

## Fire and Grazing Effects on Wind Erosion, Soil Water Content, and Soil Temperature

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### ABSTRACT

Selective grazing of burned patches can be intense if animal distribution is not controlled and may compound the independent effects of fire and grazing on soil characteristics. Our objectives were to quantify the effects of patch burning and grazing on wind erosion, soil water content, and soil temperature in sand sagebrush (*Artemisia filifolia* Torr.) mixed prairie. We selected 24, 4-ha plots near Woodward, OK. Four plots were burned during autumn (mid-November) and four during spring (mid-April), and four served as nonburned controls for each of two years. Cattle were given unrestricted access (April–September) to burned patches (<2% of pastures) and utilization was about 78%. Wind erosion, soil water content, and soil temperature were measured monthly. Wind erosion varied by burn, year, and sampling height. Wind erosion was about 2 to 48 times greater on autumn-burned plots than nonburned plots during the dormant period (December–April). Growing-season (April–August) erosion was greatest during spring. Erosion of spring-burned sites was double that of nonburned sites both years. Growing-season erosion from autumn-burned sites was similar to nonburned sites except for one year with a dry April–May. Soil water content was unaffected by patch burn treatments. Soils of burned plots were 1 to 3°C warmer than those of nonburned plots, based on mid-day measurements. Lower water holding and deep percolation capacity of sandy soils probably moderated effects on soil water content and soil temperature. Despite poor growing conditions following fire and heavy selective grazing of burned patches, no blowouts or drifts were observed.

**F**IRE IS A naturally recurring phenomenon affecting the structure and function of rangelands. The physical, chemical, and biotic properties of soil may be altered by fire through numerous complex processes across spatial and temporal scales (DeBano et al., 1998). Among the potential changes are erosion rates, soil temperature, and soil water content. Each of these factors may affect nutrient cycling and productivity of above- and belowground resources. Additionally, wind erosion can reduce air quality.

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Although fire is generally becoming a readily accepted management tool, the potential of accelerated wind erosion on sandy sites is of concern following either prescribed fire or wildfire. Yet, few have actually measured post-fire wind erosion (Zobeck et al., 1989; Whicker et al., 2002). Prescribed fire is generally conducted to minimize soil exposure by coinciding with the onset of plant growth and is applied to entire pastures to prevent selective grazing of burned patches. Highly preferential grazing of burned sites has been confirmed for cattle (Vermeire et al., 2004; Mitchell and Villalobos, 1999) and fire effects may be exacerbated by intensive herbivory. Wildfires rarely respect pasture boundaries, being of irregular shape and generally smaller than the average pasture in the western United States. Some estimates report the average wildfire in the western United States to cover about 13 ha (Higgins, 1984; National Interagency Fire Center, 2004). Following wildfire, the burned area may be fenced, or the remainder of the pasture burned to prevent concentrated herbivory on burned patches (Wright, 1974). However, that paradigm has recently been challenged in an effort to mimic natural fire–herbivore interactions and increase heterogeneity (Fuhlendorf and Engle, 2001).

Wind erosion is a product of the force applied to the soil and the resistance of the soil (Lee and Tchakerian, 1995). Erosive force varies with wind speed and the structure of the vegetation and soil surface. Erosion of dry, bare soil is well-correlated with wind speed (Stout, 2001). However, even wind exceeding 20 m s<sup>-1</sup> may produce blowing dust less than 20% of the time. Resistance to erosion also depends on soil particle size distribution, soil aggregates, and cohesion due to moisture. Threshold wind speeds for soil movement have been identified, but results vary considerably and soil water content appears to be a key factor (McKenna Neuman and Maljaars Scott, 1998; Stout, 2001; Whicker et al., 2002). Fire and grazing effects on wind erosion are primarily related to changes in vegetation structure and ground cover. Wind erosion events are episodic, requiring multiple conditions to occur simultaneously. Therefore, removing cover or obstructions to soil surface air flow will increase the probability of large erosion events, but does not necessarily translate into elevated wind erosion for a specific event.

