FIRE EFFECTS ON TALLGRASS PRAIRIE

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Abstract. Fire has been an important natural part of tallgrass prairie ecosystems, started by both lightning and American Indians. Production of vegetation on burned areas can be double that on unburned, unmowed, and ungrazed areas where the old standing dead vegetation is deep. Burning stimulates earlier plant development than on unburned areas. In tallgrass prairie, burning stimulates flowering of warm-season grasses and increases stem density. Late spring burning results in fewer forbs but greater grass production than fall or early spring burning. Up to at least six years, above-ground biomass is positively related to the number of years between burning. In Kansas, at least, burning is effective in keeping out exotic plants where the prairie grasses are vigorous.

The few studies of fire effects consistently indicate that neither the ash left from burning nor heat from fires affects production. Warming of the increased growth resulting from burning. The increased light for new growth by removal of the old plants seems to be more important.

INTRODUCTION

This paper reviews fire effects in tallgrass or true prairie of North America, but does not cover effects in mixed or shortgrass grasslands, in which effects of fire may differ from effects in tallgrass prairie.

Lightning is an important cause of fires (Bragg 1982). Records compiled by Westover (1977 through 1984) show that 7.8% of the rural vegetation fires in all of Nebraska for the years 1976 through 1983 were caused by lightning, and these fires burned 25.8% of the area burned by all causes. Lightning has caused fires in many forests and grasslands (for example, see Komarek 1968), and has been a major influence in tallgrass prairie throughout its development. After the arrival of American Indians, fires started by them were added to those started by lightning. We do not know how often prairie areas were burned prior to European settlement. Because of the rate at which forest invades unburned tallgrass prairie (Bragg and Hulbert 1976), we infer that fires must have occurred more than once a decade, perhaps several times a decade.

Controlled experimental burning in native tallgrass prairie (not reestablished prairie) has been rare, so most of our information has been obtained from studies initiated following wild fires. The oldest experimental fire study is on the Aldous experimental plots, located on Kansas State University land close to Manhattan, Kansas. These 10 by 20 m plots have been burned every year since 1928 except eight: one of the rare and highly valuable long-term studies. Aldous plot treatments include: unburned, burned in December, early March, early April, and about the first of May; each replicated twice and not grazed (Aldous 1934). Another long-term study is the experimental burning of 17.8 ha units of cattle-grazed native tallgrass prairie at Kansas State University started in 1950. Units are burned in early March, early April, and about the first of May, another unit is unburned, and all are grazed from about May 1 to October 1 at a moderate stocking rate (2 ha/animal unit) (Owensby and Anderson 1967). Experimental burning was started on Hayden Prairie, Howard County in northeastern Iowa, in 1954 (Ehrenreich 1959). On Tucker Prairie east of Columbia, Missouri, experimental burning was started in 1958 (Kucera et al. 1963). The most extensive experimental burning was begun in 1972 on Konza Prairie Research Natural Area south of Kansas State University, Manhattan, Kansas. Watershed units in tallgrass prairie are unburned, burned in April at 1, 2, 4, and 10 year intervals, burned at irregular intervals, and burned for 3 consecutive years and then not burned for 3 years, with 4 or more replications each on ungrazed watersheds. (Grazing is scheduled to begin soon on other watersheds, also burned and unburned.) In addition, 25 by 25 m plots are burned in November and March.

Scientific names follow usage in the Flora of the Great Plains (Great Plains Flora Association 1986). Common names are from Anderson and Owensby (1969).

EFFECT OF BURNING ON RATE OF DEVELOPMENT OF PRAIRIE VEGETATION

Removal of the standing dead vegetation by either clipping or burning results in more rapid growth of warm-season grasses in the early part of the growing season than on unburned areas (Ehrenreich and Aikman 1963). In 1966, in plots burned April 9 the leaf blades of big bluestem (*Andropogon gerardi*) were 10 to 15 cm tall and fully expanded on May 12, whereas on unburned plots the blades had only grown 2 to 4 cm and were still in the coleoptiles (Hulbert 1969). On Konza Prairie it has been observed that development starts earlier on plots burned in November than on those burned in March, and earlier on March than on May 1 burned plots. Part of the reason for the earlier growth on burned than unburned areas is believed to be a result of higher soil temperatures on burned areas, resulting from greater solar heating as a response to removal of the insulating layer of standing dead vegetation (Aldous 1934, Hulbert 1969, Rice and Parenti 1978).

