=*Carex* spp.; Cool=cool-season grasses; Scurfpeas=*Psoralea* spp.; Ange=big bluestem

Table 30. Mean soil moisture (5) for the Little Bluestem study site at Gobbler's Ridge, 1978 and 1979.

Depth	Trt[1/]	78173[2/]	78198	78223	78286
30 cm	C	10.91***	3.23**	12.16***	5.29
46 cm	C	14.13	6.68***	14.48	7.68
61 cm	C	14.58	8.12**	10.97	8.06
30 cm	W	16.30***	7.29**	13.57***	5.24
46 cm	W	16.00	9.92***	13.58	6.35
61 cm	W	16.55	11.49	12.96	7.95
30 cm	M	14.26***	5.67**	12.60***	4.00
46 cm	M	18.84	12.00***	16.15	7.78
61 cm	M	17.86	14.10	14.08	8.95
30 cm	D	13.34***	4.01**	9.74***	2.88
46 cm	D	15.56	8.23***	11.81	4.83
61 cm	D	14.84	9.54**	9.00	5.05
		79106	79137	79172	7221
30 cm	C	17.31	15.25	15.64	9.34
46 cm	C	15.29	15.76	13.65	7.72
61 cm	C	13.89	14.42	12.58	8.10
30 cm	W	16.72	15.57	14.43	7.10
46 cm	W	13.19	14.44	10.28	6.08
61 cm	W	12.48	12.99	10.75	6.08
30 cm	M	16.43	14.15	12.97	7.75
46 cm	M	15.84	16.69	13.13	7.91
61 cm	M	13.12	14.46	12.58	8.08
30 cm	D	16.68	13.61	12.38	7.20
46 cm	D	15.46	15.12	10.10	6.55
61 cm	D	13.40	13.39	10.48	5.58

Probability levels: * 0.10
** 0.05
*** 0.01

1/ C=Control; W=Wet; M=Medium; D=Dry

2/ Julian date system (78173=June 22, 1978 and 78198=25 days later)

There were significant decreases in soil moisture at the 30, 46, and 61 cm depths during the second month of vegetative recovery. This was related to the peak growth of little bluestem during the warm season.

During August, 1978 soil moisture decreased significantly only at the 30 cm depth, with the lower depths recovering from the heavy drawdown in July (Table 30 and Appendix Table E-3). No significant differences were found in soil moisture content at any depth during the 1979 growing season (Table 31 and Appendix Table E-3).

No significant differences in soil moisture content or usage were detected on the Mixed Grass study sites for 1978 or 1979 (Table 31 and Appendix Table E-3). Soil access tubes were not installed at Windy Point study location and no soil moisture data was collected.

Soil Chemical Analyses

Analysis of postburn soil chemical properties showed no significant deviations from preburn (Table 32 and 33 and Appendix Table E-4).

Table 31. Mean soil moisture (%) for the Mixed Grass study site at Gobbler's Ridge, 1978 and 1979.

Depth	Trt	78173	78198	78223	78286
30 cm	C	13.71	5.66	17.92	7.94
46 cm	C	16.54	8.78	17.54	9.79
30 cm	W	15.86	5.17	16.54	6.35
46 cm	W	17.46	9.54	17.51	8.82
30 cm	M	15.65	4.59	16.39	6.46
46 cm	M	18.91	10.76	18.22	9.76
30 cm	D	17.32	5.43	17.12	7.22
46 cm	D	17.56	10.21	16.31	8.58
		79106	79137	79172	79221
30 cm	C	15.37	15.12	14.77	8.74
46 cm	C	11.77	13.08	10.16	8.03
30 cm	W	14.20	13.97	13.62	8.76
46 cm	W	11.66	14.24	10.59	7.74
30 cm	M	16.90	14.90	13.60	8.74
46 cm	M	14.80	15.99	11.96	9.11
30 cm	D	15.65	14.77	13.77	8.91
46 cm	D	12.17	12.69	9.12	7.46

* Julian date system (78173=June 22, 1978 and 78198=25 days later).
C=Control; W=Wet; M=Medium D=Dry

Table 32. Postburn soil chemical properties for the Little Bluestem study site on Gobbler's Ridge.

Treatment	Depth	H_2O (%) $\bar{X}$	H_2O (%) SD	NH_4-N ppm $\bar{X}$	NH_4-N ppm SD	NO_3-N ppm $\bar{X}$	NO_3-N ppm SD	Total N (%) $\bar{X}$	Total N (%) SD	O.M. (%) $\bar{X}$	O.M. (%) SD
Dry	0-1	28.7	6.0	28.1	5.2	6.3	2.2	0.50	.10	10.6	2.9
	1-3	30.8	4.4	22.0	3.1	8.6	8.3	0.45	.14	9.2	2.9
Med.	0-1	43.2	9.7	22.8	5.1	6.5	5.7	0.51	.07	12.0	3.1
	1-3	34.4	4.5	17.8	3.4	6.3	4.3	0.43	.08	9.8	4.2
Wet	0-1	35.2	2.6	16.3	5.1	7.1	3.2	0.53	.07	12.6	2.8
	1-3	29.3	4.2	14.0	5.4	5.6	1.7	0.41	.09	8.7	2.5

Table 33. Postburn soil chemical properties for Mixed Grass study site on Gobbler's Ridge.

