Time of Burning As It Affects Soil Moisture in an Ordinary Upland Bluestem Prairie in the Flint Hills[1]

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Highlight

Burning bluestem range reduces soil moisture. Study of long-continued annual burning in the winter and at various spring dates shows that earliest burnings cause greatest reductions. Foot-by-foot moisture levels in the upper 5 feet of soil during a 4-year period are considered.

Soil moisture shares with range management the role of determining herbage productivity. The two are so intimately associated that it is virtually impossible to ascribe effects solely to one or the other. Management affects amount of cover, botanical composition, and surface conditions, and changes in them may so greatly alter water relations as to vary herbage production widely. That, in turn, affects management.

An important phase of management that affects water relations and forage production in the Flint Hills is the widespread practice of range burning. The bluestem ranges of the Flint Hills first came under heavy, continued grazing in the early 1880's, at that time mainly for transient steers. Annual spring burning soon became a regular feature of management because steers gained more rapidly on burned than on unburned range. Fire continues to be used regularly on many thousands of acres of bluestem grassland. The study reported here was designed to isolate the effects of burning from those of grazing by using ungrazed plots for the trials. The plots have been burned annually for many years, and rather intensive studies of their productivity and botanical composition have been reported (Aldous, 1934; McMurphy and Anderson, 1963).

LITERATURE REVIEW

The literature on range burning contains many references to botanical composition, herbage yield, erosion, etc., but few to soil moisture, especially at the deeper soil layers. Aldous (1934) pointed out that the upper 3 feet of burned bluestem range were drier than those of adjacent unburned range and speculated that increased runoff caused the reduction. He also reported decreases in herbage yield following burning.

Reduction in soil moisture is associated with decreased infiltration rates as shown by Hanks and Anderson (1957). They had measured soil moisture just before an intense late-September rain of 4.47 inches. Measurements immediately after the storm showed that moisture in the upper 5 feet of soil had increased 4 inches in the unburned plots but only 2.5 inches in burned ones. This occurred on an ungrazed area on which the growth of the entire season had been left in place. Thus, the effect of burning on infiltration was seen to continue throughout the growing season despite the presence of top growth.

Hensel (1923), who started work on range burning at Manhattan, Kansas, in 1918, showed that both maximum and minimum soil temperatures averaged 3.5 to 4 F. higher for the season on burned than on unburned areas, but minimum temperatures frequently were lower on burned plots than on unburned ones in March and April. He did not measure soil moisture. Warmer soils, however, induce early, rapid plant growth, and that increases the early use of soil moisture. Such soils may be left with moisture shortages later in the season.

Yields of vegetation are reduced significantly by burning. Anderson (1964) reported that in 30 years of burning trials on ungrazed bluestem range at Manhattan, Kansas, burned plots yielded significantly less herbage than unburned ones, regardless of the time of burning. Plots burned in the late spring, however, yielded more than those burned earlier. Similar findings were reported (Smith et al., 1964) from nearby grazed bluestem range. Burned pastures yielded much less forage than unburned ones, but those burned late in the spring yielded more than those burned earlier. Despite burned pastures yielding less forage, their yields of beef were higher than yields from pastures not burned. There was, of course, no mulch in the burned areas, and the total amount of cover remaining there at the close of the growing season was no more than a third as great as on unburned range.

McMurphy and Anderson (1963) also showed that herbage yields were adversely affected by burning and that the greatest reductions occurred in the driest seasons, but range burning does not everywhere cause reductions in yield of true prairie herbage. Ehrenreich and Aikman (1957) compared yields and seedstalk production on burned and unburned prairie in northeastern Iowa. The three grasses, big bluestem *(Andropogon gerardi* Vitman), little bluestem *(A. scoparius* Michx.), and indiangrass *(Sorghastrum nutans* (L.) Nash), yielded nearly twice as much herbage and several times as many seedstalks on burned as on unburned plots. Dix and Butler (1954) reported increases in height and number of flower stalks in most prairie species the first growing season following fire in Wisconsin prairie.