Fire may affect soil water content through changes in infiltration, water repellency, evapotranspiration, and rainfall interception. Most factors indicate burning should dry soils, but soil water is commonly similar between burned and nonburned sites (Old, 1969; Ewing and Engle, 1988; Soto and Diaz-Fierros, 1997). Fire effects on infiltration have been neutral to slightly negative (Ueckert et al., 1978; Knight et al., 1983; Pierson et al., 2001; Mills and Fey, 2004). Reduced plant cover following fire has led to increased rainfall impact and surface sealing

that can limit infiltration (Hester et al., 1997; O'Dea and Guertin, 2003). Similarly, treading by animals at high stocking rates can reduce infiltration by increasing soil bulk density and reducing standing crop (Rhoades et al., 1964; Thurow et al., 1988). Volatilization of some organic substances in the fuel may also leave a coating on soil particles that reduces water absorption near the surface (DeBano et al., 1998). This has specifically been shown to occur with the burning of sagebrush (*Artemisia* spp.) leaf litter (Salih et al., 1973) and beneath shrub canopies in sagebrush communities (Pierson et al., 2001). Additionally, the potential for hydrophobicity increases with sand content (Huffman et al., 2001). Removal of plant cover also exposes soil to evaporative drying and herbaceous growth response may increase transpiration (Sharrow and Wright, 1977; Bremer and Ham, 1999). Alternatively, reduced plant cover may allow more precipitation to reach the soil and control of shrubs can decrease transpiration from deep soil layers through shrub mortality or reduced shrub leaf area (Soto and Diaz-Fierros, 1997).

Warming of the soil during early spring and the growing season following fire is well-supported and widely accepted (Old, 1969; Sharrow and Wright, 1977; Rice and Parenti, 1978; Ewing and Engle, 1988; Hulbert, 1988). Elevated soil temperature can increase plant productivity (Rice and Parenti, 1978; Knapp and Seastedt, 1986; Hulbert, 1988; DeLucia et al., 1992). The primary cause is greater solar energy input to the soil while the shading and insulating effects of litter and the plant canopy are limited (Knapp, 1984; Bremer and Ham, 1999). Whether these effects apply to the dormant season or to coarse-textured soils is less clear. Just as temperature maxima are greater on exposed soils, the lack of insulation could produce lower minimum soil temperatures and lower maximum temperatures during cold periods. Coarse-textured soils also tend to be more responsive to temperature change, in part, because water content is generally lower (DeBano et al., 1998).

Our general research objectives were to (i) determine the effects of autumn prescribed fire on wind erosion, soil water content, and soil temperature relative to nonburned sandhills during the December–April dormant season and (ii) quantify wind erosion, soil water content, and soil temperature on autumn-burned, spring-burned, and nonburned sandhills subjected to cattle grazing during the April–September growing season. We hypothesized that dormant-season wind erosion would increase on autumn-burned relative to nonburned sites, but that growing-season wind erosion would be similar across autumn-burned, spring-burned, and nonburned sites. We predicted that afternoon soil temperature would vary over time and depth, but be greater on burned sites throughout dormant and growing seasons. Finally, we hypothesized that soil water content would be similar across burn treatments, but increase with depth and vary over time.

## MATERIALS AND METHODS

The study was conducted on the Hal and Fern Cooper Wildlife Management Area, about 15 km northwest of Woodward,

OK (36°33' N, 99°32' W). Mean elevation is 625 m and the climate is continental, with mean monthly temperatures ranging from 1°C in January to 29°C in July (USDA-ARS, unpublished data, 2002). Mean annual precipitation is 602 mm, with 70% occurring as rain during the growing season (April–September).