Treat-ment	Depth	H_2O (%) $\overline{X}$	SD	NH_4-N ppm $\overline{X}$	SD	NO_3-N ppm $\overline{X}$	SD	Total N (%) $\overline{X}$	SD	O.M. (%) $\overline{X}$	SD
Dry	0-1	26.4	3.5	20.9	2.2	4.0	3.1	0.52	.05	12.3	1.6
	1-3	34.9	1.8	17.5	4.3	4.6	2.3	0.45	.05	9.6	2.0
Med.	0-1	33.6	3.0	18.1	3.0	8.3	4.7	0.58	.05	12.6	2.0
	1-3	28.7	4.9	10.4	3.6	11.3	2.2	0.47	.03	9.8	1.4
Wet	0-1	25.2	2.1	11.7	0.9	8.9	3.8	0.46	.11	10.3	1.1
	1-3	22.9	3.1	11.8	0.3	8.0	3.5	0.39	.06	8.1	0.6

SUMMARY AND CONCLUSIONS

General acceptance of prescribed burning as a range management option has been conditioned by lack of knowledge concerning possible adverse effects on vegetative recovery, yields and soil moisture content. This study addressed these questions by examining the effects of different fuel moisture levels at ignition on two grassland communities.

The two vegetative communities were a Little Bluestem community dominated by little bluestem (*Schizachryium scoparium*) and big bluestem (*Andropogon gerardi*) and a Mixed Grass community dominated by green needlegrass (*Stip viridula*) and western wheatgrass (*Agropyron smithii*). Three fuel moisture levels were imposed on these communities, dry, medium and wet, having 30, 38 and 46 percent moisture, respectively.

Comparison of preburn and postburn vegetative measurements indicated that the fuel moisture levels examined did not have adverse effects on vegetative recovery, yield or species composition. All plots regardless of treatment showed rapid recovery with no alteration of species composition. Final yield measurements showed no differences between the various burn treatments and the control plots. One exception to this was a decrease in cool-season species in the Little Bluestem study site. This was due to burning treatments being applied during a critical growth period of these species. This effect may be considered positive if prescribed burning is being done to improve warm-season ranges.

In addition to conceived adverse effects of burning on vegetation, it has been thought that the underlying soil may also be altered. This alteration could include soil physical, chemical and biological properties. However, data gathered in this study indicated that no appreciable soil chemical changes occurred.

Surface soil moisture at ignition was higher for the wet treatment but this was probably due to the addition of water to this treatment. Soil profile moisture content did not appear to be related to fuel moisture conditions. However, first year soil moisture utilization did appear to be related to postburn vegetative recovery. Moisture in the soil profile the second year was more functionally related to precipitation.

One of the more obvious effects of burning at different fuel moisture levels was on consumption of mulch, and this in turn was related to burn temperature. The amount of mulch present was a reflection of previous utilization and vegetative production. Proper timing of prescribed burning, especially with regard to fuel and soil moisture, can shorten the period the soil is exposed to erosional forces after the mulch component is consumed by fire.

With proper timing and the knowledge that fuel moisture content at time of ignition does not adversely effect composition or yield of vegetation, prescribed burning can become a more versatile management option.

Further investigations should pay close attention to soils, landscape and vegetation relationships. Recovery and occurrence of vegetation seemed to be a reflection of position on the landscape. The Little Bluestem study sites were located in an old drainage way where soil depth and fertility was probably greater because of accumulation from higher on the landscape. Deeper soil probably permitted deeper rooting characteristics and vegetation was less suceptible to drought. The Mixed Grass community occurred on the more shallow soils higher on the landscape and between drainage ways on the study area. The Mixed Grass rooting characteristics and drought susceptibility of vegetation in the Mixed Grass community were probably also reflections of soil depth. Accumulation of finer-sized soil particles enables greater water holding capacity and greater fertility which are important considerations in vegetative recovery from prescribed burning or other natural phenomena.

Careful and detailed pretreatment sampling and characterization would facilitate meaningful statistical interpretations of data collected in further research endeavors.

BIBLIOGRAPHY

Aikman, J.M. 1955. Burning in the Management of Prairie in Iowa. Proc. Iowa Academy Sci. 62:53-62.

Anderson, K.L. 1965. Time of Burning as it Affects Soil Moisture in an Ordinary Upland Bluestem Prairie in the Flint Hills. J. Range Manage. 18:311-316.

Anderson, K.L., E.F. Smith, and C.E. Owensby. 1970. Burning Bluestem Range. J. Range Manage. 23:82-92.

Barr, A.J. and J.H. Goodnight. 1979. Statistical Analysis System User's Guide. SAS Institute Inc. Raleigh, North Carolina. 492 p.

Beetle, A.A. 1970. Recommended plant names. Univ. Wyoming Agri. Exp. Sta. Bull. 31. 124 p.

Bentley, J.R. and R.L. Fenner. 1958. Soil Temperatures During Burning Related to Postfire Seedbeds on Woodland Range. J. Forestry, 56:737-740.

Bieber, G.L. and K.L. Anderson. 1961. Soil Moisture in Bluestem Grassland Following Burning. J. Soil and Water Conservation, 16:186-187.

Britton, C.M. and H.A. Wright. 1971. Correlation of Weather and Fuel Variables to Mesquite Damage by Fire. J. Range Manage. 24:136-141.

Brown, D. 1954. Methods of Surveying and Measuring Vegetation. Bulletin 42. Commonwealth Agricultural Bureaux, Bucks, England. 221 p.

Burghy, R.H. and V.H. Scott. 1952. Some Effects of Fire and Ash on the Infiltration Capacity of Soils. Transactions Amer. Geophysical Union 33, 405-416.