Curtis and Partch (1950) in Wisconsin attributed increases in yield and flower stalk production following the burning of big bluestem chiefly to removal of the insulating cover of old stems. Its removal permitted plants to begin growth early and to build up a favorable carbo-

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hydrate reserve before the normal period of flower primordium initiation. They reported that the fertilizing action of the ashes remaining from the burned litter was responsible for a small further increase in flower production but had no influence on plant height.

Dix (1960) commented further on recovery of mulch after burning. He reported that mulch structure in *Stipa comata* had returned to its prefire condition after four growing seasons. Following fire the rate of organic decomposition appeared to be slow for several years. As the mulch became deeper and more compact, the rate of decomposition increased until an equilibrium between annual herbage production and annual decomposition again became established.

Kucera and Ehrenreich (1962) in a 3-year study obtained marked increase in growth on burned plots, and flower stalks of big and little bluestem and indiangrass were more numerous. They attributed the increase in production to higher soil temperatures in early spring, reduction in shading, and greater availability of nutrients.

In another paper (1963), Ehrenreich and Aikman noted that 10 years of complete protection in the mesic Hayden Prairie in northeastern Iowa permitted a buildup of mulch that exceeded in quantity the annual yield of vegetation. They reported more early growth on burned plots than on unburned ones but no significant difference in total herbage yield. This follows somewhat the pattern of growth in Flint Hills prairie. Herbage yields in the early weeks of the growth period are generally greater on burned than on unburned areas, but later the unburned ones surpass the burned ones and usually reach greater total production for the season as a whole.

It appears that burning does not necessarily cause reductions in yield in the easternmost (wettest) part of the prairie area, but experiments reported above probably have not been continued over a sufficiently long time to determine the effects of repeated burning either on herbage yields or on soil moisture.

Burning may cause severe reductions in yield in the drier parts of the prairie. Hopkins et al. (1948) found that burning in west-central Kansas, where annual precipitation is less than 25 inches, reduced the cover of little bluestem severely. Yields of herbage were also greatly reduced. Manhattan lies in an area where annual precipitation averages 32 inches. That may be low enough for any reduction in moisture to be reflected in reduced herbage yields. Certainly, the yield reductions following burning are relatively greater in dry years than in favorable ones.

Another case of reduced forage production due to burning was reported by Elwell et al. (1941) who showed that herbage yields at Guthrie, Oklahoma, were reduced between 40 and 60% following burning. Annual plants replaced much of the original perennial vegetation. Annual precipitation is roughly the same as at Manhattan.

Bluestem burning places limitations on the range manager. He must know and understand the responses of both range plants and range animals. Martin and Cosby (1955) emphasized this in discussing the need for good grazing management both before and after range burning.

Materials and Methods

The Study Area. — The experimental area is a deep, friable, fairly level, ordinary-upland true-prairie range site lying along a ridgetop just north of the Kansas State University beef cattle barn. The soil has tentatively been classified as Geary silty clay loam. Soil of this type, if it occurred in a large enough area on a general farm, would almost certainly be plowed for cultivated crops. It is typical of the best uplands in the Flint Hills, both in kind and in amount of climax vegetation it produces. There is no sign of loss of surface soil by erosion, although there must be runoff during the heavy downpours that sometimes occur.

The vegetation is that of the true prairie climax in excellent range condition despite having been burned annually for many years. In fact, the plots protected from fire have significant amounts of the exotic, Kentucky bluegrass (*Poa pratensis* L.), and some Japanese brome (*Bromus japonicus* Thunb.) and must, therefore, be given a slightly lower range condition percentage than adjacent burned ones.

The plot area is surrounded by heavily grazed, depleted, weedy bluestem on the same range site. There has been no invasion of the weeds, either annual or perennial, into the excellent grassland of the plots, although some bluegrass plants and a little annual brome occur where fire is excluded. Despite the close proximity of weeds that mature seed each year, there seems to be no danger of invasion from this source so long as the excellent range condition is maintained. This ability of true prairie to prevent invasion has been noted before (Weaver and Clements, 1938; Aikman, 1955).