The area is undulating and hummocky with high-seral, sandhills vegetation of the sagebrush–bluestem vegetation type (Küchler, 1964). Data were collected on Deep Sand ecological sites with slopes of 1 to 12%. Eda loamy fine sands (mixed, thermic Lamellic Ustipsamments) dominate and are interspersed with Tivoli loamy fine sands (mixed, thermic Typic Ustipsamments) on the tops of dunes (Nance et al., 1960). Eda soils have a brown A horizon, 0 to 41 cm thick over loamy fine sand. Tivoli soils have a brown A horizon, 0 to 18 cm thick over fine sand. Both soils are single-grained and loose with rapid permeability and low runoff.

Sand sagebrush was the dominant woody plant, providing 20 to 50% canopy cover on Deep Sand sites. More sparsely distributed woody plants included eastern red-cedar (*Juniperus virginiana* L.), sand plum (*Prunus angustifolia* Marsh.), and skunkbush (*Rhus aromatica* Ait.). The herbaceous component was dominated by little bluestem [*Schizachyrium scoparium* (Michx.) Nash], blue grama [*Bouteloua gracilis* (H.B.K.) Lag. ex. Steud.], sideoats grama [*Bouteloua curtipendula* (Michx.) Torr.], western ragweed (*Ambrosia psilostachya* D.C.), sand bluestem (*Andropogon hallii* Hack.), and sand lovegrass [*Eragrostis trichodes* (Nutt.) Wood]. Herbaceous production is highly variable, but averages about 2750 kg ha<sup>-1</sup> on Deep Sand sites.

We selected 24, 4-ha sites of the same soil series that were located at least 1.6 km from each other and permanent water sources using soil survey maps (Nance et al., 1960). Sites were visually inspected to ensure topography and initial plant species composition were each similar among sites. Twelve sites were blocked by pasture ( $n = 4$ ) and randomly assigned autumn-burned, spring-burned, or nonburned treatments within each pasture. The experiment was repeated on four new pastures the second year. Autumn burns were conducted on 16 Nov. 1999 and 14 Nov. 2000. Spring burns were applied 17 Apr. 2000 and 12 Apr. 2001. Mean temperature, relative humidity, and wind speed during the burns were 18°C, 36%, and 2.5 m s<sup>-1</sup>, respectively. Combustion of herbaceous material was complete. Some main stems in the lower 45 cm of sand sagebrush were only charred, but most stems were consumed in the fires, leaving white ash.

Immediately after fire was applied, Big Spring Number Eight (BSNE) field samplers were centrally placed in each 4-ha plot at 20 and 40 cm above the soil surface to assess wind erosion (Fryrear, 1986). Saltation is the primary form of wind erosion measured at these heights and generally accounts for the majority of wind-blown material. The BSNE samplers have a 5- × 2-cm opening and are designed to stay oriented into the wind. Vegetation was cleared at the base of samplers as needed to allow the samplers to spin freely with changing wind direction. The BSNE samplers were monitored monthly from the burn date through August of the first post-fire growing season. Sediment was sealed in air-tight plastic bags until samples could be placed in a drying oven. Sediment was not retrieved from the traps when the amount was too small to accurately handle and weigh. Gravimetric soil water content was measured monthly on preselected dates unless precipitation was received that day. Five soil cores (1.9 cm in diameter) were randomly collected at two depths, 0 to 15 and 15 to 30 cm, and sealed in plastic bags before drying. Trapped sediment and soil cores were dried to a constant weight at 100°C and weighed to the nearest 0.01 g. Soil temperature was measured to the

nearest 0.5°C by inserting soil thermometers 7.5 and 22.5 cm into the soil adjacent to soil core sample points. Temperature was measured monthly during the afternoon.

