

Effect of Fire on Shortgrass and Mixed Prairie Species¹

J. L. LAUNCHBAUGH²

*Fort Hays Branch, Kansas
Agricultural Experiment Station, Hays, KS 67601*

THE major portion of North American grassland (Fig. 1) extends eastward from the Rocky Mountains of Canada, the United States, and Mexico to the Central Lowland of eastern United States (Weaver and Albertson 1956). There are discontinuous extensions westward into Idaho, British Columbia, Washington, Oregon, California, and Arizona.

The eastern part (Fig. 2) is Tallgrass or True Prairie with blue-stem³ dominants (Carpenter 1940; Clements and Shelford 1939; Shantz and Zon 1924). Livingston and Shreve (1921) charted the same area Grassland-Forest mixture east of a large undifferentiated Grassland. Moving westward, we see Tallgrass Prairie grading into Mixed or Shortgrass Prairie dominated by shorter species. Depending on the views of the authority, Mixed Prairie composed of short, mid, and tall grasses extends beyond the 100th meridian as an entity (Clements and Shelford 1939) or as a Grazing Disclimax of short-grasses over the Great Plains (Weaver and Albertson 1956). Carpenter (1940) recognized a zone of Mixedgrass giving way to Shortgrass at about the 100th meridian, while Shantz and Zon (1924)

¹Contribution No. 273, Fort Hays Branch, Kansas Agricultural Experiment Station.

²Professor of Range Management, Fort Hays Branch Experiment Station, Hays, Kansas 67601.

³Common names follow Anderson and Owensby (1969).

J. L. LAUNCHBAUGH

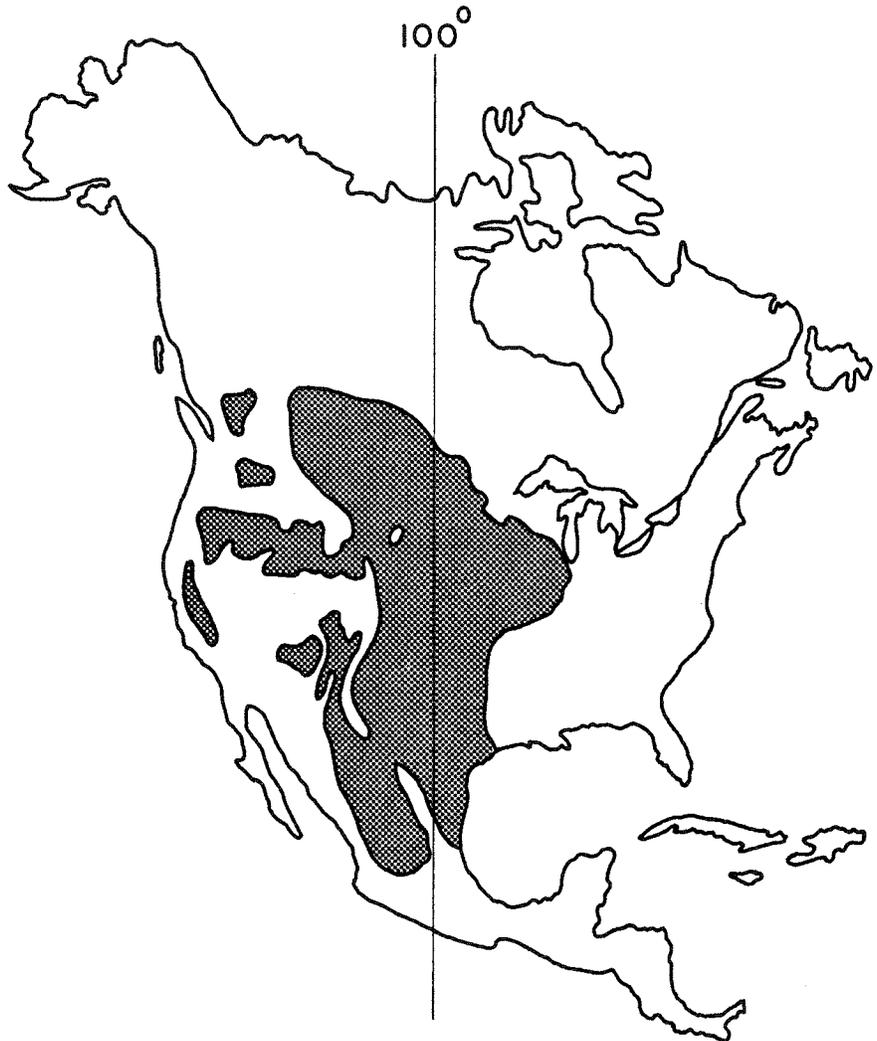


FIG. 1. The North American grassland climax adapted from Weaver and Clements (1938).

classified most everything as either Tallgrass or Shortgrass Prairie with the 100th meridian as the dividing line. In spite of differences in views there is a transition from Tallgrass Prairie on the east, to Mixed Prairie centrally, to Shortgrass Prairie on the Great Plains.

The most recent concept (Fig. 3) (Küchler 1965) embraces some of the older interpretations, along with new boundary lines separating types.

Conceived in the rain shadow of the Rocky Mountains more than 30 million years ago, the central grasslands reflect the stresses imposed on them throughout their long development. The indigenous grasses are well adapted to climatic extremes in temperature, precipitation amounts and frequencies, wind velocities, and humidities common to continental climates (Fig. 4). Climate of the grassland, particularly in the Great Plains, is characterized by extremes of all weather features.

Most of the grasses tolerate grazing, are palatable, and are highly nutritious before they mature (Fig. 5). Although continued heavy grazing Mixed Prairie will cause increases in the shorter species and lower forage yields (Launchbaugh 1967), climax species rarely give way completely to invading vegetation. In addition to a remarkable tolerance to over grazing, Mixed and Shortgrass Prairie species recuperate rapidly under proper grazing, indicating a history of grazing pressure and unquestionably a development closely associated with herds of evolving herbivores.

Finally there is the role of fire as a factor in species development and determination of prairie boundaries. The concept that frequent pristine prairie fires were instrumental in maintaining herbaceous species at the expense of shrubs and trees has not been universally accepted (Fig. 6) (Weaver and Albertson 1956; Young et al. 1948). However, the circumstantial evidence of periodic burning throughout grassland development, first by lightning and later by human agents as well, is overwhelming (Komarek 1964; Komarek 1968). Climatic and topographic characteristics are compatible with Sauer's (1950) views of features conducive to periodic, widespread burning during prairie development. Early historical accounts indicate burning was frequent and fires swept over large areas. Jackson (1965) documented prevalence and magnitude of Great Plains fires before and during settlement.