Annual burning does not, in itself, appear to cause declines in range condition, but it has caused significant reductions in yield in these same plots (McMurphy and Anderson, 1965).

Treatments.—The burning treatments in this study are:

1) Winter burning—early December
2) Early-spring burning — about March 20
3) Mid-spring burning — about April 10
4) Late-spring burning — about May 1
5) Check—unburned

The 2 x 4 rod plots were laid out in 1927 to permit study of the effects of burning on such characters as yield and botanical composition. There are two replications, making 10 plots. The first replication was burned annually and the second, biennially until the mid-1940's. Burning was stopped then but was resumed in 1950. Since then, burning has been on an annual basis on both replications.

Installation of two 6-foot aluminum access tubes in each of the 10 plots has made it possible to obtain frequent and regular readings of soil-moisture levels by 1-foot increments to the 5-foot depth with a neutron moisture gauge. This was done at approximately 2-week intervals during the growing season and monthly the rest of the year. Moisture readings for the 4-year period, 1960-63, are treated in these comparisons. Readings are also available for more than half of 1959, but during that season only one access tube had been installed in each plot and the measurements were not continued through the winter. Therefore, the 1959 readings, which follow closely the pattern observed in subsequent seasons, are not reported.

Soil moisture levels are reported as inches of total water per foot of soil because the meter does not distinguish available moisture as such. Comparisons are made among years, replications, dates of burning, sampling depths, and sampling dates. In addition, a number of interactions are considered.

Precipitation.—Precipitation during the first 3 years of the test was approximately normal except for May and September, 1961, each of which received about twice the expected amount. Total annual precipitation averages 32 inches. The average for the 3 years, 1960-62, was almost 34 inches.

The year, 1963, was extremely dry. Rainfall for that year totaled a little less than 18 inches. Soil moisture levels fell lower that summer than in the previous years, and the soil moisture was not replenished the following fall and winter.

Table 1 shows month-to-month variations in precipitation of those 4 years and of the average 1938-60 rainfall. Data are from an official weather station at the Kansas State University agronomy farm a little more than a half-mile west of the experimental area.

Table 1. Precipitation in inches by months, Kansas State University Agronomy Farm, approximately one-half mile west of the burning trial area.

Month	1938-1960 Av.	1960	1961	1962	1963
Jan.	0.95	1.45	0.05	0.83	0.41
Feb.	1.04	2.31	1.06	1.06	0.60
March	1.79	1.32	3.30	2.07	2.06
April	2.78	2.94	2.51	1.14	1.47
May	4.20	2.77	7.28	5.98	2.06
June	5.62	4.17	4.19	4.40	2.53
July	4.26	5.35	3.17	2.86	1.15
Aug.	3.70	5.76	1.76	4.50	2.01
Sept.	3.17	2.83	7.82	4.56	2.09
Oct.	2.26	2.34	3.87	2.65	2.04
Nov.	0.94	0.10	1.98	1.23	1.36
Dec.	0.89	1.23	0.75	0.29	0.15
Total	31.60	32.57	37.74	31.57	17.93

Results and Discussion

This experiment was designed to study moisture levels and their fluctuations in the uppermost 5 feet of soil following burning of ordinary upland bluestem range in excellent range condition. Data from foot-by-foot soil moisture determinations taken throughout the 4-year period, 1960-63, were subjected to analysis of variance (Table 2).

Major sources of variation in the analysis all show highly statistically significant differences and are discussed one by one.

Replications. — The mean difference between the two replications, while significant statistically, is only 0.14 inch of water per foot of soil. The patterns of rise and fall in soil moisture were almost exactly alike in both replications, so changes in management would not be required because of such differences. There was no significant difference between duplicates within plots.