EFFECT OF BURNING ON PRODUCTIVITY OF VEGETATION

The effect of burning on productivity depends on soil type, frequency of burning, season of burning, weather conditions, and other factors. The difference in productivity is greater on deep, nonrocky loam soils than on shallow, rocky soils. Ungrazed, unmowed, and unburned prairies have distinctly lower yields of vegetation than burned prairies (Table 1). Apparently, an important reason for this effect of fire is the removal of old growth of vegetation, because mowing and removal of dead vegetation results in production similar to that in burned plots (Old 1969, Hulbert 1969, and Rice and Parenti 1978). The earlier an area is burned (i.e., the longer the period between burning and resumption of growth) the lower the production. This has been attributed to lower amounts of water storage in plots burned early than those burned later, due at least in part to greater runoff and therefore less infiltration during the period between burning and the beginning of growth of the vegetation (Anderson 1965).

TABLE 1. Production of aboveground biomass on ungrazed, unmowed, and unburned prairie as a percent of that on adjacent burned prairie.

Location	Yield of unburned prairie as percent of burned	Reference
Oklahoma	60	Rice and Parenti 1978
Oklahoma	64	Adams and Anderson 1978
Kansas	53	Hulbert 1969
Missouri	46	Kucera and Ehrenreich 1962
Iowa	77	Ehrenreich and Aidman 1963
No. Illinois	30	Hadley and Kieckhefer 1963
No. Illinois	65	Old 1969
So. Illinois	50	Anderson and Van Valkenburg 1977

EFFECT OF BURNING ON PLANT REPRODUCTION

Burning stimulates flowering of at least most warm-season grasses. The concept obtained from explorers and early settlers that one needed to be on a horse to see over the grass is misleading, if one assumes that this means the prairie is always that tall. It is true that flower stalks of big bluestem and indiangrass (*Sorghastrum nutans*) can reach 2 to 3 m., but that occurs only on deep loam soil after spring burning and in years with adequate precipitation during the growing season. On Konza Prairie during the 13 years from 1972 through 1984, big bluestem seed stalks grew 2.6 m tall only in 1973 and 1981. Flowering and seed production is particularly good in wet years that follow dry years, a combination that occurred in 1980-81. In September, 1981, as a result, there were stretches of mowed fireguards where one saw only two walls of grass. In contrast, there may be almost no flower stalks in dry years.

The density of flower stalks commonly is increased by burning. In Wisconsin big bluestem flower stalk density was 7 times greater on burned than on unburned plots in the reestablished Curtis Prairie (Curtis and Partch 1950); in Iowa burned plots had 2 to 10 times as many flower stalks of big bluestem, little bluestem (*Andropogon scoparius*), indiangrass and prairie dropseed (*Sporobolus heterolepis*) as unburned plots (Ehrenreich and Aikman 1963); and in Missouri the increase was 2.7 times for big bluestem, 12 times for little bluestem, and 4 times for indiangrass (Kucera and Ehrenreich 1962). Anderson and Van Valkenburg (1977) found little difference in flower culm density of grasses on burned and unburned plots, but the burning occurred in December, a time that is less favorable for stimulating flower stalk production than spring burning (Anderson and Van Valkenburg 1977). However, legumes increased dramatically in response to this fall burning.

Flowering of many species is reduced by spring burning. Both leaf production and flowering of Kentucky bluegrass (*Poa pratensis*) are reduced by burning (Ehrenreich and Aikman 1963, Towne and Owensby 1984). Other cool-season species generally respond in the same way, especially when the fires are in late spring. On Konza Prairie heath aster (*Aster ericoides*) commonly does not flower on areas burned that spring, in contrast to abundant flowering on areas not burned. The response to fire varies, of course, among the hundreds of forbs in prairie.