Byram, G.M. 1958. Some Basic Thermal Processes Controlling the Effects of Fire on Living Vegetation. U.S. Dep. Agr., Southeastern Forest Exp. Sta. Research Note 352-353.

Countryman, C.M. 1974. Moisture in Living Fuels Affects Fire Behavior. U.S. Dep. Agr., Forest Service. Fire Management 35:10-13.

Curtis, J.T. and M.L. Patch. 1950. Some Factors Affecting Flower Production in Andropogon gerardi. Ecology 31:488-489.

Dix, R.L. 1960. The Effects of Burning on the Mulch Structure and Species Composition of Grasslands in Western North Dakota. Ecology 41:49-56.

Dix, R.L. and J.E. Butler. 1954. The Effects of Fire on A Dry, Thin-Soil Prairie in Wisconsin. J. Range Manage. 7:265-268.

Ehrenreich, J.H. and J.M. Aikman. 1963. An Ecological Study of the Effects of Certain Management Practices on Native Prairie in Iowa. Ecological Monographs 22:113-130.

Fenner, R.L. and J.R. Bentley. 1960. A Simple Pyrometer for Measuring Soil Temperatures During Wildland Fires. U.S. Dep. Agr. Pacific Southwest Forest and Range Exp. Sta. Misc. Paper No. 45. 15 p.

Fischer, W.C. 1971. Determination of the Effects of Fire on Wildland Ecosystems for Application in Fire and Resource Management. U.S. Dep. Agri., Northern Forest Fire Lab. Report Int - 2108. 10 p.

Gartner, F.R. and W.W. Thompson. 1972. Fire in the Black Hills Forest-Grass Ecotone. Proc. Annual Tall Timbers Fire Ecol. Conf. 12:37-68.

Gartner, F.R. 1975. Wind Cave National Park Grassland Ecology. Final report to National Park Service, Rocky Mtn. Region. 29 p. and appendix. (unpublished).

Gartner, F.R., R.I. Butterfield, W.W. Thompson and L.R. Roath. 1978. Ecological Effects of Prescribed Burning on South Dakota Grasslands. Proc. First International Rangeland Congress. pp. 687-790.

Greig-Smith, P. 1964. Quantitative Plant Ecology. 2nd Edition. Butterworths Inc., Washington, D.C. 256 p.

Hanks, R.J. and K.L. Anderson. 1957. Pasture Burning and Moisture Conservation. J. Soil and Water Conservation 12:228-229.

Hopkins, H.H. 1954. Effects of Mulch upon Certain Factors of the Grassland Environment. J. Range Manage. 7:255-258.

Hough, W. 1926. Fire as an Agent in Human Culture. Smithsonian Institution, U.S. Natural Museum Bull. 139. 270 p.

Jackson, M.L. 1958. Soil Chemical Analysis. Prentice-Hall, Inc. Englewood Cliffs, New Jersey. 498 p.

Jemison, G.M. 1935. Influence of Weather Factors on Moisture Content of Light Fuels in Forests of the Northern Rocky Mountains. J. Agr. Res. 51:885-906.

Komarek, E.V. 1962. Fire Ecology - Grasslands and Man. Proc. Annual Tall Timbers Fire Ecol. Conf. 4:169-220.

Kucera, C.L. and J.H. Ehrenreich. 1962. Some Effects of Annual Burning on Central Missouri Prairie. Ecology 43:334-336.

Launchbaugh, J.L. 1964. Effects of Early Spring Burning on Yields of Native Vegetation. J. Range Manage. 17:5-6.

Launchbaugh, J.L. 1973. Effects of Fire on Shortgrass and Mixed Prairie Species. Proc. Annual Tall Timbers Fire Ecol. Conf. 12:129-151.

Lemon, P.C. 1968. Fire and Wildlife Grazing on an African Plateau. Proc. Annual Tall Timbers Fire Ecol. Conf. 8:71-88.

Lotti, T. 1962. The Use of Prescribed Fire in the Silviculture of Loblolly Pine. Proc. Annual Tall Timbers Fire Ecol. Conf. 1:109-120.

Lovass, A.L. 1976. Introduction of Prescribed Burning to Wind Cave National Park. The Wildl. Soc. Bull. 4:69-73.

McMurphy, W.E. and K.L. Anderson. 1965. Burning Flint Hills Range. J. Range Manage. 18:265-269.

Nelson, D.W. and J.M. Bremner. 1972. Preservation of Soil Samples for Inorganic Nitrogen Analyses. Agron. J. 64:196-199.

National Oceanic and Atmospheric Admin. 1973. Monthly Normals of Temperature, Precipitation; and Heating and Cooling Degree Days 1941-70. Environmental Data Service Climatography of U.S. No. 81. 10 p.

Olsen, S.R. and L.A. Dean. 1965. Phosphorous. In C.A. Black (ed.) Methods of Soil Analysis. Amer. Soc. Agron. Madison, Wisconsin. Agron. 9:1035-1049.

Philips, W.S. 1962. Fire and Vegetation of Arid Lands. Arizona Agr. Exp. Sta. Tech. Paper No. 720. 13 p.

Schripsema, J.R. 1977. Ecological changes on pine-grassland burned in spring, late spring, and winter. (M.S. thesis, South Dakota State University, 1977), p. 84.

Scott, V.H. 1956. Relative Infiltration Rates on Burned and Unburned Upland Soils. Transactions Amer. Geophysical Union 33 37:67.

Sharrow, S.H. and H.A. Wright. 1977. Effects of Fire, Ash and Litter on Soil Nitrate, Temperature, Moisture and Tobosagrass Production in the Rolling Plains. J. Range Manage. 30:266-270.

