Temperatures of Headfires in the Southern Mixed Prairie of Texas[1]

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Highlight

Maximum soil surface temperatures varied from 182 F to 1260 F for fuels that varied from 1546 to 7025 lb/acre Tempil card data correlated well with these data—r = 0.919. The duration of temperatures above 150 F varied from 0.9 to 5.4 minutes. The data from this study can be used to simulate approximate intensities of natural fires with a portable burner. Fires with soil surface temperatures above 1000 F show potential to kill mesquite trees.

This study is the beginning of a series of fire studies on mesquite (*Prosopis glandulosa* var. *glandulosa*) to determine the potential of fire as a tool in the management of mesquite. The primary objective of this study was to determine the range of temperatures that occur in different grass communities on which mesquite and other brush species grow. By knowing the range of temperatures that occur in different grassland communities, we can simulate these temperatures on experimental plots to determine the potential role of natural fire in brush management.

Several studies indicate that fire damages young mesquite trees and, to a limited extent, old mesquite trees (Glendening and Paulsen, 1955; Reynolds and Bohning, 1956; Cable, 1965). Most desirable, however, fire does not harm grass production in the mixed prairie for more than two years (Hopkins et al., 1948; Launchbaugh, 1964). With only slight harm to grasses and with some damage to mesquite, fire appears to have a potential for at least containing mesquite.

Maximum temperatures that occur in grassland communities are quite varied. Moreover, temperatures above the soil surface increase sharply, whereas temperatures below the soil surface decrease sharply (Bently and Fenner, 1958; Whittaker, 1961). Since the soil surface is a reasonably good reference point for comparing maximum temperatures between communities, and is probably the best point from which to establish a general relation for temperatures at different heights above the soil surface, this review will pertain mostly to temperatures at or near the soil surface.

In rangeland infested with medusahead (*Elymus caput-medusae L.*), McKell et al. (1962) reported maximum soil surface temperatures that averaged 335 F to 1100 F. Fuel weighed 5200 lb/acre. By contrast, temperatures recorded by Bently and Fenner (1958) in California and by Ito and Iizumi (1960) in Japan were considerably lower. Bently and Fenner recorded soil surface temperatures of 200 F to 250 F in annual grasslands. Ito and Iizumi recorded soil surface temperatures of 186 F to 616 F in bunchgrass communities that contained plants from 3 to 6 ft high. Unfortunately, neither of these authors presented fuel data for further interpretation.

Smith and Sparling (1966) recorded temperatures from 374 F to 716 F at soil surface in vegetation dominated by grasses and low shrubs in Northern Ontario, Canada. The duration above 150 F varied from 1.4 to 6.0 minutes at the soil surface.

Temperatures at the soil surface or in plants are dependent on distance from the flames, intensity of heat, and duration of heat. These are dependent on type of fuel, size, and spatial distribution of fuel, moisture, slope of ground, and atmospheric influences like wind speed, air temperature, and relative humidity (Hare, 1961).

Sampson (1944) found that the kind of fuel influenced the magnitude of temperatures. He found the hottest fires in slash, followed in decreasing order by mixed chaparral, chamise, and grass. Bently and Fenner (1958) also reported higher temperatures in brush fuel than in grass fuel.

Small, loosely distributed particles sustain higher rates of fire spread than large pieces arranged in a compact mass (Byram, 1957). Moreover, fuel size and fuel arrangement have their greatest effect on small fires and in the initial stages of the build-up of a major fire (Byram, 1958).

Heyward (1938) found that the highest soil temperatures were in forest stands with two or three years of accumulated litter. Lowest soil temperatures were in forest stands with 15 years of accumulated litter. Compactness of fuel and poor aeration were thought to be the chief cause of the comparatively low temperatures.

As fuel moisture increases, the rate of fire spread decreases linearly with no wind (Anderson and Rothermel, 1965). Byram (1958) also states that high moisture content of the forage slows down the combustion rate and heat yield. Smith and Sparling (1966), however, reported that the highest relative humidity was recorded at the highest temperatures in jack pine, indicating that moisture content of litter and vegetation, which would be related to humidity, is of minor importance at least after ignition and spread of fire.