EFFECT OF BURNING ON WOODY PLANTS

The cause of the "treelessness on the prairies" has been much debated since the beginning of settlement of the prairies (Gaskill 1906, Shimek 1948). Fire and poor drainage were emphasized first, but later other explanations gained proponents, including insufficient rainfall, type of soil, drying winds, geologic formations, and overgrazing by bison. Shimek felt that fire was a minor cause, and emphasized the drying power of the air and the low soil moisture as basic causes of prairie. He disagreed with Gleason (1913) who emphasized the importance of fire as a cause of the lack of trees in prairies.

These disagreements resulted partly from insufficient evidence. Shimek used the observation that trees had not invaded prairie in Iowa since settlement as evident that fire is not a major cause of treelessness (Shimek 1911). Observations over a longer time have corrected that interpretation, especially where tree seed sources were nearby. Another reason for the disagreements was the human tendency to emphasize single causes. It is now clear that fire is necessary to keep woody plants from replacing tallgrass prairie, but fire alone does not make prairie. It is the combination of fire, climate, substrate, and topography that accounts for prairie (Bell and Hulbert 1974).

Forest or woodland invades even the driest part of the tallgrass prairie area when it is left unburned for several decades. In the Flint Hills of Kansas, redcedar (*Juniperus virginiana*) is an especially successful invader of unburned tallgrass prairie (Owensby et al. 1973), along with other species (Towne and Owensby 1984). Comparison of the area occupied by forest at the time of settlement, as recorded in the 1856 Land Office Survey, with area occupied by forest in the 1970's showed that on frequently burned prairies woody plants occupied about the same area today as over a century ago, but on areas not burned for 20 years or longer, forest had invaded, frequently on half or more of the area (Bragg and Hulbert 1976).

Although the season of burning affects the results, most species of woody plants are reduced by most fires (Adams et al. 1982). Autumn burning appeared to be more effective than spring burning in Iowa (Landers 1976, personal communication). Studies in the Flint Hills of Kansas involve spring burning. Late spring burning is particularly helpful in reducing such species as buckbrush or coralberry (*Symphoricarpos orbiculatus*), because it produces leaves prior to late spring fires, and so is hurt when its carbohydrate reserves are low. Smooth sumac (*Rhus glabra*) in contrast, is less affected because new leaves are produced after warm-season grasses have begun to grow, when burning is less likely. Although burning kills the tops of sumac, stem density may increase in response to burning (Adams et al. 1982). However, the amount of sumac on burned and grazed range was less than on unburned in a Kansas study (Owensby and Smith 1973).

EFFECT OF FREQUENCY OF BURNING

Almost all experimental burning has compared annual burning with no burning; the effect of fire frequency has generally been neglected. Kucera and Koelling (1964) report that annual burning of Tucker Prairie in Missouri resulted in a uniform grass cover with a marked reduction in forbs compared to unburned areas. Burning every other year resulted in a greater number of forbs, and burning at 5-year intervals differed little from unburned.

On Konza Prairie Research Natural Area near Manhattan, Kansas, six burning treatments: unburned, burned at 1, 2, 4, and 10 year intervals, and burned irregularly (after each year with more than 1.2 times the median precipitation) were started in 1972 on watershed units. An early finding was that the interval between fires does affect productivity. On ungrazed areas that had not been burned for several years, flower stalks of big bluestem and indiangrass in the first growing season after burning were taller and denser than on sites burned annually. In the first growing season after burning, denser and taller flower stalks resulted from burning every two years than from annual burning, and burning after 6 years resulted in denser and taller stalks than after 2 years (Hulbert and Wilson 1983). Total aboveground biomass showed the same trend, but the difference was less than for flower stalk yield. At present we can only speculate on the cause, which may be related to nutrient supply. It is too early to recommend any particular frequency of burning.

Indiangrass responds distinctly differently than big bluestem to fire interval. Big bluestem in the Kansas Flint Hills is dominant regardless of burning frequency. On ungrazed areas, however, indiangrass declines rapidly as the length of time since burning increases (Fig. 1) (Towne and Owensby 1984, Hulbert and Wilson 1983). Differences in response of the two species are less on shallow than on deep soils, perhaps because of less standing dead on shallow soils. If the amount of standing dead is an important factor, burning would then make less difference to indiangrass than on deep soils.