Smith, E.F. and V.A. Young. 1959. The Effects of Burning on the Chemical Composition of Little Bluestem. J. Range Manage. 12:139-141.

Soil Survey Staff. 1951. Soil Survey Manual. U.S. Dep. of Agri. Handbook 18. 503 p.

Steel, R.G.D. and J.H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Company, Inc. New York, NY. 481 p.

White, E.M. and F.R. Gartner. 1975. Immediate Effects of Prairie Fire on the Soil Nitrate, Ammonium, Available Phosphorus and Total N Content. Proc. South Dakota Academy Sci. 54:188-193.

White, E.M., W.W. Thompson, and F.R. Gartner. 1973. Heat Effects on Nutrient Release from Soils Under Ponderosa Pine. J. Range Manage. 26:22-24.

White, E.M. and F.R. Gartner. 1974. Phosphorus and Iron Contents of Some Black Hills Soils. Proc. South Dakota Academy Sci. 53:29-35.

Wright, H.A. 1972. Fire as a Tool to Manage Tobosa Grasslands. Proc. Annual Tall Timbers Fire Ecol. Conf. 12:153-168.

APPENDIX A

Scientific and common names of all grasses and grass-like plants, forbs and shrubs encountered in and near the study areas at Wind Cave National Park. Nomenclature follows that of A.A. Beetle (1970), Recommended Plant Names.

APPENDIX A

Scientific Name	Common Name
GRASSES AND GRASSLIKE PLANTS	
Agropyron cristatum (L.) Gaertn.	Crested wheatgrass
Agropyron smithii Rydb.	Western wheatgrass
Andropogon gerardi Vitman.	Big bluestem
Aristida longiseta Steud.	Red threeawn
Bouteloua curtipendula (Michx.) Torr.	Sideoats grama
Bouteloua gracilis (H.B.K.) Lag. Steud.	Blue grama
Bromus inermis Leysser.	Smooth brome
Bromus japonicus Thurn.	Japanese brome
Bromus tectorum L.	Cheatgrass brome
Buchloe dactyloides (Nutt.) Englem.	Buffalograss
Carex filifolia Nutt.	Threadleaf sedge
Carex heliophila Mackenzie.	Sun sedge
Koeleria cristata (L). Pers.	Prairie junegrass
Poa pratensis L.	Kentucky bluegrass
Schizachyrium scoparium (Michx.) Nash.	Little bluestem
Stipa comata Trin. and Rupr.	Needleandthread
Stipa viridula Trin.	Green needlegrass

FORBS

Achillea millefolium (L.) ssp. lanulosa (Nutt.) Pipper	Common yarrow
Allium textile A. Nelson & Macbridge.	Prairie onion
Antennaria rosea Greene.	Rose pussytoes
Argemone polyanthemos (Fedde) G.B.O.	Pricklepoppy
Asclepias speciosa Torrey.	Showy milkweed
Astragalus adsurgens Pallas var. robustior Hooker.	Standing milkvetch
Astragalus crassicarpus Nutt.	Groundplum milkvetch
Astragalus missouriensis Nutt.	Missouri milkvetch
Artemisia frigida Wild.	Fringed sagewort
Calochortus nuttallii Nutt.	Sego mariposalily
Calylophus serrulatus (Nutt.) Raven.	Yellow eveningprimrose
Campanula rotundifolia L.	Bluebell bellflower
Castilleja sessiliflora Pursh.	Largeflowered Indian-paintbrush
Cirsium ochrocentum Gray.	Yellow thistle
Dodecatheon pulchellum (Raf.) Merr.	Shooting star
Echinacea pallida Nutt. var. angustifolia (DC) Crongq.	Pale echinacea
Erigeron divergens T. & G.	Spreading fleabane
Erysimum asperum (Nutt.) DC.	Western wallflower
Gaura coccinea Pursh.	Scarlet gaura
Gilia spicata Nutt.	Spike gilia

Hymenoxys acaulis (Pursh.) Parker	Stemless actinea
Leucocrinum montanum	Common starlily
Lesquerella ludoviciana (Nutt.) Watson	Foothill bladderpod
Linum perenne L. var. lewisii (Pursh) Eat. & Wright.	Perennial flax
Linum rigidum Pursh.	Yellow flax
Lithospermum incisum Lehm.	Narrowleaf gromwell
Mammillaria vivipara (Nutt.) Haw.	Pincushion cactus
Opuntia polyacantha (Engelm.) Haw.	Plains pricklypear
Oxytropis lambertii Pursh.	Lambert loco-weed
Penstemon albidus Nutt.	White penstemon
Petalostemon candidum (Willd.) Michx.	White prairieclover
Petalostemon occidentale (Gray) Fern.	White prairieclover
Petalostemon purpureum (Vent.) Rydb.	Purple prairieclover
Phlox alyssifolia Greene.	Alyssiumleafed phlox
Phlox hoodii Rich.	Hoods phlox
Plantago patagonica Jacquin.	Woolly plantain
Polygala alba Nutt.	White polygala
Potentilla pensylvanica L.	Pennsylvania cinquefoil
Psoralea tenuiflora Pursh.	Slimflower scurfpea
Senecio plattensis Nutt.	Prairie groundsel
Sisyrinchium montanum Greene.	Colorado blueyedgrass