All sites were exposed to grazing by cow-calf herds from early April to September. Herds had open access to all three fire treatments within their pasture. Pasture-wide stocking rates were light at 21 to 23 animal-unit days ha<sup>-1</sup> (1 AUD is 9.1 kg daily dry wt. forage consumption). Livestock water sources are well-distributed throughout the study area, with most water sources within 3.2 km of another. Cattle were expected to selectively graze burned patches, which comprised less than 2% of each pasture. Therefore, a cattle enclosure, measuring 5 × 10 m and constructed of wire cattle panels 132 cm tall, was established within each of the 24 sites and paired with a 5- × 10-m plot open to cattle grazing. Forage utilization was estimated in late August or early September by clipping end-of-season standing crop from ten 0.1-m<sup>2</sup> quadrats from each of the paired plots within sites. Ten additional quadrats were clipped along pace transects with about 15 m between sampling points on each site to estimate herbaceous standing crop for the 4-ha plots. Herbage samples were air-dried to a constant weight at 53°C and weighed to the nearest 0.01 g.

Wind erosion was monitored from 1999 through 2001 whereas soil water and temperature were monitored from 1999 through 2000. Spring-burned sites were not burned until mid-April, so only autumn-burn and nonburn treatments were monitored during the dormant season (November–April). Additionally, grazing by cattle was limited to the growing season (April–September). Therefore, dormant- and growing-season data were analyzed separately. Data were analyzed as a randomized block design with the MIXED procedure of SAS (Littell et al., 1996). Model assumptions of normality and sphericity were tested using Shapiro–Wilk tests from the UNIVARIATE procedure and Mauchly's tests from the GLM procedure of SAS, respectively (SAS Institute, 1989). Erosion analyses included year, burn, sampling height, and all interactions in the model. Soil water and temperature models included burn, soil depth, month, and all interactions and were analyzed as repeated measures. Erosion data were log-transformed to meet the assumption of normality, but were presented as arithmetic means to facilitate interpretation. Soil water and temperature data met the assumptions of normality and sphericity. Significant interactions were followed by tests of simple effects at a 0.05 probability level.

## RESULTS AND DISCUSSION

Burning treatment, year effects, and sampling considerations (e.g., depth of soil sampling for soil temperature and moisture; height of sampling for erosion) often interacted in their effects on the variables measured in this study. It is clear that effects of burning on erosion, soil moisture, and soil temperature depended on the season of burning and sampling considerations as well as on general environmental effects (i.e., “year” effects). The primary focus of this study was to document effects of burning; therefore, burning effects are highlighted by holding year or sampling effects constant in our analyses of simple effects following significant interactions (Kirk, 1995).

Burning treatment, year of burn, and sampling height interacted ( $P < 0.01$ ) in their effects on dormant-season wind erosion. Erosion was greater on autumn-burned than nonburned sites at each sampling height both years

**Table 1. Dormant-season (December–April) wind-eroded sediment catch on nonburned and autumn-burned sites by year and sampling height on loamy fine sands near Woodward, OK.**

Height	Sediment catch			
	1999–2000		2000–2001	
	No burn	Autumn burn	No burn	Autumn burn
cm	g			
20	0.78b†	19.03a	0.78b	4.20a
40	0.12b	5.70a	0.46b	1.24a

† Burn means within a year and sampling height followed by the same letter do not differ ( $\alpha = 0.05$ ; standard error of the mean = 0.21).

(Table 1). However, the magnitude of increased erosion varied by a factor of about 2 to 48 among sampling heights and years. Sediment catch on nonburned sites was similar between years at 20 cm, but greater at 40 cm during the 2000–2001 season. Erosion of autumn-burned sites during the 2000–2001 season was about 20% of that from the first season at each sampling height.

Increased erosion on autumn-burned plots may be explained by weather conditions and the lack of plant growth throughout most of the dormant period. Even small amounts of ground cover can reduce erosion (Fryrear, 1995). Sand sagebrush sprouts did not emerge until late March and early April and growth initiation by most dominant herbaceous plants occurred in mid-April and early May. Therefore, burned plots were predominantly bare throughout the dormant period. Differences in wind events and precipitation likely contributed to reduced erosion on autumn-burned sites during the 2000–2001 season. Daily peak wind speed at 10 m exceeded 13.4 m s<sup>-1</sup> for 41% of the 1999–2000 dormant period and only 24% of the 2000–2001 dormant period (Oklahoma Climatological Survey, 2004; Table 2). Additionally, autumn and winter precipitation was greater the second season than the first (Fig. 1) and wetting of soil typically reduces wind erosion (McKenna Neuman and Maljaars Scott, 1998; Stout, 2001).