Years.—This source of variation represents change in soil moisture due to the year-to-year variability in precipitation. As shown in Tables 4 and 5, average soil-moisture levels for 1960-62 were not greatly different, but in 1963 they were far lower because precipitation was so low. Although moisture levels had been quite high at the beginning of 1963 as a result of carryover from 1962, they fell far below levels of the previous 3 years during the lows of July and August, and in all but the upper layers failed to rise again in the fall. The great decline is illustrated in Figures 1 and 2.

Soil moisture in the upper 5 feet of the profile averaged 3.56 inches per foot of soil for the 4 years of the experiment. For 1960-62 the average was 3.76 inches and in dry 1963 it was 3.12 inches. It fell to that low figure despite the high at the beginning of the year.

McMurphy and Anderson (1965) pointed out that by 1961 a pattern of water removal from bluestem range soil by vegetation could be observed. The pattern occurred in seasons of relatively abundant rainfall, and subsequent sampling showed that the same trends occurred in dry 1963 as well. Soil moisture

Table 2. Analysis of variance for soil moisture levels for the years 1960-63 under annual burning of excellent bluestem range.

Source	D.F.	M.S.	F	Significance
Replication	1	32.1362	23.42	
Years	3	191.3807	139.45	***
Treatments	4	30.5016	22.23	***
Years x Treatment	12	3.2920	2.40	*
Error a	19	1.3724		
Depths	4	12.7529	45.03	***
Years x Depths	12	7.0982	25.06	***
Treatments x Depths	16	3.6441	12.87	***
Years x Treatments x Depths	48	0.3359	1.19	ns
Error b	80	0.2832		
Dates: Years	60	26.3094	688.73	***
Treatments x Dates: Years	240	0.1741	4.56	***
Depths x Dates: Years	240	2.3424	61.32	***
Treatments x Depths x Dates: Years	960	0.0549	1.44	***
Duplicates	3200	0.0336	0.88	ns
Error c	1500	0.0382		

*** Significant at the 0.001 level.
* Significant at the 0.05 level.
ns Not significant.

has declined each year during the period of most rapid herbage growth (May, June, and July in the Flint Hills), despite that period also being the one of most abundant precipitation. Replenishment occurs in the low-rainfall fall and winter months that follow. Soil moisture levels in 1963 behaved like those in the preceding years except that they fell farther and were replenished that fall only in the upper foot of soil. The alert range manager will consider this year-to-year fluctuation in planning stocking rates and other grazing practices.

Treatments. — Treatment, in this case the various dates of burning, is a major factor affecting soil moisture in these tests. Table 3 shows average soil-moisture levels at 1-foot intervals as influenced by the various treatments, and Figures 1 and 2 compare changes in moisture in the upper 5 feet of soil of plots burned in the winter and those not burned.

Differences in soil moisture due to treatment (time of burning) are very highly significant. Soil in the unburned areas has consistently had significantly more moisture than that in any of the burned ones, and among the latter, late spring burning has had the highest and winter burning the lowest moisture levels. The mean difference between the highest and the lowest average moisture (check vs. winter burned) was 0.39 inch per foot of soil, a total of nearly 2 inches in the upper 5 feet. That is enough to cause significant differences in herbage yield, as indeed there have been (McMurphy and Anderson, 1963). Such differences in herbage yield call for differences in management.

Burning in the late spring allows a greater accumulation of soil moisture than does any of the earlier burnings. These trials provide strong evidence that if management practices include range burning, it should be delayed as long in the spring as possible. Burning just as spring growth is starting leaves the soil exposed a minimum time and, as Smith et al. (1964) have shown, animal gains are also greater following late spring burnings than following earlier ones. Some change in time of burning bluestem range has taken place over the past two or three decades. February or early March formerly was the favored time to burn, whereas now most burning occurs in late March or early April.

Table 3. Average soil moisture showing interaction of treatments by depths for the 4 years, 1960-63. Moisture is expressed as inches per foot of soil.