Sphaeralcea coccinea (Pursh) Rydb.	Scarlet globemallow
Tragopogon dubius Scopoli.	Yellow salsify
Viola nuttallii Pursh.	Yellow prairie violet
Viola pedatifida G. Don.	Purple prairie violet
Zygadenus venenosus Watson.	Meadow deathcamus

SHRUBS AND TREES

Pinus ponderosa	Ponderosa pine
Rosa blanda Ait.	Meadow rose
Rhus radicans L.	Poison ivy
Symphoricarpos occidentalis Hook.	Wolfberry
Symphoricarpos albus (L.) Blake	Snowberry

APPENDIX B

Soil Profile Descriptions

SOIL 1 Relative Elevation: 3085.7 m

Depth, cm	Horizon	Description
0-18	A1	Dark brown (10 YR 3/3) gravelly silt loam; weak fine granular structure; friable; 20% coarse limestone fragments; gradual boundary; calcareous.
18-25	A3	Brown to dark brown (10 YR 4/3) gravelly silt loam; weak medium granular structure; friable; 40% coarse limestone fragments 5.1-15.0 cm; roots very dense between fragments; clear boundary; calcareous.
25-41+	C	Yellowish brown (10 YR 5/4) gravelly silt loam; massive structure; friable; 90% coarse limestone fragments 5.1-15.0 cm in diameter; calcareous.

SOIL 2 Relative Elevation: 3035.2 m

Depth, cm	Horizon	Description
0-18	A1	Very dark grayish brown (10 YR 3/2) fine gravelly silt loam; weak fine granular structure; friable; many limestone particles 3-10 mm in diameter; clear boundary; calcareous.
18-30	A3	Dark grayish brown (10 YR 4/2) gravelly silt loam; weak medium granular structure; friable gravel particles 5-15 mm in diameter; abrupt boundary; calcareous.
30-41+	C	Yellowish brown (10 YR 5/4) gravelly silt loam; massive structure; firm; greater than 75% limestone fragments up to 15.0 cm in diameter; calcareous.

SOIL 3

Relative Elevation 2965.3 m

Depth, cm	Horizon	Description
0-15	A1	Very dark grayish brown (10 YR 3/2) gravelly silt loam; weak fine granular structure; limestone cobbles 5.1-25.0 cm in diameter; friable; gradual boundary; calcareous.
15-20	A3	Dark brown (7.5 YR 3/2) gravelly silt loam; moderate fine granular structure; limestone cobbles 5.1-25.0 cm in diameter; friable; clear boundary; calcareous.
20-30	B2	Brown to dark brown (7.5 YR 4/4) clay loam; moderate medium angular blocky structure; limestone cobbles 5.1-25.0 cm in diameter; friable; clear boundary; calcareous.
30-46	B3	Brown to dark brown (7.5 YR 4/4) silt loam; moderate fine angular blocky breaking to moderate medium granular structure; limestone cobbles 5.1-25.0 cm in diameter; friable; clear boundary; calcareous.
46+	C	Greater than 75% coarse limestone cobbles.

SOIL 4 Relative Elevation: 2907.7 m

Depth, cm	Horizon	Description
0-15	A1	Dark brown (10 YR 3/3) loam; weak fine granular structure; friable; 40% gravel 2-5 mm in diameter; clear boundary; calcareous.
15-30	A3	Brown to dark brown (10 YR 4/3) loam; weak fine granular structure; friable; 40% gravel 2-5 mm in diameter; clear boundary; calcareous.
30-38	C1	Brown to dark brown (10 YR 4/3) loam; massive structure; friable; 75% gravel 5-10 mm in diameter; abrupt boundary; calcareous.
38+	C2	Brown to dark brown (7.5 YR 4/4) loam; massive structure; firm; 90% limestone cobbles; calcareous.

SOIL 5

Relative Elevation: 2936.4 m

Depth, cm	Horizon	Description
0-10	A1	Dark, reddish brown (5 YR 3/2) loam; weak fine granular structure; friable; gradual boundary; calcareous.
10-28	A3	Dark reddish brown (5 YR 3/4) loam; moderate fine granular structure; friable; gradual boundary; calcareous.
28-38	B1	Dark reddish brown (5 YR 3/4) silt loam; moderate medium angular blocky structure; friable; gradual boundary; calcareous.
38-56	B2	Reddish brown (5 YR 4/4) silty clay loam; moderate medium angular blocky structure; friable; gradual boundary; calcareous.
56-66	B3	Dark reddish brown (2.5 YR 3/4) loam; weak medium angular blocky structure; friable; clear boundary; calcareous.
66-76+	C	Dark red (2.5 YR 3/6) loam; massive structure; friable; 50% coarse fragments up to 10 mm in diameter; calcareous.

SOIL 6 — Relative Elevation: 3011.4 m

Depth, cm	Horizon	Description
0-13	A1	Very dark grayish brown (10 YR 3/2) silt loam; weak fine granular structure; friable; clear boundary; slightly calcareous.
13-23	A3	Dark brown (10 YR 3/3) silt loam; weak fine granular structure; friable; clear boundary; calcareous.
23-30	B1	Dark grayish brown (10 YR 4/2) silty clay loam; moderate medium angular blocky structure; friable; clear boundary; calcareous.
30-48	B2	Brown to dark brown (10 YR 4/3) clay loam; moderate medium angular blocky structure; friable; clear boundary; calcareous.
48-58	B3	Weak red (2.5 YR 4/2) clay loam; weak medium angular blocky structure; friable; clear boundary; calcareous.
58-71+	C	Brown to dark brown (10 YR 4/3) clay loam; weak fine angular blocky structure; many coarse prominent dark grayish brown (2.5 Y 4/2) mottles; friable; calcareous.