Burning treatment, years, and sampling height also interacted ( $P < 0.03$ ) in their effects on growing-season erosion. Relative to burning treatment comparisons, sediment catch at 20 cm more than doubled with autumn or spring burning and the selective grazing of those patches in 2000, compared with that on nonburned sites (Fig. 2). During the same year, nearly seven times as much sediment was caught at 40 cm on autumn-burned sites than spring-burned or nonburned sites. In 2001, nonburned sites again produced half the sediment at 20 cm as spring burning and selective grazing, but did

**Table 2. Number of days with maximum 5-s mean wind speeds exceeding 13.4, 17.9, and 22.4 m s<sup>-1</sup> during dormant (December–April) and growing (April–August) seasons of 1999 through 2001 near Woodward, OK. Data from Oklahoma Climatological Survey (2004).**

Maximum wind speed	Dormant season		Growing season	
	1999–2000	2000–2001	2000	2001
m s <sup>-1</sup>	d			
>13.4	61	36	86	55
>17.9	18	15	17	20
>22.4	2	4	8	6



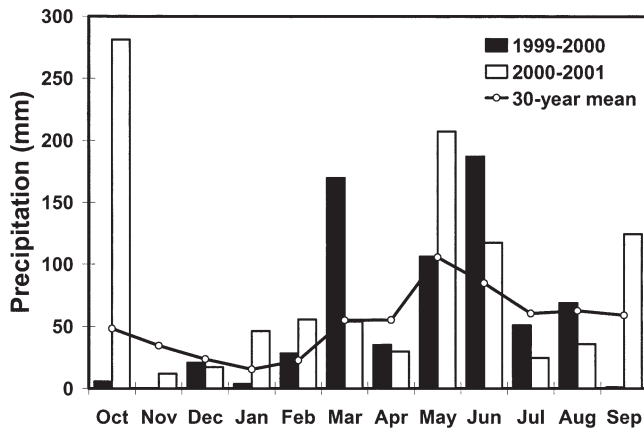


Fig. 1. Monthly and 30-yr mean precipitation near Woodward, OK, from October 1999 through September 2001.

not differ from autumn-burned sites. Sediment catch was similar across burn treatments at 40 cm. Relative to year comparisons, sediment catch at 20 cm was similar between years for spring-burned and nonburned sites, but was greater in 2001 for both treatments at 40 cm. In contrast, wind erosion on autumn-burned sites was less during 2001 than 2000 at both sampling heights. Zobeck et al. (1989) found a greater relative difference in wind erosion between burned and nonburned sites than we observed, with sediment catch about 920 (at 15 cm) and 76 (at 50 cm) times greater on burned sites. However, they compared a sandy grassland burned by summer wildfire to an undisturbed shinnery oak (*Quercus havardii* Rydb.) community.

Reduced sagebrush canopy volume and herbage standing crop on burned sites probably contributed to increased growing-season wind erosion. Fire greatly reduced sand sagebrush canopy volume, which was only 36% of pre-fire levels by the end of the first growing season (Vermeire, 2002). Gould (1982) showed control of mesquite (*Prosopis glandulosa* Torr.) reduced wind

erosion because herbaceous cover increased and wind speed was believed greater at the perimeter of the trees. The sand sagebrush sites differed from the sandy mesquite grasslands in that herbaceous cover was more continuous and dominant herbs were similar in height to sand sagebrush. Peak herbage standing crop was about 1460 kg ha<sup>-1</sup> on burned sites compared with 2690 kg ha<sup>-1</sup> on nonburned sites. Much of the difference in herbage standing crop was caused by increased cattle grazing on burned sites (Vermeire et al., 2004). However, grazing was not considered a primary factor in erosion rates throughout the entire growing season. Vermeire et al. (2004) showed standing crop to be similar between autumn- and spring-burned sites. Had grazing been a major factor in erosion, we would not have expected erosion of autumn-burned sites to be similar to that of nonburned sites or less than that of spring-burned sites, as was the case in 2001. The period of greatest vulnerability to wind erosion during the growing season was early spring, before substantial plant growth had occurred.