Burning favors tall warm-season grasses. Perhaps because this makes them more competitive with other species, the number of species is lowest with annual late-spring burning and increases with increasing intervals between fires (Fig. 2).

EFFECT OF SEASON OF BURNING

If a prairie is ungrazed or lightly grazed and not burned recently, there will be enough dead material so that fires can occur any month of the year (Bragg 1982). Lightning fires probably are most

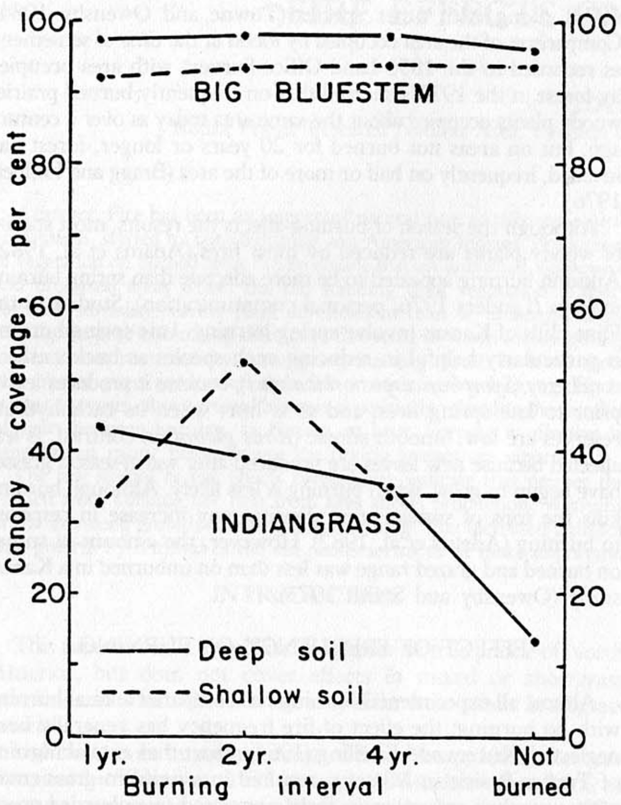

FIG. 1. Effect of frequency of burning on canopy coverage of big bluestem (*Andropogon gerardii*) and indiangrass (*Sorghastrum nutans*) on deep (Tully silty clay loam) and shallow, rocky (Florence cherty silt loam or silty clay loam) soils on Konza Prairie Research Natural Area in Kansas in 1983. Because canopies overlap, the combined totals regularly exceed 100%. Burning was in April each year.

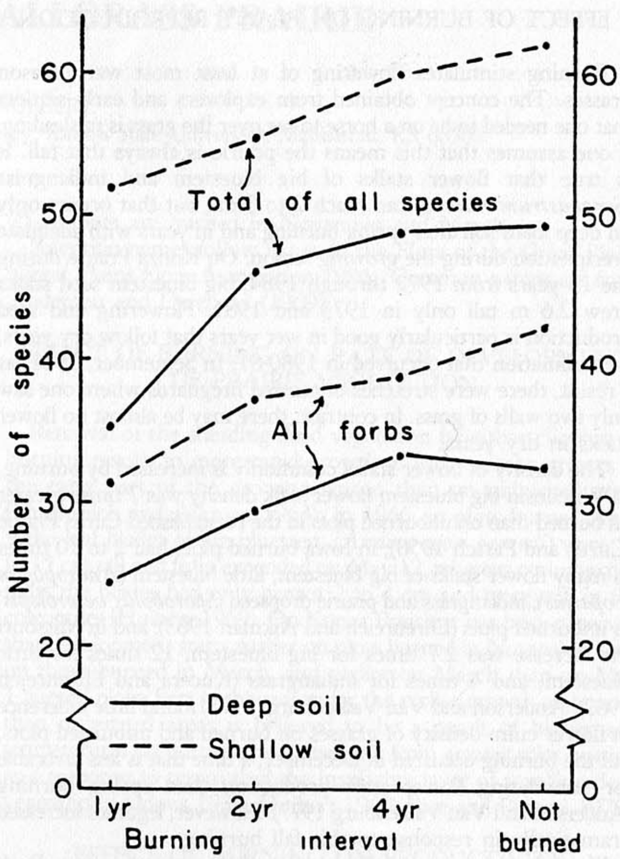

FIG. 2. Effect of frequency of burning and soil depth on number of species in tallgrass prairie on Konza Prairie in 1983.

common in late summer (Bragg 1982). The little evidence indicates that late summer fires reduce productivity. In plots burned in August, 1983, on Konza Prairie, canopy coverage of the grasses was markedly reduced the following growing season.