Water holding capacity of soils at field capacity on Gobbler's Ridge study sites.

Soil Profile	mm/cm
1	44.4
2	72.0
3	95.2
4	36.0
5	112.0
6	126.7

APPENDIX C

Climatological Data

Long term average monthly and annual temperatures at Hot Springs and Custer, South Dakota

	TEMPERATURE, °C	
Month	Hot Springs *	Custer **
Jan	-4.3	-7.0
Feb	-2.1	-5.0
Mar	0.8	-2.8
Apr	7.7	3.3
May	13.2	8.6
Jun	18.2	13.7
Jul	22.8	17.6
Aug	21.6	17.2
Sep	16.1	11.6
Oct	10.1	6.3
Nov	2.4	-0.9
Dec	-2.2	-4.7
Annual	8.8	4.8

* 30 year average 1941-1970.

** 20 year average 1943-1963.

Precipitation (mm) at Wind Cave National Park

Month	1977	1978	1979
Jan	5.3	2.5	14.5
Feb	0.0	0.0	9.9
Mar	22.9	0.0	9.6
Apr	61.0	61.0	20.8
May	53.3	129.5	33.8
Jun	38.1	38.1	72.1
Jul	58.4	81.3	68.8
Aug	78.7	78.7	111.3
Sep	94.0	12.7	7.4
Oct	12.7	15.0	*
Nov	15.2	0.0	*
Dec	15.2	0.0	*
Annual	454.7	431.5	

* Not available at time of writing.

Precipitation and deviation from normal (mm)
at Hot Springs and Custer 1978

	Hot Springs		Custer	
	1978	Dev	1978	Dev
Jan	8.9	0.2	4.8	-6.1
Feb	15.5	4.8	24.9	13.7
Mar	10.2	-8.1	4.1	-20.8
Apr	41.6	0.0	46.7	3.8
May	124.2	50.3	223.8	+136.4
Jun	37.8	-47.7	39.4	-52.8
Jul	81.8	15.5	96.8	37.3
Aug	89.1	56.6	72.1	23.1
Sep	10.4	-22.6	27.7	-1.3
Oct	10.9	-7.6	4.6	-13.2
Nov	8.4	0.0	20.3	8.1
Dec	14.0	-5.8	17.3	9.9
Annual	453.9	+35.6	582.4	+138.2

Custer is located approximately 11 miles NW of WCNP. *

Hot Springs is located approximately 7 miles S of WCNP. *

* aerial distances

Appendix D

Means and Standard Deviations

of Data

Preburn and postburn soil chemical properties within treatments on the Little Bluestem study site at Gobbler's Ridge, 1978.

Trt	Depth	H_2O % $\bar{X}$	SD	NH_4^+ - N ppm $\bar{X}$	SD	NO_3^- - N ppm $\bar{X}$	SD	Total N, % $\bar{X}$	SD	O.M., % $\bar{X}$	SD
PREBURN											
Control	0-1	27.8	6.3	10.5	1.9	3.0	1.1	.48	.11	11.1	3.8
	1-3	25.5	3.4	10.8	2.8	3.1	1.4	.40	.06	7.8	2.3
Dry	0-1	33.2	4.6	14.0	2.6	8.5	5.9	.46	.05	10.4	1.5
	1-3	31.4	3.2	14.7	2.3	8.0	4.3	.44	.07	8.8	1.6
Med.	0-1	41.4	6.2	14.8	4.3	7.0	1.8	.57	.10	12.3	2.7
	1-3	37.5	8.4	15.8	5.6	6.6	3.3	.46	.12	8.8	1.8
Wet	0-1	46.5	1.5	16.3	6.8	7.8	1.3	.54	.05	12.2	1.1
	1-3	37.6	2.6	13.7	4.8	7.3	1.6	.42	.06	8.8	1.5
POSTBURN											
Dry	0-1	28.7	6.0	28.1	5.2	6.3	2.2	.50	.10	10.6	2.9
	1-3	30.8	4.4	22.0	3.1	8.6	8.4	.45	.14	9.2	2.9
Med	0-1	43.2	9.7	23.5	7.1	6.5	5.7	.51	.07	12.0	3.1
	1-3	34.4	4.5	17.8	3.4	6.3	4.3	.43	.08	9.8	4.2
Wet	0-1	35.2	2.6	16.3	5.1	7.1	3.2	.53	.07	12.6	2.8
	1-3	29.3	4.2	13.9	5.4	5.6	1.7	.41	.09	8.7	2.5

Preburn and postburn soil chemical measurements within treatments on the Mixed Grass study site at Gobbler's Ridge, 1978.