In most quarters concern now has shifted from whether the North American central grasslands burned regularly under pre-settlement conditions to how and where fire may be used in grass-

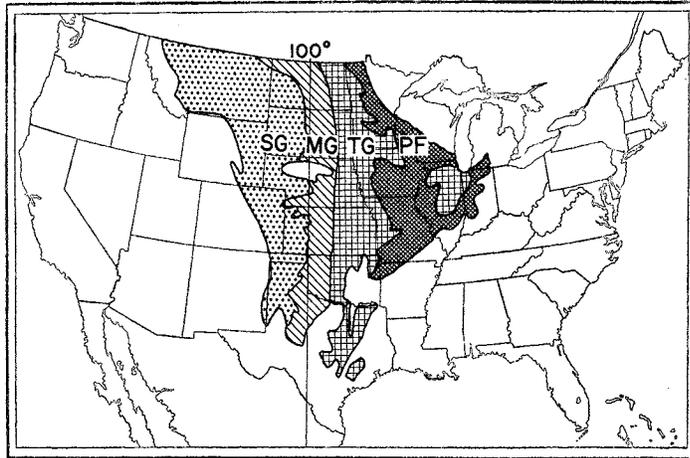


FIG. 2a

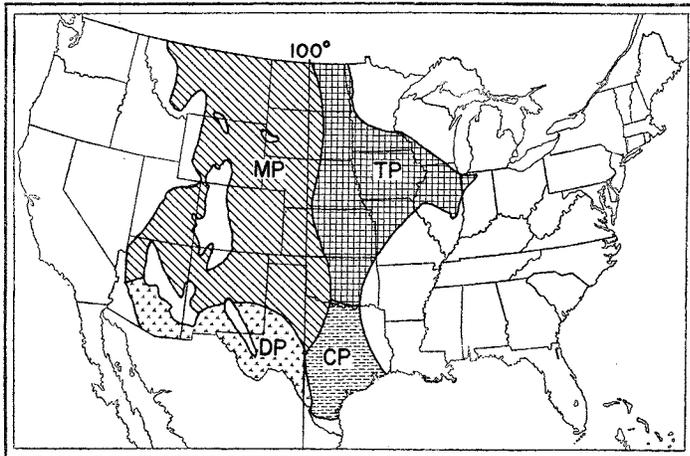


FIG. 2b

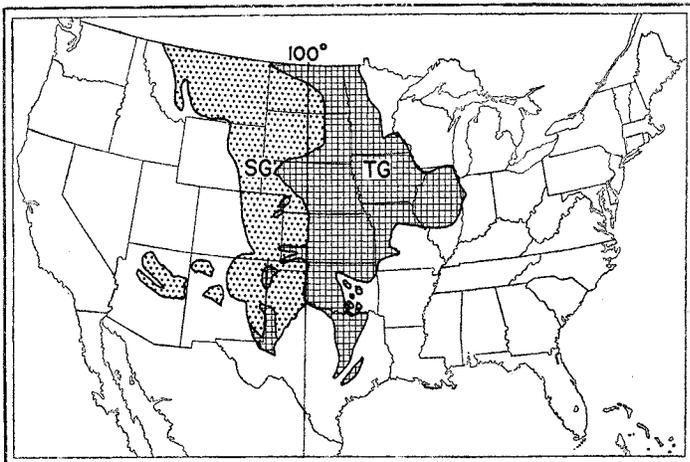


FIG. 2c

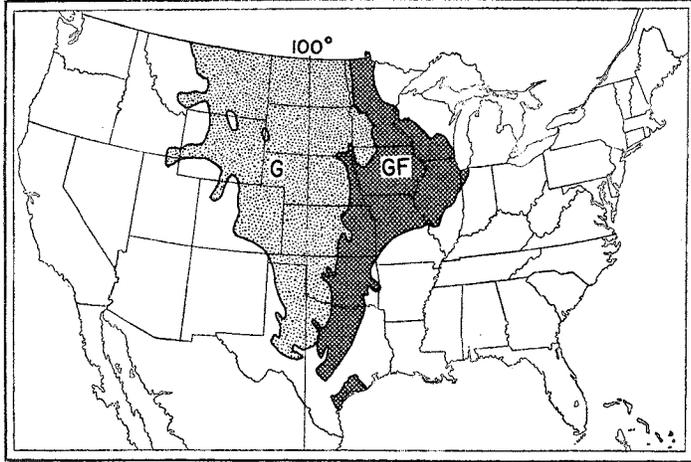


FIG. 2d

Figs. 2a-d. Generalized classifications of Central United States grasslands from various authorities. 2a Carpenter (1940), PF = Prairie-Forest Ecotone; TG = Tall-grass Prairie; MG = Mixed-grass Prairie; SG = Short-grass Plains; 2b Clements & Shelford (1939), TP = True Prairie; MP = Mixed Prairie; CP = Coastal Prairie; DP = Desert Plains; 2c Shantz & Zon (1924), TG = Tall Grass Prairie; SG = Short Grass Plains; 2d Livingston & Shreve (1921), GF = Grassland-Forest Transition; G = Grassland.

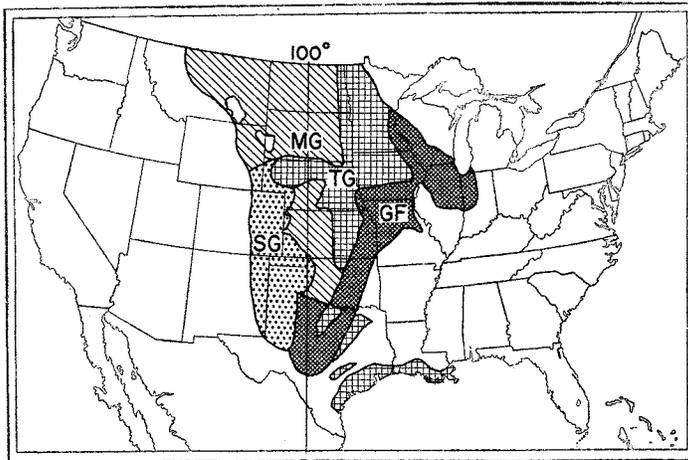


FIG. 3. Generalized potential natural vegetation of Central United States grasslands from Küchler (1965). GF = Grassland and Forest Combinations; TG = Tall to Medium Tall Grass Dominants; MG = Short to Medium Tall to Tall Grass Dominants, SG = Short Grass Dominants.