Time of burning	Soil depths—Foot of Soil 1st	2nd	3rd	4th	5th	Average
Winter	3.57	3.52	3.38	3.23	2.85	3.31
Early spring	3.57	3.60	3.47	3.65	3.59	3.58
Mid spring	3.60	3.62	3.49	3.51	3.43	3.53
Late Spring	3.73	3.75	3.60	3.56	3.56	3.64
Check (unburned)	3.72	3.81	3.68	3.75	3.64	3.72
Average	3.64	3.66	3.52	3.54	3.41	3.56

LSD	Averages	Treatments within depths
at 0.05 level	0.097	0.217
at 0.01 level	0.132	0.296

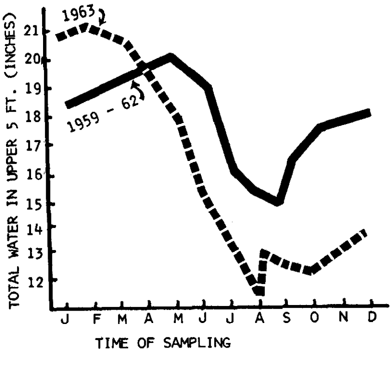

FIGURE 1. Soil water in bluestem range burned annually in December.

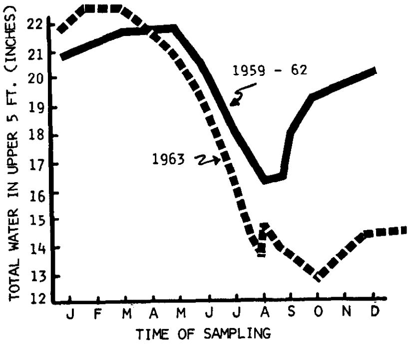

FIGURE 2. Soil water in unburned bluestem range.

Depths.—Variation in soil moisture due to depth was quite pronounced and highly significant, especially during times of low soil moisture levels and times of maximum removal. The moisture level in the first foot of soil fluctuated most, rising and falling rapidly with precipitation or its lack. The second foot fluctuated less widely, and the third foot still less. At the fourth and fifth feet the fluctuations were chiefly seasonal. Soil moisture there fell gradually during the growing season and was replaced gradually when adequate rains came.

Considering soil moisture variations due to depth (Table 5), the total mean difference between the highest and lowest was only 0.25 inch, the deeper layers having the smaller amount of moisture. This fact in itself probably has little significance so far as herbage production is concerned. Roots penetrate the entire 5 feet in this area and remove soil moisture from all the layers. What is probably more important is the highly significant interaction of treatments x depths. The deeper layers in the earliest burning have been especially low in water. Thus, in seasons of low precipitation, vegetation in range burned early is likely to suffer severely from drought, and the careful manager adjusts his management practices accordingly.

The interaction of depths by sampling dates within years, while statistically significant, is probably of little or no importance. It does show that differences among depths may vary throughout the year, but the main effect of soil depth remains unchanged.

Dates of Sampling Within Years.—This is also significant but it simply shows that the pattern of precipitation and hence week-to-week and month-to-month changes in soil moisture varied from year to year.

Despite the fluctuations, seasonal trends are also clearly apparent. They may, in fact, be more pronounced than the week-to-week or month-to-month fluctuations which occur within the seasonal trends and which are relatively more evident in upper than in lower soil layers. Seasonal trends are shown in the depths x dates-within-years interaction.

The significant interaction between depths and dates-within-years appears to be caused by greater fluctuation occurring in the upper layers of soil in dry years than in wet ones. The moisture reserve is removed gradually in dry seasons and is not replaced except in the upper layers. Meanwhile, repeated replenishment and withdrawal from the upper layers may take place as showers come amid dry, hot weather. This leads to rapid fluctuation in soil moisture near the surface, but does not prevent gradual and continued withdrawal from deeper layers. In fact, fluctuations at the deeper layers are likely to be smaller in dry years than in wet ones while total withdrawal is greater.