Burning in late spring (when warm-season grasses have grown 1 to 3 cm) results in greater production but fewer species than earlier burning. On the Aldous plots in Kansas, burned annually at different seasons for 49 of the last 57 years, production was lowest in the December and March burns, intermediate in the April burn, and highest in the May 1 burned plots. There was a larger difference in the grass production than in total production (Towne and Owensby 1984).

On pastures grazed by cattle from May 1 to October 1 and burned about March 10, April 10, or May 1, a similar response was observed. Grass production was about 75% in the March and 90% in the April burned pastures as in the May 1 burned pastures (Owensby and Anderson 1967).

Composition also is affected by season of burning. On Konza Prairie it was found that May 1 burning was better than earlier burning dates for big bluestem and indiangrass, but was less favorable for many other species of grasses and forbs. The greatest number of species was found in the areas burned in March (Fig. 3). Pitcher sage (*Salvia pitcheri*) was most abundant in the late spring burned areas, but most forbs were more common in areas burned in winter or early spring than in those burned in late spring on Konza Prairie and also in the Aldous plots in Kansas (Towne and Owensby 1984).

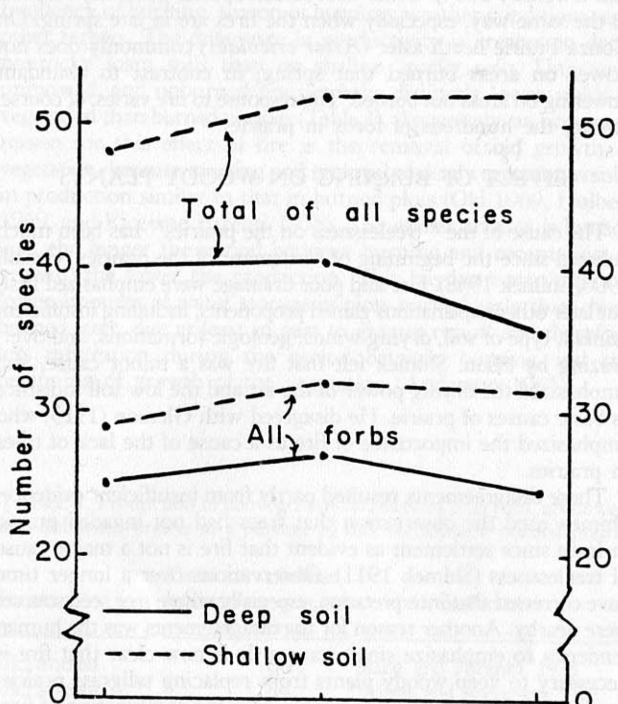

FIG. 3. Effect of season of burning and soil depth on number of species in tallgrass prairie on Konza Prairie in 1983.

EFFECT OF BURNING ON STEM DENSITY

Indiangrass and little bluestem produce distinctly more tillers or stems per unit area on burned than on unburned prairie. Burning has much less effect on stem density of big bluestem, but it shows some increase in stem density with burning. Cool season species, such as Kentucky bluegrass and sedges, produce more stems on unburned sites than on spring-burned areas (Dokken and Hulbert 1978, Towne and Owensby 1984). When the boundary of an annually burned area on Konza Prairie was extended into an area unburned for a decade or longer, there was a strong visual difference in stem density shortly after burning; the area that had been burned annually for several years being much greener for about two weeks because of the denser tillers. In Missouri, Kucera and Koelling (1964) also report greater basal area of grasses on burned than on unburned prairie.