J. L. LAUNCHBAUGH

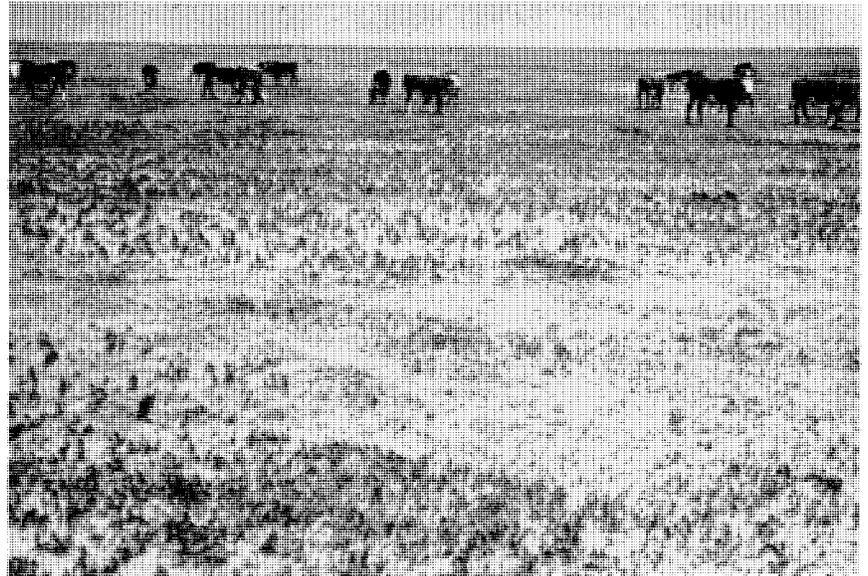


FIG. 4. Drought effects on Shortgrass Prairie.



FIG. 5. Bison grazing Mixed Prairie.

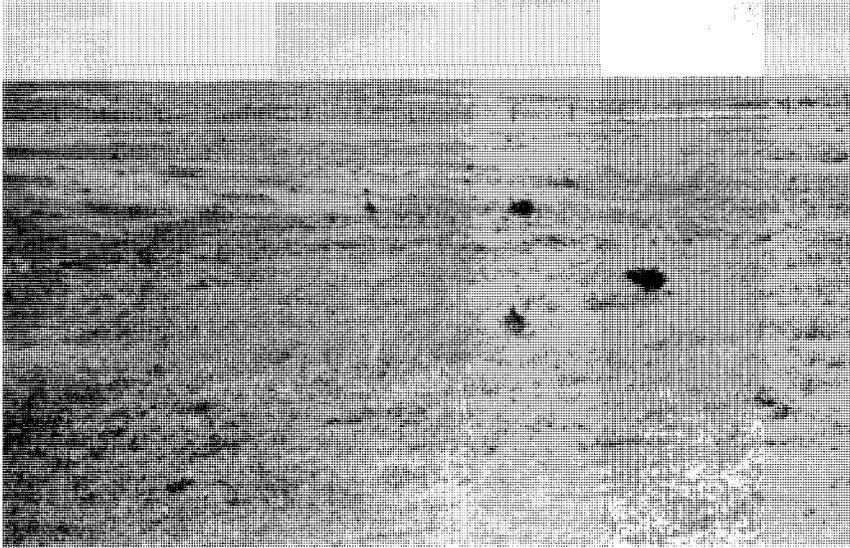


FIG. 6. Mixed Prairie near Hays, Kansas, invaded by red cedar.

land management. Widely practiced in the Flint Hills Tallgrass Prairie (Aldous 1934), burning has been primarily to improve forage quality and summer grazing performance of young cattle (McMurphy and Anderson 1965; Anderson et al. 1970), with woody plant suppression an added benefit. Farther west in other grassland types, emphasis has been on brush and weed control (Valentine 1971). Except for a few specific applications, prescribed burning is not generally used on ranges of Mixed and Shortgrass Prairie species. Indeed, much effort is made to suppress burning (Fig. 7) by maintenance of fireguards, and cooperative fire fighting activities.

Wildfires occur, however, and the effects of some have been reported. Jackson (1965) stated that accidental fires in the Texas Panhandle preceding prolonged drought set back plant succession in much the same manner as does depletion grazing, which commonly accompanies long drought periods in that region. Studies of two wildfires, one in late November and the other the following March, in contiguous Mixed Prairie sites in western Kansas showed that spring burning under the prevailing conditions was much more harmful to the vegetation than fall burning. Compared with small unburned

J. L. LAUNCHBAUGH

areas in moderately grazed vegetation, burning at either time reduced basal cover and yields of desirable grasses (big bluestem, little bluestem, sideoats grama, buffalograss, and blue grama) and increased yields of undesirable broadleaved plants, principally western ragweed (Hopkins et al. 1948). A later study of another March wildfire in the same vicinity on tight clay soils with predominantly shortgrass species showed yield reductions of all species (including buffalograss, blue grama, western wheatgrass, western ragweed, and maretail) for two seasons following the fire (Launchbaugh 1964). In addition to immediate plant crown damage, soil moisture relations apparently were less favorable where the vegetation had burned off. A late-fall wildfire in Wyoming Mixed Prairie vegetation reduced sixweeks fescue to traces (Barnes and Lang 1943). Emerged plants were killed, and new seedlings did not come up to replace them. Production of all forage was less, compared with unburned areas in the same region. Sites involved included buffalograss, blue grama, and western wheatgrass; needleandthread; and sandberg bluegrass. In each case, first-year yields were reduced about 50 percent because of



FIG. 7. Fireguard to protect rangeland from accidental burning.

reduced moisture in the top foot of soil. With nothing to catch winter snow, the soil received less moisture and was exposed to maximum evaporation losses.

Wildfires generally occur when fuel accumulations are dry, relative humidities low, and wind velocities high. Not only are highly flammable fuel conditions conducive to wildfires, but the resulting burns generally consume all top growth and mulch. Grass crowns may even be killed or partially damaged. Although wildfire effects may not indicate prescribed burning effects, Lowance (1967) reported some crown killing of blue grama in burning tests in south central New Mexico. Backfiring was used to burn the plots, resulting in the hottest fire at ground level.

Grass fires are relatively "cool", typically resulting in lower soil temperatures than brush burns (Bentley and Fenner 1958). Fuel density primarily, along with air temperature, and wind velocity, however, can alter soil heating effects greatly (Stinson and Wright 1969). In the same burn, therefore, temperatures can be highly variable and consequent killing effects equally variable. According to Byram (1958), the quantity of heat required to raise the temperature of living plant tissue up to the lethal temperature is directly proportional to the difference between that temperature and the initial vegetation temperature; hence, fires of equal intensity are more damaging on hot than on cool days. Coupled with fuel density, temperature probably is the deciding factor in whether or not a plant survives a fire. Fig. 8 shows soapweed slightly scorched, while Fig. 9 shows soapweed a few feet away killed by the same fire.