Weather was a primary factor affecting growing-season erosion among years. Twelve events produced 49 mm of precipitation between the 2000 spring burns and May sediment collections, about 35% of the April–May precipitation shown in Fig. 1. Eleven events yielded 195 mm of precipitation during the same period in 2001. The difference in spring precipitation allowed quicker herbage growth on autumn-burned sites and may explain the marked reduction in erosion of these sites in 2001. The April–May period experienced more strong wind events in 2001 than 2000 (19 vs. 12), including one exceeding 31 m s<sup>-1</sup> in May. This likely contributed to the increased sediment catch at 40 cm on spring-burned and nonburned sites in 2001. Although the majority of strong wind events occurred later in the growing season, herbage standing crop was greater after May and provided better soil protection.

Soil water content changed over time during the dormant ( $P < 0.01$ ) and growing seasons ( $P < 0.01$ ), but was similar across soil depths and burn treatments (Fig. 3). Anderson (1965) showed fire to reduce soil water content in tallgrass prairie, but the reductions resulted from decades of annual burning and occurred only at depths greater than 30 cm. Ewing and Engle (1988) determined fire did not affect soil water to depths of 45 cm and Old (1969) found no differences to 2 m. Expectations for drying of burned sites are based primarily on increased evapotranspiration (Sharrow and Wright, 1977; Bremer and Ham, 1999), water repellency (Salih et al., 1973), and reduced infiltration (Hester et al., 1997; O’Dea and Guertin, 2003). However, these factors may be nullified by reduced interception on burned sites (Soto and Diaz-Fierros, 1997), precipitation, and water holding capacity of the soil. After 20 yr of grazing, increased soil bulk density and reduced infiltration were related to increasing stocking rates on the same soils we observed (Rhoades et al., 1964). Although burned sites were heavily utilized, the short-term nature of this use either did not reduce infiltration, or the effects were over-ridden by other factors.

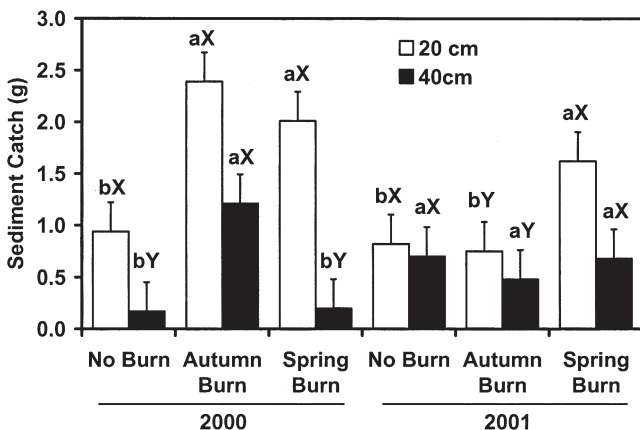


Fig. 2. Growing-season (April–August) wind-eroded sediment catch and standard error of the mean on nonburned, autumn-burned, and spring-burned sites by year and sampling height on loamy fine sands near Woodward, OK. Burn treatment means within a sampling height and year followed by the same lowercase letter (a, b) do not differ ( $\alpha = 0.05$ ); year means within a burn treatment and sampling height followed by the same uppercase letter (X, Y) do not differ ( $\alpha = 0.05$ ).