Both temperature and duration of exposure are greatly influenced by wind (Hare, 1961). Whittaker (1961) observed that an increase from a slight wind to a moderate one and the subsequent fanning of the flames caused a temperature rise of 172 F to 312 F at ground level. By contrast, if the wind was strong, the equivalent temperature was reduced because the flames swept quickly over the vegetation and their effect did not reach ground level. Smith and Sparling (1966) found that wind speed was less in the hotter fires than in the cooler fires, which indicates either that wind speed is of lesser importance or else that wind speeds over 4.46 mph have a cooling effect.

Slope has the same effect as wind in bringing the flame closer to the fuel and preheating it. As a slope becomes steeper, the average size of a fire on the slope becomes greater (Murphy et al., 1966).

In South Carolina, Lindenmuth and Byram (1948) found that head fires were consistently hotter 18 inches above the surface and that back fires were consistently hotter below

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Table 1. Herbaceous fuel and $s_{\bar{x}}$ on several northwest Texas areas before burning (lb/acre ovendry).

	High Plains at Post						Rolling Plains				
							Quanah		Guthrie		Colorado
	I	II	III	IV	V	VI	I	II	I	II	City
Current growth (cured condition)											
Hilaria mutica	2	438	1022	1813		3238	2387	1860	1995	480	3467
Buchloe dactyloides	420	271	211	128	1261	42	28	11	498	290	28
Bouteloua gracilis	430	471	153	338	262	30				185	
Panicum obtusum	231	219	94	27	1	19					
Sporobolus cryptandrus	135	229	723	9			12				
Panicum hallii	110	121	51	74					25	95	
Aristida purpurea	19	38	8	1	5						
Muhlenbergia arenicola	12	61	69	38	3	5			18		
Tridens elongatus										403	
Other grasses	49	6	68	1	2		2	8	63	162	
Forbs	290	117	91	59	11	32	23		15	95	
Subtotal	1698	1971	2490	2488	1545	3366	2452	1879	2614	1710	3495
Litter	1527	2325	2882	1274	0	3425	2451	1879	1671	1330	3530
Total	3225	4296	5372	3762	1545	6791	4903	3758	4285	3040	7025
Variation of total fuel ($s_{\bar{x}}$)	248	328	313	346	69	347	206	168	327	217	306

18 inches. Fahnestock and Hare (1964) reported similar conclusions.

Head fires develop considerably more heat than back fires because the flames are fanned by the wind to ignite new fuel ahead of the front (Hare, 1961). More fuel burns per unit of time, and more aerial fuels are consumed. Therefore, head fires usually do more crown damage than back fires.

In back fires the parts near the ground are exposed to high temperatures for a longer time (Hare, 1961). Radiation from the approaching flame front and slow movement of the front make back fires more damaging than head fires at points close to the ground (Byram, 1957; Hare, 1961). McKell et al. (1962) found that slow burning into a mild wind in mid-afternoon with low relative humidity provides the most favorable condition for maximum seed damage to medusahead grass.

Where the chief fuel is grass, size of plot for measuring temperatures is of minor importance. Soil temperatures were no higher for a fire which burned 40 acres than were temperatures for a fire which burned 0.0023 acre having the same type of vegetation (Heyward, 1938). Temperatures up to 1100 F as measured by McKell et al. (1962) on plots 30 × 30 ft also indicate that small plots are probably just as adequate as large plots for measuring temperatures.

Specific objectives of this study were (1) to determine maximum temperatures at soil surface in relation to quantity of grass fuel, (2) to determine the duration of temperatures above 150 F in relation to quantity of grass fuel, and (3) to compare maximum temperatures of thermocouples with those of Tempils.

Methods and Procedures

We collected temperature data from two separate studies in northwest Texas—one on the high plains and one on the rolling plains. On the high plains, six 1-acre burns were planned on the Bob Macy and Post Montgomery Ranches, located about 10 miles southwest of Post in Lynn County, Texas. Vegetation included mixtures or pure stands of buffalograss (*Buchloe dactyloides*), sand dropseed (*Sporobolus cryptandrus*), blue grama (*Bouteloua gracilis*), vine-mesquite (*Panicum obtusum*), tobosa (*Hilaria mutica*), and some less abundant species. Topography is level and the elevation is approximately 2880 ft.