After the fire is out, other factors are important in determining the extent of benefit or damage to Mixed and Shortgrass Prairie vegetation. The central grasslands occur on a wide range of parent materials, slopes, and soil types. In association with similar precipitation amounts and other weather factors, different soils may produce different combinations and amounts of vegetation. For range management purposes, different combinations are designated as separate range sites. Thus, sites vary from clayey to loamy to sandy; noncalcareous to calcareous; nonsaline to saline; level to sloping; and deep to shallow. Associated vegetation ranges from pure shortgrass stands to various short-, mid-, and tall-grass mixtures. Common range sites repre-

J. L. LAUNCHBAUGH

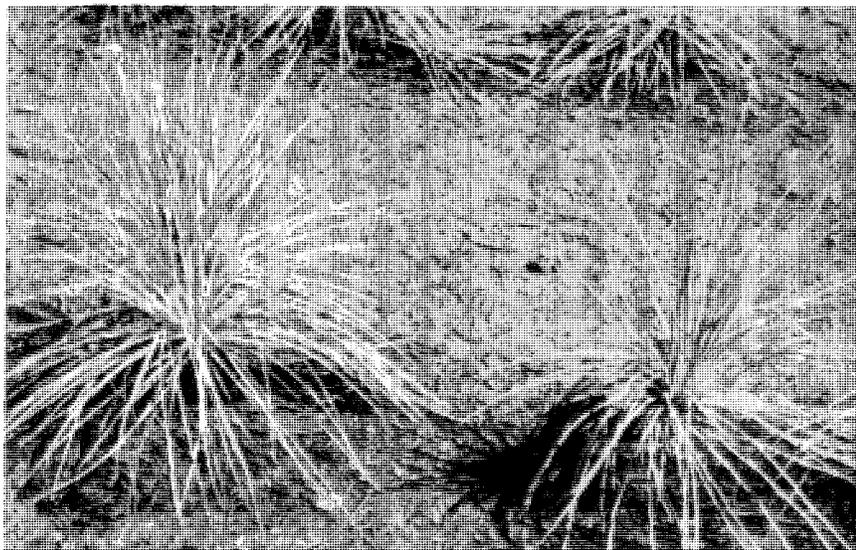


FIG. 8. Soapweed plants slightly scorched by grass fire.



FIG. 9. Soapweed plants killed by grass fire.

FIRE IN SHORT-GRASS AND MIXED PRAIRIE SPECIES

sented in the central plains include Clay upland, Loamy upland, Limy upland, Breaks, Loamy lowland, and various Sandy sites (Fig. 10). Generally, range site soil moisture relations for plants improve in the order listed above, and species shift from short grasses to mid and tall grasses in response to improved soil moisture relationships. Thus both climatic and edaphic features are important in determining distribution of Mixed and Shortgrass Prairie species. Range-site characteristics in turn are important in evaluating residual effects of burning.

Duley and Kelly (1941) in stressing the importance of soil-surface condition in regulating water intake, pointed out that the presence of a mulch greatly improved infiltration, over that of bare soil. Hopkins (1954), who reviewed the literature on effects of mulch on water intake and microclimate, presented data showing that Mixed Prairie had mulch amounts ranging from 900 to 22,600 lbs per acre, depending on variations in site, species, and grazing intensities. Although mulch reduces soil temperatures, retards evapora-

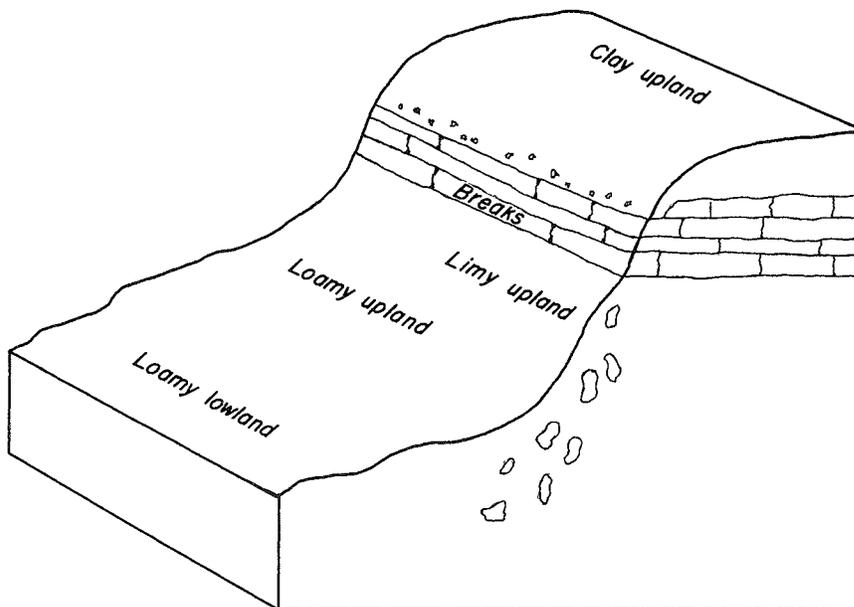


FIG. 10. Schematic view of common central plains range sites.

tion, and increases infiltration rates, excessive amounts accumulating under very light or no grazing can cause grass-stand degeneration and lower yields, even in Shortgrass Prairie (Tomanek 1948). That seldom happens under grazing intensities that remove 30 to 75 percent of the current year's growth annually. Fig. 11 shows that when large, medium, and small amounts of old growth are left on lightly, moderately, and heavily grazed Mixed Prairie at the end of the growing season, large amounts deteriorate during the following winter and next growing season. Add the influences of livestock trampling, which enhances mulch-soil contact, and natural deterioration prevents any serious residue buildup. Large quantities of old growth disappear faster than do small amounts.

It is difficult to quantify optimum amounts of mulch. While too much can be detrimental to species composition and production, total removal of tolerable amounts of dead growth and surface

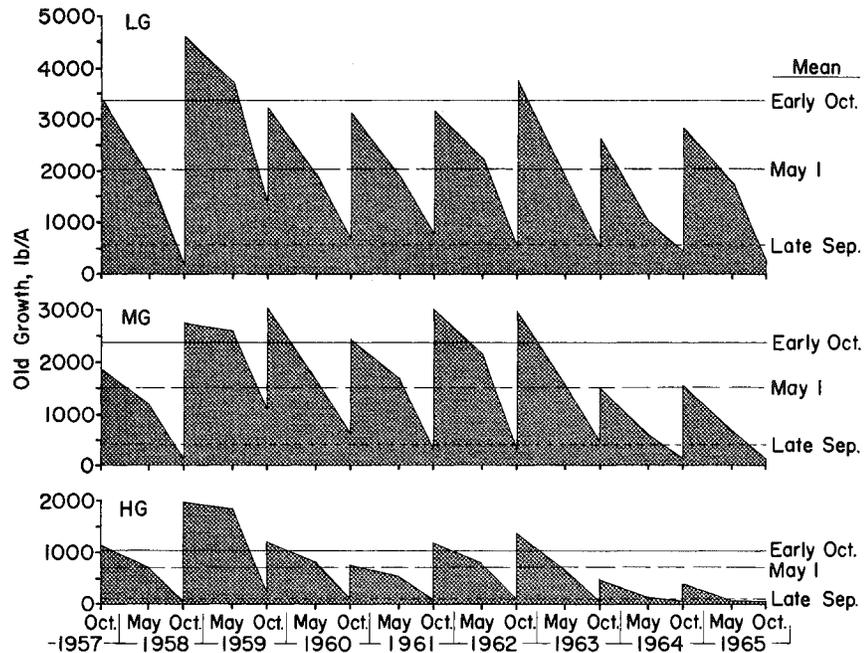


FIG. 11. Amounts of old growth left under three intensities of summer grazing on a Clay upland range site at Hays, Kansas.