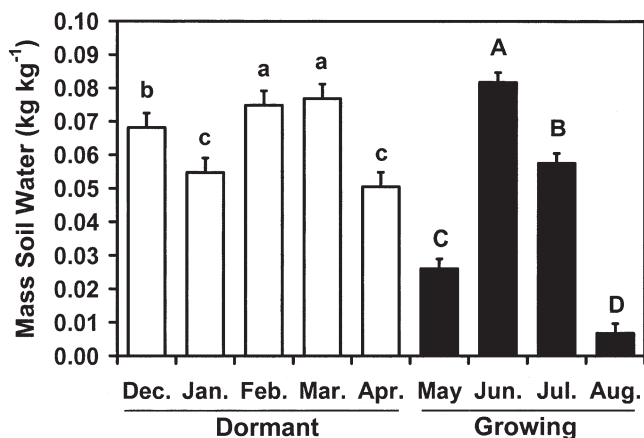


Fig. 3. Monthly mass soil water content and standard error across depths (0–15 and 15–30 cm) and burn treatments on loamy fine sands near Woodward, OK. The dormant season (December–April) includes autumn-burned and nonburned sites and the growing season (May–August) includes autumn-burned, spring-burned, and nonburned sites. Means followed by the same letter within a season do not differ ( $\alpha = 0.05$ ).

Soil temperature depended on burn treatment, measurement depth, and month as described in the five following two-way interactions. Soil temperature varied by depth and month during the dormant ( $P < 0.01$ ) and growing ( $P < 0.01$ ) seasons (Fig. 4). Soil temperature was similar at 7.5- and 22.5-cm depths during the coldest period of the year, January and February, but cooler at 22.5 cm during other periods. Soil temperatures generally increased with the progression through the growing season, as would be expected. During the growing season, soil temperature also varied by month and burn treatment ( $P < 0.02$ , Fig. 5). Soil temperature was cooler on nonburned sites than autumn- or spring-burned sites with the exception of June. Autumn-burned and nonburned sites' soil temperatures were similar in June and

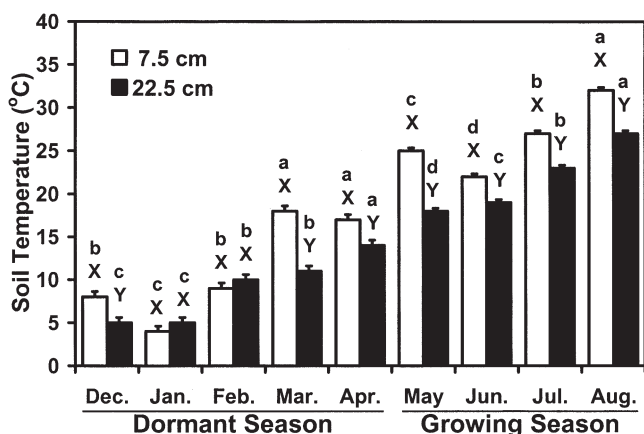


Fig. 4. Monthly soil temperature and standard error of the mean at 7.5- and 22.5-cm depths across burn treatments on loamy fine sands near Woodward, OK. The dormant season (December–April) includes autumn-burned and nonburned sites and the growing season (May–August) includes autumn-burned, spring-burned, and nonburned sites. Sampling month means within a sampling depth and a season followed by the same lowercase letter (a, b) do not differ ( $\alpha = 0.05$ ); sampling depth means within a sampling month and season followed by the same uppercase (X, Y) letter do not differ ( $\alpha = 0.05$ ).

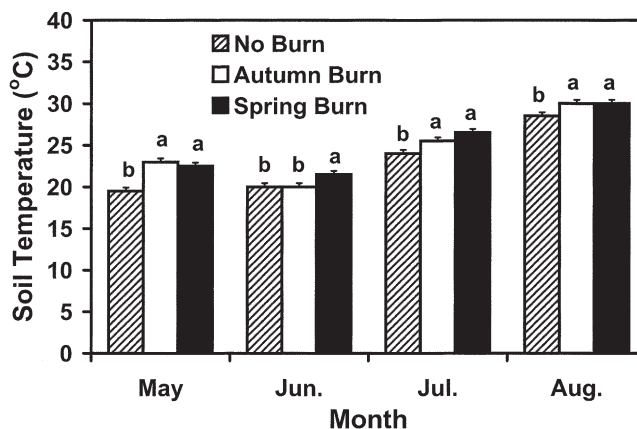


Fig. 5. Monthly growing-season soil temperature and standard error of the mean across depths on nonburned, autumn-burned, and spring-burned loamy fine sand sites near Woodward, OK. Burn means within a month followed by the same letter do not differ ( $\alpha = 0.05$ ).