On the rolling plains, five burns were planned—one near Colorado City, two about 15 miles east of Guthrie, and two about 7 miles north of Quanah. Plot size varied from 5 to 90 acres, and elevation varied from 1602 to 2130 ft. The vegetation was similar to that on the high plains.

Thirty 4.8 ft^2 quadrats were clipped to sample the fuel on each planned burn on the high plains. This was an adequate number of samples to determine the weight of fuel within 10% of the actual mean at the 0.90 confidence level. Weight of current growth (cured condition) by species and litter was collected. On the rolling plains the quantity of fuel on each area was estimated on thirty 4.8 ft^2 plots.

Moisture content in the fuel material was determined at the time of each burn. In addition, wind speed, air temperature, relative humidity, and percent sky cover were recorded. The weather conditions were determined with a field weather kit.

In preparation for the burns, firelines were graded around the areas. On the leeward sides of the areas two firelines

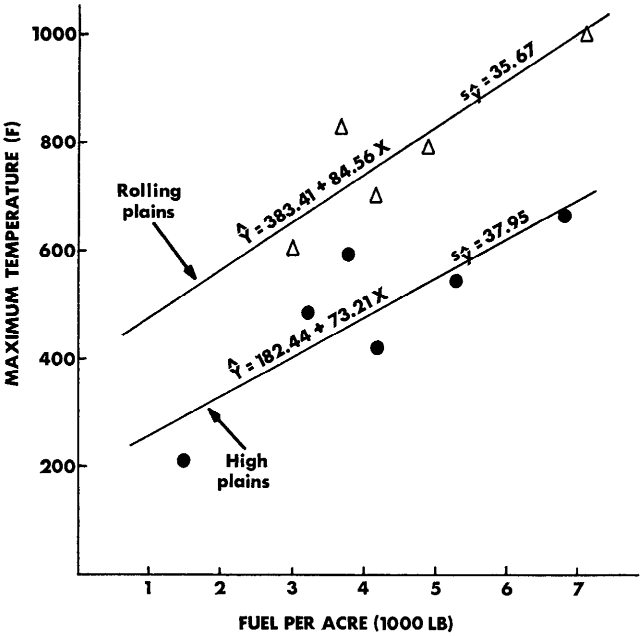

FIG. 1. Average maximum temperatures in relation to total yield of forage. Each point represents an average of 6 thermocouples.

were graded about 40 ft apart. Before burning, the strips between the firelines were backfired to have one wide fireline on the leeward side at the time of the experimental burn.

All areas were burned as natural headfires with a south to southwesterly breeze. Headfires were used in preference to backfires because they have the greatest potential to damage trees (Fahnestock and Hare, 1964). The areas on the high plains were all burned in the afternoons of a two day period in order to minimize the variability of weather conditions. The areas on the rolling plains were burned during the following week.

Maximum temperatures and durations were recorded with a Speedomax W multipoint recorder, which was powered by a 12-volt car battery and an ATR-12U-RHG Inverter. Connected to the recorder were six iron-constantan thermocouples that were located at random in each area. The double glass-wrapped silicone-impregnated wire (24 a.w.g.) and thermocouples were placed at the mineral soil surface. The thermocouples were pressed on the mineral soil surface and then released so that they were measuring soil surface temperatures, but were not in contact with the soil. Moreover, the thermocouples were placed about 60 ft from where the fire was started and in openings between the clumps of grass.

"Tempil cards," which contained commercial temperature pellets that melt upon reaching specific temperatures, were placed throughout each planned burn in vegetation comparable to the thermocouple locations to compare the accuracy of the cards with thermocouples. Maximum temperatures were recorded for the highest Tempil which stuck or melted to the .01 inch thick mica cover.