FIRE IN SHORT-GRASS AND MIXED PRAIRIE SPECIES

mulch also may reduce production of Mixed and Shortgrass Prairie species, as is shown by the results of mow and rake treatments during the dormant and early spring growth periods at Hays, Kansas (Fig. 12). Once each year (through winter and early spring) for three successive years plots were mowed at a 1½-inch stubble height and the material removed. Compared with untreated controls, mowing and raking on the various dates reduced yields nearly 25 percent the first year, nearly 50 percent by the third year. After the first season, it was more detrimental to remove old growth and sparse new growth on 1 May than removal on any other date. Although removal during the dormant season reduced production of all species, western wheatgrass and western ragweed were reduced the most. Unharvested plots showed reductions in short grasses, buffalo-

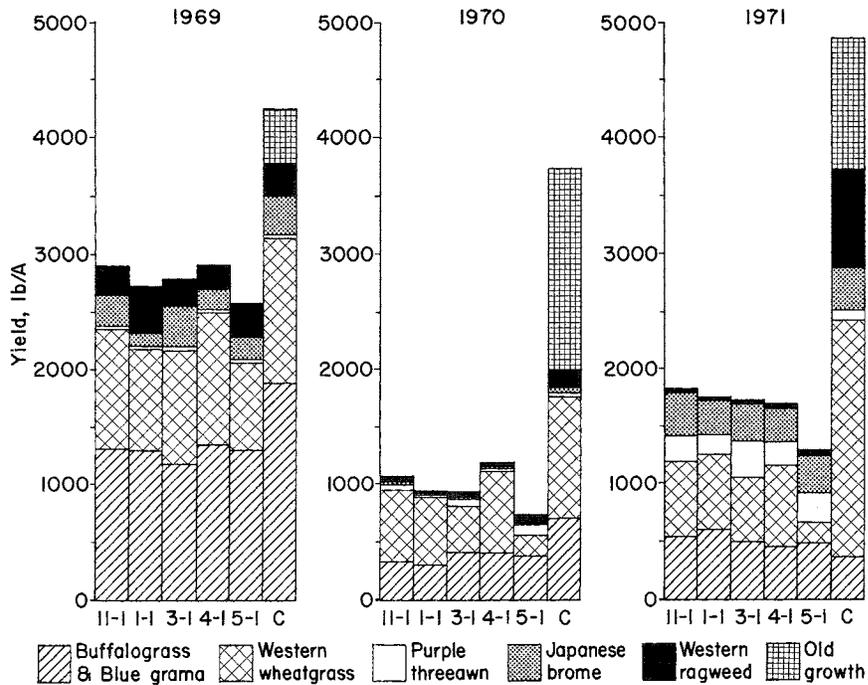


FIG. 12. Effects of removing old growth by mowing and raking during the winter and early spring months on Mixed Prairie herbage production. Material was removed on the first of November, January, March, April, and May each winter preceding these 1969-71 growing seasons.

J. L. LAUNCHBAUGH

grass and blue grama, during the third year, mainly from competition with increased amounts of western wheatgrass. It may be too early to forecast the ultimate fate of these plots particularly the unmowed controls. Under favorable growing conditions the Clay upland range site frequently degenerates to a recycling of an open grass cover to dense stands of sunflowers or other annual weeds. Fig. 13 shows a shortgrass site that degenerated to a stand of annual sunflowers when protected from grazing and burning for many years.

Yield reductions associated with removing dormant growth probably result largely from exposure to extremes of winter temperatures, increased respiration and stored food use during dormant season, and less favorable soil moisture relations than found in areas where the old growth is not removed. On silty clay loam soils of the Clay upland range site, for example, moisture intake may be less than 0.5 inch/hr where a large part of the top growth has been removed; also, evaporation rates are greater on denuded than on mulched areas. The net effect is less moisture for plant growth in a



FIG. 13. A west-central Kansas Clay upland range site that degenerated from a mixture of short grasses to annual sunflowers when protected from grazing and burning.

FIRE IN SHORT-GRASS AND MIXED PRAIRIE SPECIES

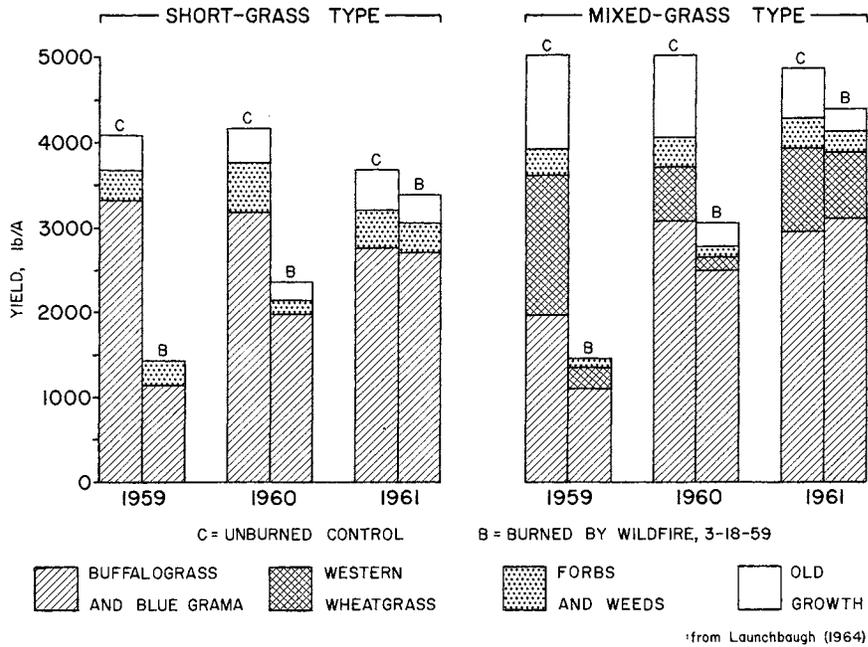


FIG. 14. Effects of a late March wildfire on species production of two Mixed Prairie sites at Hays, Kansas.

situation where soil moisture is the major limiting factor to plant growth.