cooler than spring-burned sites. Soil temperature varied by depth and burn treatment during the dormant ( $P < 0.01$ ) and growing seasons ( $P < 0.04$ , Table 3). Burning increased soil temperature at both depths during the dormant season. Autumn and spring burning produced similar soil temperatures during the growing season that exceeded temperatures on nonburned sites at both depths.

Fire has consistently been shown to increase soil temperature during spring and summer. Soil temperature at 1 cm was 6 to 11°C warmer during June and July (Ewing and Engle, 1988). At 2.5 cm, burned sites were about 4°C warmer early in the growing season (Bremer and Ham, 1999). Others have shown soil temperature at 8 cm to be 5°C warmer from May to September (Sharrow and Wright, 1977; Rice and Parenti, 1978). Soils in these studies were clays and silty clay loams. The smaller increases we observed in soil temperature on burned sites were likely due to differences in soil texture and they were similar to those on fine sands (Volesky and Connot, 2000). The 1 to 3°C increase on burned sites was less than that shown to extend the growing season or increase biomass (DeLucia et al., 1992; McMichael and Quisenberry, 1993). A 1 to 2°C increase in spring soil temperature did not increase current-year standing crop in Nebraska sandhills (Volesky and Connot, 2000).

Table 3. Dormant-season (December–April) and growing-season (May–August) soil temperature by depth across time on nonburned, autumn-burned, and spring-burned sites near Woodward, OK.

Soil depth	Soil temperature				
	Dormant season		Growing season		
cm	No burn	Autumn burn	No burn	Autumn burn	Spring burn
	°C				
7.5	10.3b†	11.9a	24.9b	27.1a	27.5a
22.5	8.4b	9.1a	20.9b	22.2a	22.8a

† Burn means within a sampling depth and season followed by the same letter do not differ ( $\alpha = 0.05$ ; dormant-season standard error of the mean = 0.28; growing-season standard error of the mean = 0.29).

## CONCLUSIONS

Autumn fire increased wind erosion during the dormant season. Although the soil was predominantly bare during this period, the magnitude of erosion was variable, indicating erosion rates are highly dependent on the coincidental occurrence of exposed soil and other factors, including frequency and intensity of precipitation and wind events. Most growing-season wind erosion occurred during late April and May and appeared to be minimally affected by patch grazing. Short-term intensive grazing of burned patches caused a visible reduction in plant height during summer, but differences were not apparent during early spring. Despite selective grazing, erosion was similar between autumn-burned and nonburned sites when spring weather promoted early plant growth. Had post-fire weather conditions allowed greater plant growth, dormant-season erosion would likely have been reduced as well. Conditions were relatively harsh, given the lack of plant growth during the dormant and early growing season and heavy selective grazing of burned patches. Although the soils were certainly more susceptible to blowouts during periods of minimal plant cover, neither blowouts nor patches of reduced productivity were observed on burned patches.

Soil water content was not affected by patch burning. Fire may have minimal effects on the water content of sandy soils because of their inherently low water holding and often deep percolation capacity. Similarly, fire effects on soil temperature appear to be moderated by sandy soils, or limited to depths not measured in this study. Burned sites were generally warmer than nonburned sites in the afternoon, but the 1 to 3°C differences were less than have been noted on other soils. Patch burn effects on soil temperature persisted throughout the growing season, but the potential for extending the growing season or increasing biomass with the minor differences observed would be limited at best.

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