OTHER EFFECTS OF BURNING

Geographical Location

Because climate, substrate, and topography vary throughout the tallgrass prairie area, the response to fire varies. One should not assume that results in one part of the region will apply to another part, but some results do seem to apply throughout. For example, burning seems to favor tall warm-season grasses in all parts of the tallgrass prairie area. On the other hand, the southern part of the tallgrass region, such as the Flint Hills of Kansas, has relatively few cool-season species, whereas the northern portion, in the Dakotas and Manitoba, has a large component of cool-season species. Such differences indicate the need for caution in extrapolating results from one area to another.

Direction of Fire in Relation to the Wind

Fires burning against the wind (back fires) move much slower and produce much lower flames than fires burning with the wind (head fires). As a result, tall woody plants are harmed more by fire with the wind, but the soil is heated less than by fires against the wind. On Konza Prairie we can readily tell whether an area had burned with or against the wind, because ash on the area burned with the wind is black (indicating incomplete fuel consumption), but that burned against the wind is much grayer. Because of this difference we have established four 25 by 25 m plots, two of which are spring burned with the wind, and two against the wind. Species composition was analyzed on two plots burned for 9 years. A statistically significant difference in coverage was found for only one uncommon species. Apparently direction of the fire is unimportant on annually burned areas.

Introduced Plants

Kentucky bluegrass, smooth bromegrass (*Bromus inermis*), sweetclovers (*Melilotus* spp.), and other plants have invaded tallgrass prairie in certain places. Research on these species has been scarce. In the Flint Hills of Kansas where burning has been a regular practice, alien plants are rare except where the native tallgrasses have become weak or absent due to disturbance. Frequent fire eliminates Kentucky bluegrass where the native warm-season grasses are vigorous, but without fire Kentucky bluegrass increases, especially when the area is grazed. Unplowed tallgrass prairie that is grazed but not burned becomes dominated by Kentucky bluegrass from northern Kansas on to the north and east. Often grazed and unburned prairie areas have not been recognized as remnants of tallgrass prairie because of the dominance of bluegrass and weedy forbs. After grazing was reduced and burning initiated, some of these areas have shown remarkable recovery because the native warm-season plants were still present and the fire favored them but hurt the cool-season and weedy species.

On Konza Prairie, yellow sweetclover (*Melilotus officinalis*) entered an annually summer mowed and hayed strip on the south boundary and became dominant some years, yet on the adjacent area, burned annually in April, it is essentially absent. However, it also has entered and become common on a plot burned in November each year.

When Konza Prairie was acquired musk thistle (*Carduus nutans*) was present in heavily grazed spots. Observations indicated that burning favored seedling establishment of musk thistle in areas where grazing had reduced vigor of prairie grasses. However, where the native prairie plants were vigorous, it has been crowded out, whether burned or not. In most cases it appears that the combination of vigorous native prairie plants and frequent burning prevents invasions by exotic plants.

Belowground Effects of Fire

Few people have studied the belowground portion of prairies, and even fewer have compared belowground production on burned and unburned areas. Old (1969) found no difference in root and rhizome weights of plants in burned and unburned prairie in Illinois, but because of the small sample size, differences present may not have been detected. Kucera and Dahlman (1968) in Missouri found 39% less root and rhizome biomass in prairie unburned for 6 years than in prairie burned annually for 10 years. A reduction in belowground biomass is expected to accompany the reduction in aboveground biomass.

Studies on the effects of fire on nutrient supply, soil structure, and soil flora and fauna are much needed. With half or more of the prairie belowground, the importance of understanding what happens there as a result of fire should be obvious.

WHY DOES FIRE AFFECT PRAIRIE?

Effects of fire have been discussed above, but mostly we do not know why they occur. Because fires differ greatly in speed and intensity due to variation in humidity, temperature, wind speed, moisture content, amount of fuel, and predicting effects of a particular fire is difficult. Understanding why fires cause the various effects would much improve our ability to predict.

Hypothesis proposed to account for fire effects on prairie are: loss of nutrients in smoke, increase in the readily available nutrient supply in ash, increase in soil temperature from solar heating after burning, increased light intensity on leaves near the ground due to removal of standing dead plants, and removal of toxicity from dead plants (allelopathy).