Such an effect was shown in a study of a wildfire that burned off the standing dead and essentially all mulch and litter on a Clay upland range site 18 March, 1959. Burning onto the crowns of buffalograss and blue grama resulted in some stand thinning, but accounted for only part of the yield reductions illustrated in Fig. 14. Until the third season after the fire, soil moisture conditions appeared to be less favorable on burned than on adjacent, unburned areas. That study is described in detail by Launchbaugh (1964).

Late-summer controlled burning or close mowing and raking during 2 successive years in the Dakota Sandstone area of north-central Kansas resulted in nearly 40 percent yield reduction of Mixed and Shortgrass Prairie species 1 year following the last treatment compared with no burning or mowing (Fig. 15). Except for

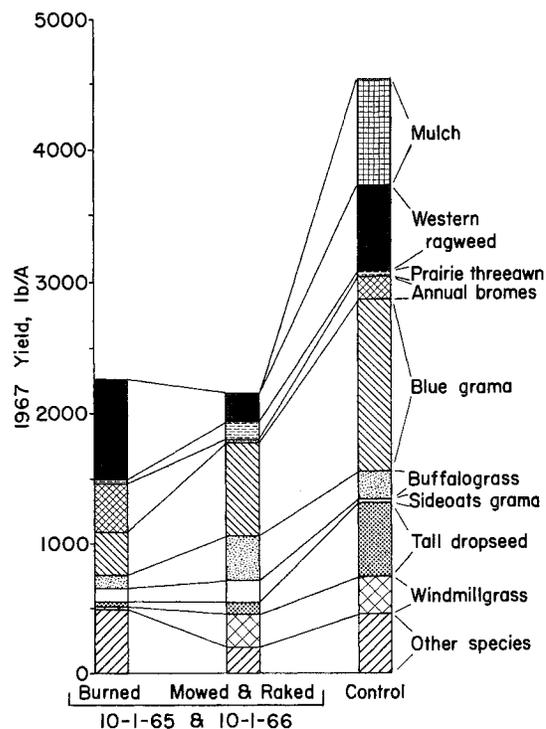


FIG. 15. Effects of 1 October burning or mowing and raking, two successive years, on species yields of a Clay upland range site in the Dakota Sandstone area of north-central Kansas.

significantly different reductions in ragweed from mowing, and in blue grama and windmillgrass from burning, other species responded similarly to both treatments. Again, those treatments were on relatively tight soils in the Clay upland range site, where removing all soil protection resulted in less favorable soil moisture intake and greater evaporation.

Three burning experiments (at Hays) involving planted Short-grass and Mixed Prairie species in pure stand illustrate the major role of soil type (hence, range site) as a factor in influencing species responses to topgrowth removal by fire or mowing and raking.

To develop management techniques for grasslands that receive little or no grazing use (such as protected areas around reservoirs

FIRE IN SHORT-GRASS AND MIXED PRAIRIE SPECIES

and similar sites set aside for public use), a combination of mowing, raking, and burning treatments were imposed on four native grasses planted in pure stands on a tilled, Limy upland range site. Generally that site takes in moisture faster than nearby Clay upland sites do. The study involved the management of mowed material. All treatments were mowed at a 2-inch stubble height about 1 October each year (early in the dormant period). Subsequent treatments included raking immediately after mowing, fall burning (1 November) of the freshly mowed material in place, spring burning (1 April) of the residual mowed material in place, and leaving the fall-mowed material in place. Fig. 16 shows the herbage-yield means for 8 years of treatment (upper row of bars) for the four grasses studied. Switchgrass and big bluestem yields were significantly higher under a system of mowing and leaving the material in place than under any other treatment. Mowing and raking resulted in the next best yields that

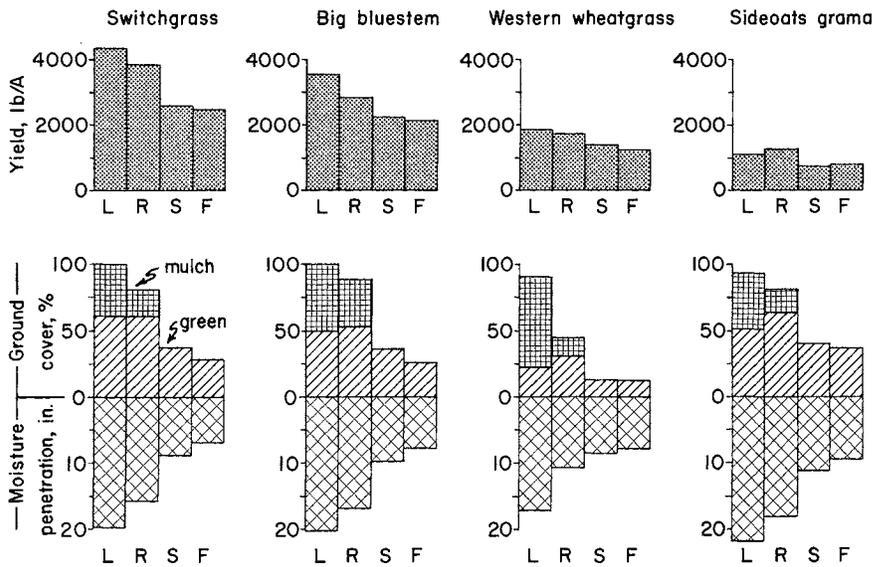


FIG. 16. Eight-year average herbage yields of four grasses (first row) from fall mowing and leaving mowed material (L), fall mowing and raking (R), fall mowing and spring burning mowed material (S), and fall mowing and fall burning of mowed material (F); ground cover sixth year (upper bars of second row); and average depth of soil moisture penetration (lower bars of second row) following approximately 3.5 inches precipitation on each of two 24-hour periods.

J. L. LAUNCHBAUGH

were significantly better than burning the mowed material either in the fall or the following spring. For western wheatgrass and sideoats grama, there were no differences between mowing and leaving and mowing and raking or between the two burning dates. Burning on either date resulted in significantly lower mean yields compared with mowing or a combination of mowing and raking. Fig. 16 (upper portions of the lower row of bar graphs) also shows percentages of soil coverage by living and dead material for each species and treatment in mid summer 1965, 6 years after treatments were initiated. On each of two occasions during that summer, when the upper soils in all plots were dried by evapotranspiration to the wilting point or below, and grasses were dormant, approximately 3.5 inches of rain fell in less than 6 hours. At field capacity, the soils hold about 2 inches of water per foot of depth. The lower portions of the bottom row of graphs (Fig. 16) show average moisture penetration resulting from the two separate rainstorms measured the day following each rain. The penetration means are highly meaningful in that there were no significant species, date, or depth of penetration interactions. Penetration depths were different and greatest under complete soil protection by both living and dead material, and at the rate of 2 inches per foot of soil the intake accounted for most of the precipitation that fell. Although mowed and raked plots generally had slightly more living plant coverage than did the unraked, there was significantly less dead residue coverage, hence, some exposed soil. Moisture intake was correspondingly less, compared with plots where the material was not removed. Annual fall or spring burning consumes essentially all the mulch and litter resulting in less green cover and less moisture intake. Paradoxically, a high percentage soil coverage is essential to have a high percentage of moisture intake and high percentage intake is essential to produce large quantities of soil cover.