Results

Quantity of fuel in the different burns ranged from 1545 to 7025 lb/acre (Table 1). Corresponding maximum fire temperatures at the mineral soil surface varied from 182 F to 1260 F, while maximum temperatures of Tempil cards at comparable locations averaged about 10% below thermocouple maximums. The duration of temperatures above 150 F usually lasted from 2 to 4 minutes, but occasionally they lasted as long as 8.5 minutes in heavy tobosa.

For the two sets of thermocouple data, (1) high plains and (2) rolling plains, the regression of maximum fire temperature (Y) on quantity of fuel (X) is significant (r = 0.69). However as indicated in Fig. 1, the standard error of the predicted mean temperature for both sets of data is high.

The difference in magnitude of fire temperatures between the two sets of data is puzzling, but is partially attributed to a significant difference in air temperatures. Average air temperature for the high plains was 69 F whereas average temperature for the rolling plains was 81 F (Table 2). Wind

Table 2. Average weather conditions and plant moisture.

Location	Date of burn	Air temperature (F)	Relative humidity (%)	Wind velocity (mph)	Sky conditions	Plant moisture (% dry wt)
Planned areas						
Post I	3/23/68	65	36	5	Clear	13.0
II	3/23/68	67	30	6	Clear	13.5
III	3/23/68	65	36	6	Clear	13.1
IV	3/24/68	73	20	7	Clear	18.4
V	3/24/68	69	30	7	Clear	12.0
VI	3/24/68	76	19	5	Clear	15.7
Average		69	28	6		14.3
Unplanned areas						
Quanah I	3/28/68	76	50	9	Partly cloudy (60%)	18.8
II	3/28/68	76	50	11	Partly cloudy (60%)	18.8
Guthrie I	3/29/68	83	38	5	Clear	21.8
II	3/29/68	86	44	8	Clear	16.5
Colorado City	3/25/68	83	25	7	Overcast	19.8
Average		81	41	8		19.1

Table 3. Maximum temperature range of thermocouples and Tempil cards on each burn.

	Temperatures (F)				Duration (min.) above 150 F	
	Thermocouples		Tempil cards			
Location	Range	Avg.	Range	Avg.	Range	Avg.
High plains						
Post I	320– 665	479	200–700	344	1.5–2.9	2.1
II	237– 683	427	150–600	417	1.6–4.0	2.3
III	350– 743	539	400–700	538	1.8–2.5	1.9
IV	465– 650	593	400–600	538	1.0–2.6	2.0
V	182– 257	217	150–200	194	0.6–1.5	0.9
VI	560– 880	664	600–800	700	2.9–5.9	3.8
Rolling plains						
Quanah I	655– 890	783			3.4–5.0	4.0
II	480–1045	819	600–800	667	2.9–7.8	4.9
Guthrie I	380–1160	692	500–800	600	2.6–3.1	2.8
II	430– 820	595	300–600	460	1.4–2.3	1.9
Colorado City	800–1260	984			8.9–8.5	5.4

might also have increased temperatures, but wind speed was poorly correlated with maximum fire temperatures (r = 0.36). Wind speed for the high plains averaged 6.0 vs. 8.0 mph for rolling plains. Most puzzling, fire temperatures increased as fuel moisture increased (r = 0.80); we interpret this to mean that fuel moisture within the range of 12 to 22% did not affect maximum temperatures.

Maximum temperatures were usually quite variable within each burn (Table 3). Some of this variation can be explained by the variation in composition such as mixed patches of tobosa, vine-mesquite, buffalograss, blue grama and sand dropseed which all differ in yield. Also, the uneven soil surface within each area seemed to affect temperatures.

The correlation between average Tempil maximums and average thermocouple maximums in Table 3 is 0.919. On all areas except one, average maximum temperatures for Tempil cards were lower than the average thermocouple maximums. This over-all difference is statistically significant, but is biased since the Tempil intervals were 100 F. In other words, the Tempil intervals were not close enough to expect an exact correlation.