Trt	Depth	H_2O % $\overline{X}$	H_2O % SD	NH_4^+ - N ppm $\overline{X}$	NH_4^+ - N ppm SD	NO_3^- - N ppm $\overline{X}$	NO_3^- - N ppm SD	Total N, % $\overline{X}$	Total N, % SD	O.M., % $\overline{X}$	O.M., % SD
PREBURN											
Control	0-1	21.4	2.8	6.3	2.0	4.1	1.6	.55	.08	14.0	2.6
	1-3	40.6	4.5	8.3	1.7	7.3	9.4	.44	.02	9.5	.8
Dry	0-1	34.4	3.4	13.3	1.7	7.5	1.9	.54	.13	11.7	3.6
	1-3	27.6	3.9	11.6	2.6	5.3	1.2	.40	.09	8.7	2.0
Med	0-1	33.9	2.0	12.2	1.2	13.3	7.0	.58	.21	14.7	6.1
	1-3	27.0	9.5	12.1	1.8	9.1	3.5	.47	.06	10.3	1.7
Wet	0-1	44.3	4.4	10.7	2.0	11.6	6.1	.60	.19	14.5	5.5
	1-3	37.4	6.3	9.8	1.2	11.5	9.5	.45	.16	11.6	4.6
POSTBURN											
Dry	0-1	26.4	3.5	20.9	2.2	4.0	3.1	.52	.05	12.3	1.6
	1-3	23.9	1.8	14.1	2.4	4.6	2.3	.45	.05	9.6	2.0
Med	0-1	33.6	3.0	18.1	3.0	11.9	3.2	.58	.05	12.6	2.0
	1-3	28.7	4.9	10.4	3.6	11.3	2.2	.47	.03	9.8	1.4
Wet	0-1	25.2	2.1	11.7	.9	8.9	3.8	.46	.11	10.3	1.1
	1-3	22.9	3.1	11.8	.4	8.0	3.5	.39	.06	8.1	0.6

Postburn culm heights (cm) of little bluestem on Little Bluestem study site at Windy Point, 1979.

Identification			Within Plots $\bar{X}$	Within Plots SD	Within Reps $\bar{X}$	Within Reps SD	Between Reps $\bar{X}$	Between Reps SD
1	1	Control	63.8	9.7				
1	7	Wet	60.3	5.1				
1	8	Dry	59.8	6.4	61.3	2.2		
2	3	Control	45.2	9.1				
2	4	Wet	64.8	13.1				
2	2	Dry	72.8	13.7	60.9	14.2		
3	9	Control	51.5	5.7				
3	5	Wet	56.9	7.3				
3	6	Dry	44.7	7.5	51.0	6.1		
4	10	Control	68.8	9.6				
4	11	Wet	72.5	6.8				
4	12	Dry	71.3	7.1	70.9	1.9	61.0	8.1

Comparison between treatments of postburn culm heights (cm) of little bluestem at Windy Point study site, 1979.

Treatment	Mean	Standard deviation	Mean	Standard deviation
Control	57.3	10.9		
Wet	63.6	6.7		
Dry	62.1	13.0	61.0	3.3

Data used in the determination of correlations of live and dead weight to percent basal cover on the Little bluestem study sites on Gobbler's Ridge.

Identification			Percent basal cover	Fuel weight Dead	Live
				gms/m^2	
1	1	D	39	225.0	9.2
1	2	C	39	209.7	7.0
1	3	M	49	218.0	5.7
1	4	W	37	218.2	9.7
2	1	M	71	483.0	4.7
2	2	W	55	548.0	5.2
2	3	C	64	564.5	5.0
2	4	D	50	542.0	3.7
3	1	W	35	479.5	9.5
3	2	C	35	352.0	8.0
3	3	M	35	316.2	32.5
3	4	D	23	354.2	11.0
4	1	M	36	394.0	11.0
4	2	C	47	356.0	16.2
4	3	D	41	315.5	15.0
4	4	W	49	279.2	12.5

D=Dry C=Control M=Medium W=Wet Treatments.

Appendix E

Analysis of Variance Mean Squares for Soil Moisture, Vegetation Yields and Soil Chemical Changes

Table E-1. Analysis of Varaicne Mean Square Data for Vegetation Yield (gms/m^2).

Gobbler's Ridge Study Area

Source	d.f.	Scsc	Grama	Sedge	Cool	Ange	Forbs	Shrubs	Scurfpeas
1978									
Little Bluestem study sites									
Rep	3	536.00	16.96	35.78	47.38	4.84	78.47	2.58	32.16
Trt	3	63.30	0.79	14.69	77.79*	4.77	83.00	4.28	31.57
R&T	9	502.37	1.56	11.77	21.47	4.77	42.67	2.07	42.75
Plot/RT	48	391.23	0.85	11.03	3.84	3.21	23.84	1.58	24.92
Mixed Grass study sites									
Rep	2	33.97	0.92	7.07	1.20	0.05	17.01	3.54	67.01
Trt	3	150.21**	2.76	42.60***	2.27	0.05	15.32	1.57	120.20
R&T	6	15.27	0.66	2.86	1.54	0.05	9.24	2.21	129.18
Plot/RT	36	20.56	1.10	0.99	1.77	0.05	21.86	1.54	84.36
1979									
Little Bluestem study sites									
Rep	3	2606.60	36.41	146.81	50.74	0.09	36.84	29.86	102.34
Trt	3	2110.53	1.99	29.11	11.96	0.09	4.58	12.57	38.86
R&T	9	884.39	4.11	11.88	10.04	0.14	8.47	10.40	27.64
Plot/RT	48	314.39	2.35	15.50	5.12	0.14	6.50	4.56	34.10
Mixed Grass study sites									
Rep	2	96.43	0.50	3.61	1.57	3.89	24.86	0.84	22.39
Trt	3	12.94	2.24	1.98	0.67	14.06*	30.41	0.36	9.75
R&T	6	25.09	6.55	11.10	0.71	3.59	26.54	1.00	10.67
Plot/RT	36	35.88	2.63	6.31	1.28	3.51	3.94	0.94	14.56

Scsc=little bluestem; Sedges=*Carex* spp.; Cool=cool season grasses; Scurfpeas=*Psoralea* spp.; Ange=big bluestem.

Table E-2. Analysis of Variance Mean Squares Data for Vegetation Yields (gms/m^2).