The second experiment involved a Loamy lowland site with silt loam alluvial soils having generally excellent soil moisture-plant growth relationships. Burning or mowing and raking improved the stand and at least did not reduce yields of seeded western wheatgrass in pure stands (Fig. 17). Four years of treatment indicated that plant shoot numbers (top row of graphs) were 1½ to 4 times greater where growth was removed annually by burning or mowing

FIRE IN SHORT-GRASS AND MIXED PRAIRIE SPECIES

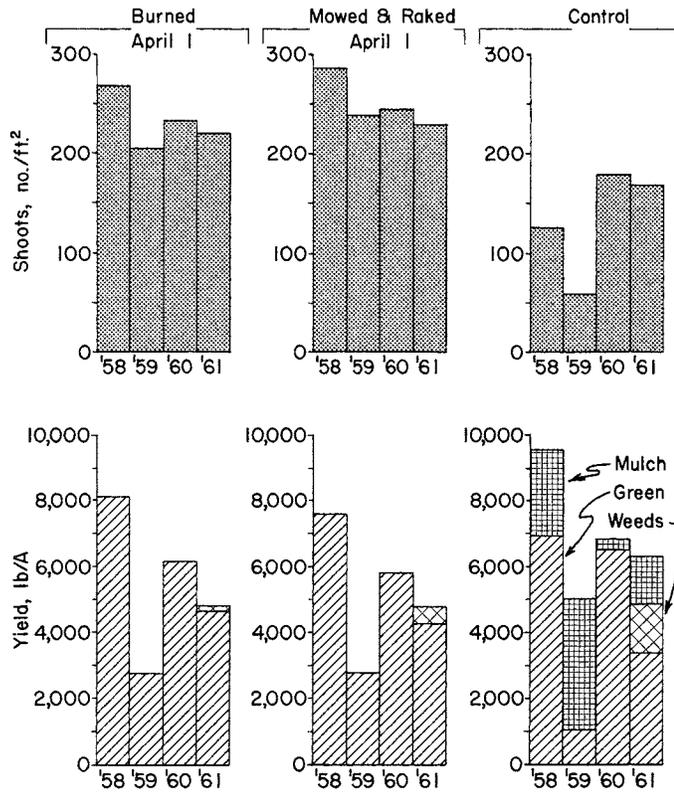


FIG. 17. Effects of spring burning, mowing and raking, and total protection on shoot number and yield of seeded western wheatgrass on a Loamy lowland range site at Hays, Kansas.

and raking on 1 April than where it was not. Yields of green growth were generally greater under annual burning or mowing and raking, particularly in 1959, a year following an accumulation of nearly 5 tons of living and dead material per acre. Though recovery from self-mulching was complete the next year (1960), a similar buildup apparently could have been repeated. In addition, protected western wheatgrass became heavily infested with perennial and annual weedy vegetation. Burning or otherwise removing top growth minimized invasion of western wheatgrass by other species.

The final experimental burn was included in a 1-year study of method and date of residue removal on a switchgrass field planted

J. L. LAUNCHBAUGH

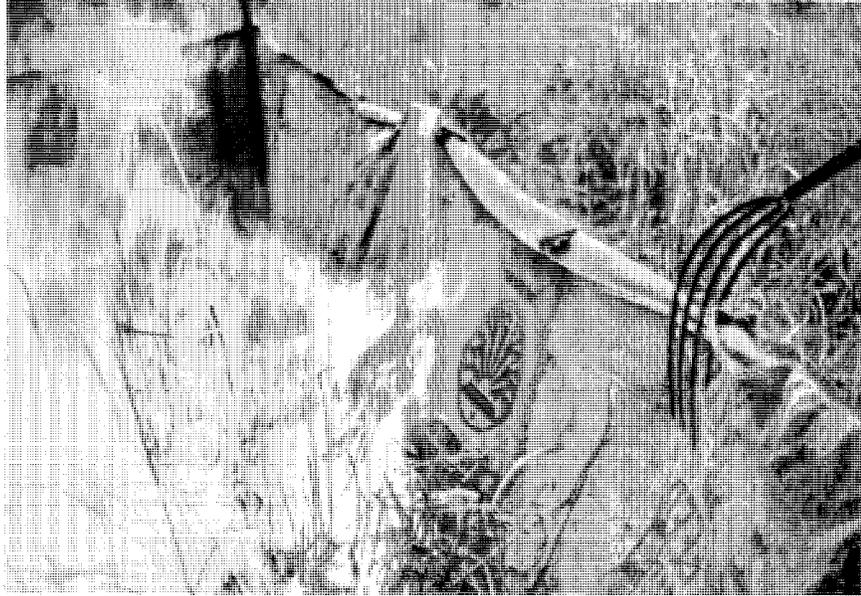


FIG. 18. Using flame resistant vertical fireguards to control burn switchgrass plots at Hays, Kansas.



FIG. 19. General view of switchgrass plots at Hays, Kansas, following 1 April mowing or burning, 1 May mowing or burning, and no treatment.

FIRE IN SHORT-GRASS AND MIXED PRAIRIE SPECIES

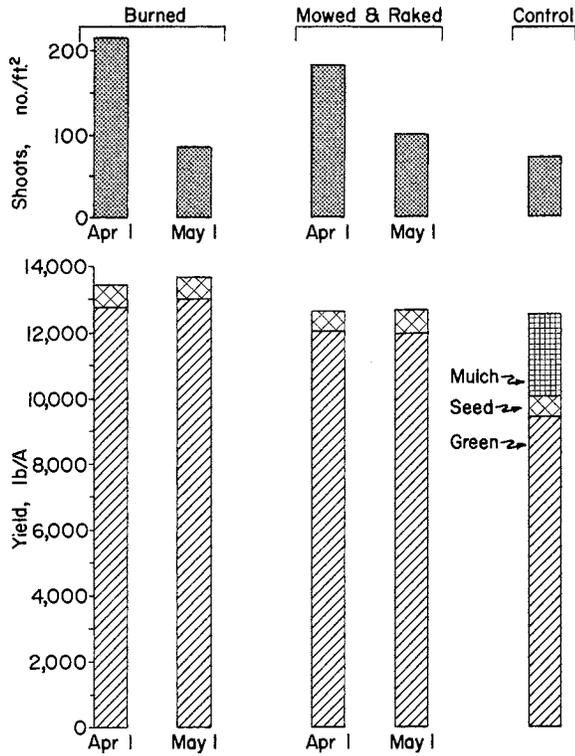


FIG. 20. Effects of early and late spring burning, mowing and raking, and total protection on shoot number, total yield, and seed production of switchgrass seeded in rows on a Loamy lowland range site at Hays, Kansas.