Nutrient Changes Due to Burning

Studies on the effect of ash have all yielded negative results. Three studies in tallgrass prairie and one in grassland in England (Lloyd 1972) have detected no effect of the ash in the growing season subsequent to burning. In a study in Kansas, dead vegetation was clipped and then burned in a metal pan. The ash then was returned to the plot. No difference in aboveground yield was detected between this treatment and clipped plots with no ash (Hulbert 1969). In a later study in Kansas, three times as much ash was added to clipped plots as would result from normal burning, yet again no difference from clipped plots without ash was detected (Manuscript in preparation). In Illinois, Old (1969) did a similar study, also with no yield differences detected. It is difficult to accept the idea that leaving nutrients in ash is not important, but it may be that nutrients used the year after burning come primarily from sources already in the soil rather than from ash at the surface. Also, it seems reasonable that the nutrients in ash are less important than nitrogen, which is nearly absent in ash. Studies of soil chemistry on areas long burned show some differences from unburned areas, although the differences were not thought to be important to productivity (Owensby and Wyrill 1973).

Allelopathy

Elroy Rice, a specialist in allelopathy, conducted an experiment in Oklahoma to see if standing dead plants produced chemicals that inhibited new growth of prairie plants. The results indicated that no such inhibition was present (Rice and Parenti 1978). Thus, the present evidence does not support the hypothesis that removal of allelopathy accounts for increased prairie production as a result of burning.

Increased Soil Temperature as a Result of Burning

Rice and Parenti (1978) concluded from their study of allelopathy that the increased productivity of burned areas resulted from the warmer temperature of burned than of unburned soils. Soils of burned areas warm distinctly faster than soils of unburned plots, due to removal of the litter and standing dead plants, and perhaps also due to the darker surface resulting from burning (Kelting 1957, Hulbert 1969). To test this hypothesis, water in an insulated tank heated by electric heaters was pumped through small plastic tubes inserted under standing dead plants in unburned plots so the tubes lay on the soil surface. Soil temperature was monitored. The resulting aboveground biomass was significantly greater on the plots unburned and warmed than on those unburned and not warmed. However, the increase in production was much less than that on burned plots, so it appears that soil warming is only a minor part of the reason for the increased production resulting from burning. It seems highly probable that increased light intensity for early growth resulting from the removal of standing dead vegetation is an important factor (Manuscript in preparation).

ACKNOWLEDGEMENTS

Contribution No. 85-245-A, Division of Biology and Kansas Agricultural Experiment Station.

LITERATURE CITED

Aldous, A.E. 1934. Effect of burning on Kansas bluestem pastures. Kans. Agric. Exp. Sta. Tech. Bull. 38. 65 pp.

Adams, D.E. and R.C. Anderson. 1978. The response of a central Oklahoma grassland to burning. Southwest. Nat. 23:623-632.

Adams, D.E., R.C. Anderson and S.L. Collins. 1982. Differential response of woody and herbaceous species to summer and winter burning in an Oklahoma grassland. Southwest. Nat. 27:55-61.

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. and C.E. Owensby. 1969. Common names of a selected list of plants. Kans. Agric. Exp. Sta. Tech. Bull. 117. 62 pp.

Anderson, R.C. and C. Van Valkenburg. 1977. Response of a southern Illinois grassland community to burning. Ill. State Acad. Sci. Trans. 69:399-414.

Bell, E.L. and L.C. Hulbert. 1974. Effect of soil on occurrence of cross timbers and prairie in southern Kansas. Kans. Acad. Sci. Trans. 77:203-209.

Bragg, T.B. 1982. Seasonal variations in fuel and fuel consumption by fires in a bluestem prairie. Ecology 63:7-11.

Bragg, T.B. and L.C. Hulbert. 1976. Woody plant invasion of unburned Kansas bluestem prairie. J. Range Manage. 29:19-24.

Curtis, J.T. and M.L. Partch. 1950. Some factors affecting flower production in *Andropogon gerardi*. Ecology 31:488-489.

Dokken, D. and L.C. Hulbert. 1978. Effect of standing dead plants on stem density in bluestem prairie. Pages 78-81 in D.C. Glenn- Lewin and R.Q. Landers, Jr., editors. Fifth Midwest Prairie Conf. Proc., Iowa State University, Ames.