While variation in soil moisture due to depth was striking, especially during the period of most rapid removal, that is a natural response to the forces of removal. Soil moisture is added to the upper layers first and removed from them before being removed rapidly from deeper ones.

The interaction of treatment by sampling dates within years was also significant, indicating that if moisture at all depths was more or less uniform, as it might be in a wet season, differences are less easily detected. It has been observed that whenever substantial rains fall frequently throughout the growing season, differences in forage yield may not be very great.

Years x Treatments.—This significant interaction indicates that moisture levels fall lower in some treatments in some years than in others. Those burned early exhibit the lowest moisture levels in the driest years. This constitutes added evidence that burning bluestem range, especially early in the season, reduces moisture levels. Comparisons are shown in Table 4.

Years x Depths.—This interaction is highly significant, but is one about which not much can be done in the way of range management. It shows that in years of favorable precipitation the upper layers of soil will, on the average, be at least as moist

Table 4. Average soil moisture (inches per foot of soil) showing interaction of years and treatments for the 4 years, 1960-63.

Time of burning	Year 1960	1961	1962	1963	Ave.
Winter	3.32	3.38	3.73	2.95	3.31
Early spring	3.72	3.69	3.76	3.25	3.58
Mid spring	3.79	3.69	3.79	3.04	3.53
Late spring	3.92	3.82	3.95	3.09	3.64
Check (unburned)	3.97	3.82	4.00	3.27	3.72
Average	3.74	3.68	3.85	3.12	3.56
LSD	Average treatment	Average year	Treatments within years		
at 0.05 level	0.097	0.087	0.193		
at 0.01 level	0.132	0.119	0.264		

Table 5. Average soil moisture (inches per foot of soil) showing interaction of years by depths for the 4 years, 1960-63.

Depth in feet	Year 1960	1961	1962	1963	Average
1st	4.12	3.85	3.92	2.92	3.64
2nd	3.81	3.83	3.98	3.20	3.66
3rd	3.62	3.63	3.84	3.15	3.52
4th	3.65	3.61	3.80	3.23	3.54
5th	3.51	3.48	3.70	3.09	3.41
Average	3.74	3.68	3.85	3.12	3.56
LSD	Average year	Average depth	Depths within years		
at 0.05 level	0.087	0.042	0.111		
at 0.01 level	0.119	0.055	0.084		

as the lower ones. In such dry years as 1963, on the other hand, the upper layer of soil is likely to be drier than the deeper ones (Table 5). It does serve as a warning to the range manager, however. Vegetation grazed so hard as to shorten its root systems may fail to utilize fully the moisture in the deeper layers, and in dry years that may be about all that is available for them.

Treatments x Depths. — The highly significant treatment x depth interaction may be observed in Table 3. Close examination of the data shows a steadily increasing difference with depth between the highest and lowest moisture contents as affected by treatment. In the uppermost foot of soil, the difference is only 0.16 inch, but it gradually increases to 0.79 inch at the fifth foot. This implies that certain burning treatments, namely the earliest ones, permit less water to reach the deeper soil layers. This could become critical in periods of dry weather because of reduced amounts of soil moisture available for plant growth.

Treatments x Depths x Dates: Years.—While this interaction is significant statistically, the magnitude of the variation is small. It indicates that the effect of any treatment at a given depth (relative to another treatment at the same depth or the same treatment at a different depth) varies throughout the year. Lack of significance of the years x depths x treatments interaction emphasizes this low relationship. Variation of this sort is so small that it is not likely to be reflected in forage yields and is of minor importance in range management.

Conclusions

In these trials range burning has clearly been shown to reduce significantly the levels of soil moisture at all depths. The reduction is greater following early burning than late burning and is greater in deeper soil layers than in upper ones. The implications are clear. Burn no more than is necessary for good range management and good livestock husbandry. If burning is practiced, do it in the late spring rather than earlier, recognizing that soil moisture levels, and hence herbage yield, will be reduced by burning. The earlier one burns, the less herbage he will have for harvest by livestock.

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