The duration of temperatures above 150 F averaged from 0.9 to 5.4 minutes (Table 3). The thin and light fuel, like buffalograss, had average temperatures above 150 F for only 0.9 min. Temperatures in the heavy tobosa remained over 150 F for 2 to 4 min longer than on all other areas. This longer duration is most likely related to larger quantities of fuel. These longer durations may have also been influenced by the compact and somewhat woody growth form of tobosa.

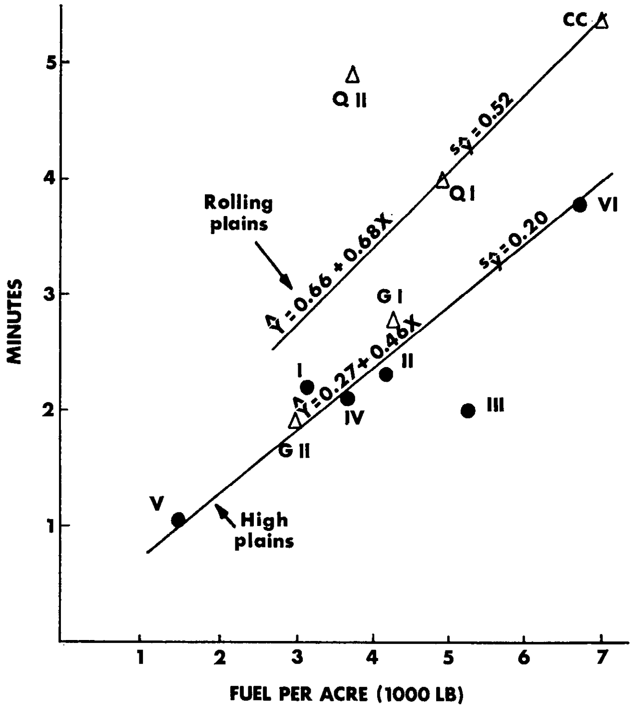

FIG. 2. Duration of temperatures above 150 F in relation to quantity of grass fuel.

Discussion

Our range of maximum temperatures for the High and Rolling Plains of Texas are comparable to those recorded in medusahead grass in California by McKell (1962). His temperatures varied from 335 F to 1100 F for fuel that averaged 5200 lb/acre. By contrast, our temperatures are considerably higher than those reported by Bently and Fenner (1958) and Ito and Iizumi (1960).

For a given set of weather conditions, maximum temperatures increased linearly as fuel increased. This was shown for two sets of data in this paper. The linearity of the regression lines should be helpful to other researchers in planning the temperature capacity of equipment needed for burning studies. The lines should also be helpful in approximating a range of realistic temperatures for artificial burns.

Species composition did not affect maximum temperatures, but on area III of the high plains it affected duration (Fig. 2). This one area had a lot of sand dropseed which was consumed very rapidly by fire. This is the only case in which duration of temperature was not in proportion to quantity of fuel on the high plains. On the rolling plains variation was too high to draw any conclusions. Duration of temperatures were generally related to quantity of fuel.

It is well known that wind speed, air temperature, and relative humidity influence temperatures (Hare, 1961). Air temperature was apparently influential in this study. Wind indicated an effect