Ehrenreich, J.H. 1959. Effect of burning and clipping on growth of native prairie in Iowa. J. Range Manage. 12:133-137.

Ehrenreich, J.H. and J.M. Aikman. 1963. An ecological study of the effect of certain management practices on native prairie in Iowa. Ecol. Monogr. 33:113-130.

Gaskill, A. 1906. Why prairies are treeless. Soc. Amer. Foresters Proc. 1:158-178.

Gleason, H.A. 1913. The relation of forest distribution and prairie fires in the middle west. Torreya 13:173-181.

Great Plains Flora Association. 1986. Flora of the Great Plains. University Press of Kansas. Lawrence.

Hadley, E.B. and B.J. Kieckhefer. 1963. Productivity of two prairie grasses in relation to fire frequency. Ecology 44:389- 395.

Hulbert, L.C. 1969. Fire and litter effects in undisturbed bluestem prairie in Kansas. Ecology 50:874-877.

Hulbert, L.C. and J.K. Wilson. 1983. Fire interval effects on flowering of grasses in Kansas bluestem prairie. Pages 255-257 in C.L. Kucera, editor. Seventh North Am. Prairie Conf. Proc., Southwestern Missouri State Univ., Springfield.

Kelting, R.W. 1957. Winter burning in central Oklahoma grassland. Ecology 38:520-522.

Komarek, E.V., Sr. 1968. The nature of lightning fires. Pages 5-41 in E.V. Komarek, Sr., editor. Tall Timbers Fire Ecology Conf. Proc. No. 7.

Kucera, C.L. and R.C. Dahlman. 1968. Root-rhizome relationships in fire-treated stands of big bluestem, *Andropogon gerardi* Vitman. Am. Midl. Nat. 80:268-271.

Kucera, C.L. and J.H. Ehrenreich. 1962. Some effects of annual burning on central Missouri prairie. Ecology 43:334-336.

Kucera, C.L., J.H. Ehrenreich and C. Brown. 1963. Some effects of fire on tree species in Missouri prairie. Iowa State J. Sci. 38:179-185.

Kucera, C.L. and M. Koelling. 1964. The influence of fire on composition of central Missouri prairie. Am. Midl. Nat. 72:142- 147.

Lloyd, P.S. 1972. Effects of fire on a Derbyshire grassland community. Ecology 53:915-920.

Old, S.M. 1969. Microclimate, fire, and plant production in an Illinois prairie. Ecol. Monogr. 39:355-384.

Owensby, C.E. and K.L. Anderson. 1967. Yield responses to time of burning in the Kansas Flint Hills. J. Range Manage. 20:12-16.

Owensby, C.E., K.R. Blan, B.J. Eaton and O.G. Russ. 1973. Evaluation of eastern redcedar infestations in the northern Kansas Flint Hills. J. Range Manage. 26:256-260.

Owensby, C.E. and E.F. Smith. 1973. Burning true prairie. Pages 1- 4 in L.C. Hulbert, editor. Third Midwest Prairie Conf. Proc., Div. of Biology, Kansas State University, Manhattan.

Owensby, C.E. and J.B. Wyrill, III. 1973. Effects of range burning on Kansas Flint Hills soil. J. Range Manage. 26:185-188.

Rice, E.L. and R.L. Parenti. 1978. Causes of decreases in productivity in undisturbed tall grass prairie. Am. J. Bot. 65:1091-1097.

Shimek, B. 1911. The prairies. Bull. Lab. of Nat. Hist., State Univ. of Iowa, VI(1):167-240 plus plates.

Shimek, B. 1948. The plant geography of Iowa. Univ. Iowa Studies in Nat. Hist. 18(4):1-178.

Towne, G. and C. Owensby. 1984. Long-term effects of annual burning at different dates in ungrazed Kansas tallgrass prairie. J. Range Manage. 37:392-397.

Westover, D.E., compiler. 1977-1984. Nebraska wildfires. Annual reports of Dept. of Forestry, Fisheries and Wildlife, Univ. Nebr., Lincoln. Reports for 1976 through 1983 used.