Windy Point Study Area

1979

Little Bluestem study sites

Source	d.f.	Scsc	Grama	Sedge	Cool	Angr	Forbs	Shrubs	Scurfpeas
Rep	3	3526.50	1.52	34.42	22.61	.003	93.22	81.38	98.14
Trt	2	1530.27	0.47	18.33	10.11	.003	110.06	82.42	35.65
R&T	6	581.90	0.38	46.23	3.30	.003	110.46	81.38	36.12
Plot/RT	36	197.00	0.40	3.04	4.35	.000	61.99	28.53	53.76

Scsc=little bluestem; Sedges=*Carex* spp.; Cool=cool season grasses; Scurfpeas=*Psoralea* spp.; Ange=big bluestem.

Table E-3. Analysis of Variance Mean Squares Data for Soil Moisture Content at Different Soil Depths.

Gobbler's Ridge Study Area

1978

Little Bluestem Study Sites

Source	d.f.	30 cm 78173[1/]	46 cm 78173	61 cm 78173	30 cm 78198	46 cm 78198	61 cm 78198
Rep	3	104.30	83.40	64.84	52.04	24.76	93.79
Trt	3	39.94**	31.10	18.97	26.11**	41.72**	55.19**
R&T	9	3.95	7.17	5.86	4.30	6.02	8.93
Plot/RT	16	5.95	1.30	2.83	4.81	2.85	1.33
		78223	78223	78223	78286	78286	78286
Rep	3	81.29	87.46	74.05	10.52	66.98	76.50
Trt	3	21.21***	26.24	40.15	45.12	15.31	23.04
R&T	9	2.90	9.00	10.35	2.72	6.34	5.59
Plot/RT	16	7.85	4.39	2.88	2.59	23.21	2.21

Mixed Grass Study Sites

Source	d.f.	30 cm 78173	46 cm 78173	30 cm 78198	46 cm 78198	30 cm 78223	46 cm 78223	30 cm 78286	46 cm 78286
Rep	2	10.12	0.83	3.78	0.19	0.22	0.41	0.53	1.31
Trt	3	13.19	5.72	1.26	4.40	2.90	3.80	3.29	2.37
R&T	6	14.35	4.34	8.40	7.80	5.42	4.51	5.23	4.30
Plot/RT	12	2.49	6.09	2.82	3.25	2.13	5.56	2.21	5.89

p = < ***0.01, ** 0.05, * 0.10

[1/]Julian date system (78173=June 22, 1978 and 78198 = 25 days later).

Table E-3. Analysis of Variance Mean Squares Data for Soil Moisture Content at Different Soil Depths.

Gobbler's Ridge Study Area

1979

Little Bluestem Study Sites

Source	d.f.	30 cm 79106	46 cm 79106	61 cm 79106	30 cm 79137	46 cm 79137	61 cm 79137
Rep	3	45.05	48.85	40.99	62.69	83.50	58.01
Trt	3	1.11	11.34	2.78	6.29	0.50	4.43
R&T	9	5.17	8.11	9.28	5.00	5.29	11.13
Plot/RT	16	2.56	3.11	3.17	7.13	4.80	3.58
		79173	79172	79172	79221	79221	79221
Rep	3	31.88	36.22	54.31	47.89	29.91	31.16
Trt	3	17.26	27.65	10.37	8.23	6.36	14.58
R&T	9	5.15	13.77	13.16	6.69	4.65	4.87
Plot/RT	16	6.10	4.77	1.78	2.67	2.01	1.59

Mixed Grass Study Sites

Source	d.f.	30 cm 79196	46 cm 79196	30 cm 79137	46 cm 79137	30 cm 79172	46 cm 79172	30 cm 79221	46 cm 79221
Rep	2	1.68	1.51	1.52	3.73	2.49	2.11	8.08	1.40
Trt	3	3.34	10.95	6.92	13.17	1.61	8.27	0.04	3.14
R&T	6	7.89	2.85	7.46	3.00	5.32	5.30	3.62	3.01
Plot/RT	12	1.61	5.16	1.55	3.80	2.18	5.61	3.95	3.40

p = < ***0.01, **0.05, *0.10

Table E-4. Analysis of Variance Mean Squares Data for Soil Chemical Changes.

Gobbler's Ridge Study Area

Little Bluestem Study Sites

Source	d.f.	H_2O	NH_4^+ - N	NO_3^- - N	Total N	O.M.
Rep	3	35.81	27.96	14.79	0.030	13.26
Trt	2	196.95**	2.67	71.90	0.002	0.94
R&T	6	34.78	92.29	62.32	0.010	9.41
SDEP	1	97.32**	30.43	0.53	0.030*	41.78*
Trt&SDEP	2	33.08	37.85	9.03	0.007**	5.17
Rep&SDEP	3	3.34	18.54	20.11	0.006	6.71
R&T&S	6	25.29	14.88	17.32	0.000	1.02

Mixed Grass Study Sites

Source	d.f.	H_2O	NH_4^+ - N	NO_3^- - N	Total N	O.M.
Rep	2	87.08	41.10	28.09	0.08	62.75
Trt	2	142.70	53.42**	12.80	0.00	1.53
R&T	4	87.66	11.10	43.20	0.01	6.00
SDEP	1	187.24	0.70	29.38**	0.08	67.57
Trt&SDEP	2	1.61	0.28	20.44	0.00	2.04
Rep&SDEP	2	24.36	31.88	0.40	0.01	10.43
R&T&S	4	6.18	7.20	7.38	0.00	3.04