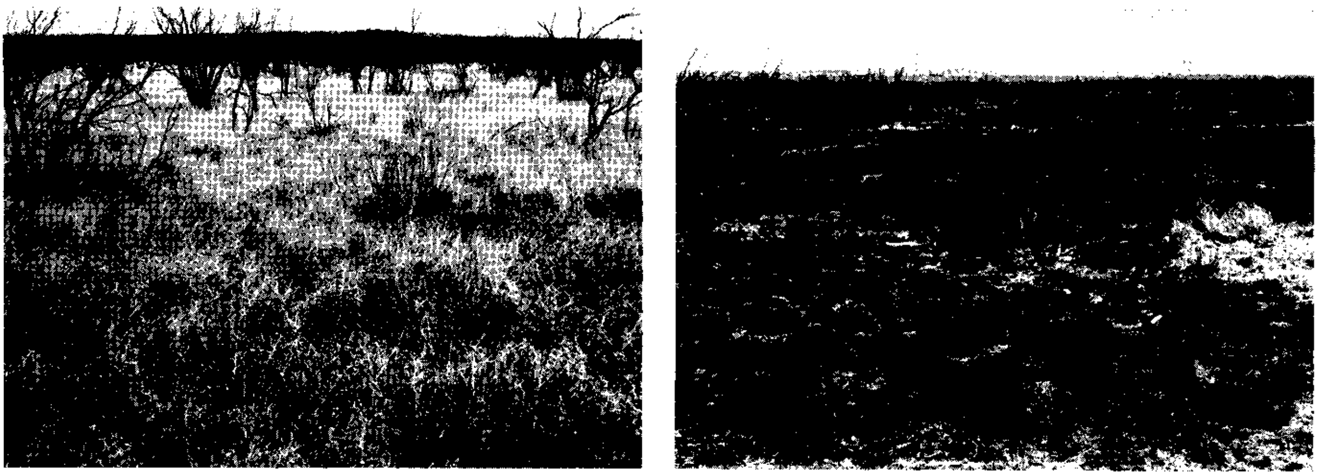

FIG. 3. View of heavy tobosa grass fuel (7025 lb/acre) before (left) and after (right) burning. Maximum soil surface temperatures averaged 984 F.

but it was not significant. High wind, however, is the only explanation for higher temperatures on the Quanah II burn. Relative humidity showed a very minor influence, if any (r = 0.19).

Fuel moisture, 12.0 to 21.8% on an ovendry weight basis, did not have much effect on the temperatures in this study since the highest temperatures occurred with the highest fuel moistures. Byram (1958) stated that high moisture of forage slows down the combustion rate and heat yield, but Smith and Sparling (1966) indicate that high moisture does not slow down the combustion rate and heat yield. They recorded the highest relative humidity with the highest temperatures in jack pine (*Pinus banksiana*). Thus Smith and Sparling concluded that "moisture content of litter and vegetation, which would be related to humidity, is of minor importance at least after ignition and spread of fire." With limited data, our conclusions on fuel moisture within the range of 12.0 to 21.8% agree with Smith and Sparling. In fact, our correlation of maximum temperatures with fuel moisture was highly significant (r = 0.80)—indicating that as fuel moisture increased, fire temperatures increased. This seems erroneous, but the correlation is too high to be ignored. Possibly fuel moisture is confounded with an over-riding variable that we do not know about, or at this level (12 to 22%) fuel moisture is unimportant.

In the burn at Colorado City the mesquite had been sprayed three years previously and had resprouts 3 ft tall. Many of these resprouts and the dead trunks were completely burned off at the base in the heavier tobosa (Fig. 3). In this burn, fire killed 32% of the trees. This indicates that when we have enough fuel to generate soil surface temperatures of 1000 F, we might be able to use fire as an effective tool to burn down sprayed mesquite trees and reduce the number of living trees.

Summary and Conclusions

Eleven areas with varying quantities of fuel were burned in the Southern Mixed Prairie of Texas to determine the range of maximum temperatures at the soil surface and duration above 150 F. Maximum temperatures, measured with a 6-channel multipoint recorder, varied from 182 F to 1260 F for fuels that varied from 1545 to 7025 lb/acre. The duration of temperatures above 150 F varied from 0.9 to 5.4 min.

On nine of the areas temperatures were also recorded with Tempil cards to evaluate their correlation with thermocouple data. The correlation was 0.919. Maximum temperatures from Tempil cards averaged about 10% lower than thermocouple maximums, but this reduction was probably caused by the 100 F interval of Tempils used.

As fuel weight increased, maximum temperatures increased proportionately. The linear regression of maximum temperature on clipped fuel weights was significant for two sets of data—six areas were burned at an average air temperature of 69 F and five areas were burned at an average air temperature of 81 F. Air temperature was the only weather factor that significantly affected maximum temperatures, but wind also appeared to have an effect.

Information from this study can be used to simulate approximate intensities of natural fires, and permit the burning of individual mesquite plants with a portable burner. With a portable burner we have more flexibility in the number of treatments that can be applied and more control over the variables that influence the results.

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