on a Loamy, lowland site similar to that described in the lowland western wheatgrass studies. Four treatments, burning on 1 April, mowing and raking on 1 April, burning on 1 May, and mowing and raking on 1 May, plus an untreated control were carried out in 1958 on material planted in 42-inch rows and winter-irrigated for seed production. Following seed harvest by combining in August, 1957, the residue composed of 30-inch stubble and threshings was left in place until spring, 1958. Fig. 18 illustrates the method of burning using fire-resistant vertical fireguards (Launchbaugh, 1971). Some early May differences are shown in Fig. 19. Fig. 20 (upper row) indicates that early burning or mowing and raking more than doubled plant shoot numbers compared with late burning or late mowing and raking or with no treatment. All residue-removal treatments in-

J. L. LAUNCHBAUGH

creased total yields significantly. Yields were greatest on the two burning treatments, but seed yields, not influenced significantly by treatment, averaged approximately 600 lbs/acre on all treatments. Although added accumulations of residue might have reduced seed yields eventually, annual removal was essential to facilitate cultivation and row maintenance. Burning was effective and the least expensive method.

SUMMARY

Reports of burn effects on the great central grasslands of North America and results of burning studies near Hays, Kansas suggest several generalizations about effects of burning Shortgrass and Mixed Prairie species. Where mulch accumulations of herbaceous vegetation are extremely great, burning will be beneficial, resulting in increased yields. Where mulch accumulations are tolerable, burning probably will reduce yields. That agrees with conclusions reported by Hulbert (1969). Reduced grass yields may result directly from heat kill and removal of growing points or indirectly from crown exposure to temperature extremes and from unfavorable soil moisture relationships associated with subjecting high clay content soils to the puddling action of raindrops.

Unless the overriding purpose is to control woody plants, to suppress wildfire hazard, or to reduce excessive mulch accumulation on special areas, periodic burning may result in such yield sacrifices that it cannot be considered as a practice per se of increasing livestock performance on many Mixed and Shortgrass Prairie range sites.

LITERATURE CITED

- Aldous, A. E. 1934. Effect of burning on Kansas bluestem pasture. Kansas Agric. Exp. Sta. Tech. Bull. 38.
- Anderson, K. L. and C. E. Owensby. 1969. Common names of a selected list of plants. Kansas Agric. Exp. Sta. Tech. Bull. 117.
- Anderson, K. L., E. F. Smith, and C. Owensby. 1970. Burning bluestem range. *J. Range Manag.* 23:81-92.
- Barnes, O. K. and R. Lang. 1943. Effect of range fires on forage production. *Wyoming Farmer-Stockman*. July. p. 4.
- Bentley, J. R. and R. L. Fenner. 1958. Soil temperatures during burning related to postfire seedbeds on woodland range. *J. Forest.* 56:737-740.
- Byram, G. M. 1958. Some basic thermal processes controlling the effects of fire on living vegetation. United States For. Serv. South East. For. Exp. Sta. Res. Note 114.

FIRE IN SHORT-GRASS AND MIXED PRAIRIE SPECIES

- Carpenter, J. R. 1940. The grassland biome. *Ecol. Monog.* 10:617-684.
- Clements, F. E. and V. E. Shelford. 1939. *Bio-ecology*. John Wiley & Sons, New York.
- Duley, F. L. and L. L. Kelly. 1941. Surface condition of soil and time of application as related to intake of water. United States Dept. Agric. Circ. 608.
- Hopkins, H. 1954. Effects of mulch upon certain factors of the grassland environment. *J. Range Manag.* 7:255-258.
- Hopkins, H., F. W. Albertson, and A. Riegel. 1948. Some effects of burning upon a prairie in west-central Kansas. *Trans. Kansas Acad. Sci.* 51:131-141.
- Hulbert, L. C. 1969. Fire and litter effects in undisturbed bluestem prairie in Kansas. *Ecology* 50:874-877.
- Jackson, A. S. 1965. Wildfires in the Great Plains grasslands. *Proc. Tall Timbers Fire Ecol. Conf.* no. 4, p. 241-259.
- Komarek, E. V., Sr. 1964. The natural history of lightning. *Proc. Tall Timbers Fire Ecol. Conf.* no. 3, p. 139-183.
- . 1968. Lightning and lightning fires as ecological forces. *Proc. Tall Timbers Fire Ecol. Conf.* no. 7, p. 169-197.
- Küchler, A. W. 1965. Potential natural vegetation of the conterminous United States. *American Geogr. Soc. Special Pub.* 36. (Rev. of 1964 map).
- Launchbaugh, J. L. 1964. Effects of early spring burning on yields of native vegetation. *J. Range Manag.* 17:5-6.
- Launchbaugh, J. L. 1967. Vegetation relationships associated with intensity of summer grazing on a clay upland range site in the Kansas 20- to 24-inch precipitation zone. *Kansas Agric. Exp. Sta. Tech. Bull.* 154.
- Launchbaugh, J. L. 1971. Vertical fireguards to control burning in small plots. *J. Range Manag.* 24:313.
- Livingston, B. E. and F. Shreve. 1921. The distribution of vegetation in the United States, as related to climatic conditions. *Carnegie Inst. Washington, Pub.* 284.
- Lowance, S. A. 1967. Burning and fertilization of a blue grama range site. Master's Thesis, New Mexico State Univ. Las Cruces, N.M.
- McMurphy, W. E. and K. L. Anderson. 1965. Burning Flint Hills range. *J. Range Manag.* 18:265-269.
- Sauer, C. O. 1950. Grassland climax, fire, and man. *J. Range Manag.* 3:16-21.
- Shantz, H. L. and R. Zon. 1924. Natural vegetation. United States Dept. Agric., *Atlas of American Agriculture*, part 1, sec. E.
- Stinson, K. J. and H. A. Wright. 1969. Temperatures of headfires in the southern Mixed Prairie of Texas. *J. Range Manag.* 22:169-174.
- Tomanek, G. W. 1948. Pasture types of western Kansas in relation to the intensity of utilization in past years. *Trans. Kansas Acad. Sci.* 51:171-196.
- Valentine, J. F. 1971. Range development and improvements. Brigham Young Univ. Press.
- Weaver, J. E. and F. W. Albertson. 1956. Grasslands of the Great Plains their nature and use. Johnson Publishing Co., Lincoln, Nebr.
- Weaver, J. E. and F. W. Clements. 1938. *Plant ecology*. 2nd ed. McGraw-Hill Book Co., Inc., New York.
- Young, V. A., F. Anderwald, and W. G. McCully. 1948. Brush problems on Texas ranges. *Texas Agric. Exp. Sta. Misc. Pub.* 21.